Essays on Technological Progress in East Asia

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In memory of my father Robert Jan Bruno (1952-1995), loved and sorely missed

Preface

This thesis marks the end of a seven-year long journey starting in January 2007. It has taken far longer than I anticipated, and I am delighted to finally see the project ending. The thesis is in many ways a continuation of my master's degree, which fuelled my interests in East Asia and technological progress.

I have received much support while writing this thesis. The most influential, without a doubt, has been my supervisor Stig Tenold. He was the one who started me down this path during his economic history classes by asking the question 'why are some countries rich and others poor?' I have been lucky to have had the best academic supervisor one can possibly have. An eternal gratitude therefore goes to him for shaping me academically and helping me develop as a person.

Many other people have also helped along the way. Thanks goes to my co-supervisor Ha-Joon Chang, whose academic work and research interests have opened up my perspective and is a source of inspiration. Thanks also go to my second co-supervisor Karl Rolf Pedersen, for insightful feedback on various chapters of dissertation.

The Norwegian School of Economics, and especially the Department of Economics, gave me the opportunity to write this thesis. My sincerest gratitude for their financial support, a good working environment and other means necessary for me to conduct my work. Special thanks go to Agnethe Harbitz, Turid Elvebakk, Dagny Kristiansen and Trude Gudmundset for administrative and day-to-day support, in addition to being the friendly people they are.

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I also have a large amount of gratitude towards BI Bergen in general and Elisabeth Seim in particular. BI Bergen gave me a temporary position as a lecturer in which I was given a great amount of trust to teach at the bachelor level. It also allowed me to continue with my PhD thesis while staying in an academic environment. It would not have been possible to finish my PhD without the support of BI. Special thanks also go out to Hans-Martin Straume for reading parts of my dissertation in the closing stages of my thesis. Vivienne Knowless and Heidi Ødegård have also provided invaluable support through proofreading most of my PhD, hammering my English in better shape.

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This thesis would also never have come to fruition without the support and the patience of my family. My mother, Anne Lise, has given me all the care and support anyone can ever wish for and I am proud to be her son. Anneke and Marjan are my sisters and best friends in life. Words cannot describe what they mean to me, and their support means more than they probably realise themselves. Big thanks to my wife Randi for her love, and especially patience with me while I worked on this thesis. Finally, I would like to thank my most precious daughter Sarah, who is my delight.

A final and rather different kind of thanks goes to George Lucas for creating the *Star Wars* universe. Countless nights while reading one of the numerous Star Wars novels, I was carried into a ‘galaxy far, far away’, and in the process, let my mind drift away from the stresses of everyday work as I fell asleep.

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Introductory Chapter[*]

> *‘An Indian will, on average, be twice as well off as his grandfather; a Korean 32 times … I do not see how one can look at figures like these without seeing them as representing* possibilities. *Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia's or Egypt's? If so,* what, *exactly? If not, what is it about the ‘nature of India’ that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else.’*
>
> Lucas Jr (1988) pp.4-5

Introduction

This quote summarises the major motivation for studying economic development, namely improving human welfare. In general, people in richer countries live longer, are more educated, and they experience lower levels of child mortality. Each of these factors in turn is known to increase the quality of life. Income in itself is a tool, since increased income, in general, leads to increased human welfare in the long run.[1] Economic growth, meaning the increase in income/production, is therefore a major field of economic research.

East and Southeast Asia, from 1950 until the present, is in many ways the Holy Grail in research on economic growth. In no other region has economic growth and human welfare improved more rapidly.[2] Economic growth is traditionally measured as the increase in gross domestic product (GDP) per capita. Table 1 summarises the improvements in income level for different regions measured with this indicator. In Asia, GDP per capita in 2010 was more than six times that of 1960. This increase was twice as high as the growth in the next highest growth region, Western Europe.

Table 1: Gross Domestic Product (GDP 1990 Int. GK$) per capita, 1960 and 2010

	Western Europe	Western Offshoots	Latin America	Asia	Africa	World
GDP per capita 1960	6,806	10,961	3,130	1,026	1,055	2,764
GDP per capita 2010	20,889	29,564	6,767	6,307	2,034	7,814
2010 relative to 1960	3.07	2.70	2.16	6.15	1.93	2.83

Source: Bolt and van Zanden (2013); the Western Offshoots are Australia, Canada, New Zealand and the US.

Table 2 shows the relative income of a number of East and Southeast Asian economies compared to the US. The US is the world’s largest economy, has been among most advanced in the post-1945 period and is therefore a natural choice for making comparisons. In 1960, the living standard in China was only 6% of the living standard in the US whilst it was 26% in 2010, meaning that living standards relative to the US improved more than fourfold. However, China has not seen the most dramatic change, as South Korea’s relative performance has been even more spectacular with a more than sixfold increase in relative living standards compared to the US.

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[*] I am grateful for valuable comments from Stig Tenold, Ola Honningdal Grytten, Ingelin Orten, Karl Rolf Pedersen and Ragnhild Wiik.

[1] My claim is not that these are perfectly correlated, since a high income level can co-exist with large income inequalities including a low living standard for much or most of the population. However, as most high-income countries also have a high living standard, the link is sufficiently strong to assume a close relationship between the two. A broader indicator of welfare, the Human Development Index (HDI), is also correlated with higher levels of GDP, which is partly so because GDP is a part of the HDI; see for instance UNDP (2013). See Wolff *et al.* (2011) for a criticism of the HDI measure.

[2] Not all East and Southeast Asian economies have had high growth rates. For instance, North Korea has stagnated and remains a low income economy. For the sake of simplicity, I focus on the high-growth economies of East and Southeast Asia, which means China, Hong Kong, Indonesia, Japan, Malaysia, Singapore, South Korea, Taiwan and Thailand.

Table 2: GDP per capita relative to the US, 1960 and 2010

	China	Indonesia	Japan	Malaysia	Singapore	S. Korea	Thailand
1960	6 %	9 %	35 %	14 %	20 %	11 %	10 %
2010	26 %	15 %	72 %	33 %	95 %	71 %	31 %
2010 relative to 1960	4.5	1.7	2.0	2.5	4.7	6.6	3.2

Source: Based of figures from Bolt and van Zanden (2013)

To improve our understanding of the process of economic growth, this PhD thesis focuses on one of the main drivers of long-term economic growth, namely, technology.[3] In its simplest definition, technology is the process through which labour, capital and raw materials produce output. Technological progress allows this process to be more efficient, thereby producing more or allowing new products to be produced. Without such progress, economic growth becomes unsustainable and will eventually stagnate. This PhD thesis has two interrelated research questions:

1. What was the importance of state support in promoting technological progress and increased value-added in individual sectors in selected East and Southeast Asian countries?

2. How does technological progress affect economic growth in resource-abundant countries in East and Southeast Asia and beyond?

To answer these two questions, I have divided the thesis into two subthemes. The first subtheme is industrial policy, which focuses on the promotion of technology and the increased value-added of the production structure. In particular, the thesis conducts a number of case studies of successful industrial policy. I use the term 'successful' in the sense of managing to establish internationally competitive industries. I am aware of the selection bias, and I do not claim that industrial policies work under all circumstances. The aim is primarily to understand why industrial policy was successful in the cases analysed. Three essays (1, 2 and 3) consider how industrial policy has worked in various industries in East and Southeast Asia, while essay 4 focuses on an area where industrial policy could potentially be used, but is not explicitly discussed.

The second subtheme is natural resources, and how natural resources can either hinder or bolster an economy's technological progress. In Southeast Asia, Indonesia, Malaysia and Thailand are resource-rich and have achieved high economic growth rates. As the 'resource curse' literature highlights, being rich in natural resources does not always lead to an automatic improvement of economic conditions, whereas in these countries, it seemingly has. Increasing our understanding as to why this is the case yields potential lessons for other developing countries. Three essays (2, 3 and 4) focus on natural resources and their relationship to technological progress.

This introductory chapter consists of five main parts. First, it elaborates on technological progress, and its relationship to economic growth. This part relates to economic growth in East and Southeast Asia over the past 50 years. Second, the relationship between industrial policy and technological progress is discussed. In the third part, the focus is on the relationship between natural resources and technological progress, with a specific focus on East and Southeast Asian resource-led growth. Fourth, the different methodologies of the various essays of this thesis are presented. Finally, I present a brief summary of the four essays of the PhD thesis. In the conclusion, a brief summary of the broader contributions of this PhD thesis is presented.

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[3] Obviously, there are other determinants of economic growth, including institutions. This also needs to be considered when judging economic performance. In the PhD essays in which cross-country comparisons are made in essays 3 and 4, institutions are a part of the analysis.

1. Economic Growth, Technological Progress and Structural Change

There is a near consensus among economists that long-term economic growth is determined by technological progress. The neoclassical growth model claims that long-term growth is determined by exogenous technological progress.[4] New, or endogenous, growth theory instead focuses on how technological progress is determined and how this in turn affects economic growth. Some of the determinants of technological progress mentioned are (i) Externalities; (ii) Human Capital; and (iii) Research and Development (R&D).[5] Other theories, focusing on structural change as a cause of economic growth, emphasise how barriers to structural change must be overcome for economic growth to occur.[6]

Despite the view that long-term economic growth is determined by technological progress, the nature of the growth process in East and Southeast Asia has been an issue of debate. There are two main views. The first view, often referred to the accumulation view, argues that economic growth in East and Southeast Asia has been driven primarily by increased factor accumulation; in effect, increased labour and capital. This means that the residual, called total factor productivity (TFP), is small. Mankiw *et al.* (1992), using an augmented Solow model, argue that nearly 80% of the variations in cross-country incomes can be explained by differences in physical and human capital.

In the case of East and Southeast Asia, similar results were found by Young (1992; 1994; 1995), and Krugman (1994), who claimed that East and Southeast Asian economic growth could almost exclusively be explained by increases in investments and a decreasing population growth.[7] In other words, no large improvement in productivity was observed—implying that from 1966 to 1990, technological progress was limited. Krugman (1994) argued that East Asian growth was primarily an input-driven process and that decreasing marginal returns would eventually set in. He even went as far as comparing the economic growth in East and Southeast Asia to the early stages of growth in the Soviet Union, which had more to do with increased investments than improvements in technology.

However, the accumulation view is associated with a number of problems (Madsen and Islam, 2012). First, it assumes that technology is easily codified and can easily be adopted regardless of the existing level of technology. This assumption is most likely false, as the costs of adopting already existing technology are high. Second, technological progress can also be endogenous to the level of investment, which might lead to increasing returns, as highlighted in endogenous growth theory. If true, the assumption of decreasing marginal returns of capital would be false, which will have implications for how TFP is estimated. Finally, the empirical results are highly sensitive to a number of underlying assumptions regarding the capital stock and the factor income.[8] Capital stock figures prior to 1960 are often non-existent, and estimates of the appropriate measures of the true capital stock, in general, yield large differences based on the assumptions underlying the estimations. Factor income is also highly uncertain at the level of the total economy, as the government is not included and markets are not free as assumed in the Solow model. Estimates of total factor productivity (TFP) are in turn highly sensitive to the factor shares used. Consequently, the claim that the productivity increase is small in East and Southeast Asia is problematic.

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[4] The Solow-Swan model states that the long-term growth rate is determined by the exogenously generated technological progress. See Solow (1956) and Swan (1956). Mankiw *et al.* (1992) expand the Solow-Swan model by including human capital.

[5] See for instance Romer (1986, 1990, 1993), Grossman (1993), Jones (1995, 1999), Aghion *et al.* (1998), Strulik (2005) and Acemoglu (2009).

[6] The link between economic growth, technological progress and structural change is one of the most established, and is in large part based on the seminal work of Schumpeter (1934). See Aghion and Howitt (1992) for a formal Schumpeterian model.

[7] The age dependency ratio is the share of people aged 0-14 and 65 and over relative to the people aged 15-64, which are most likely to be a part of the labour force. People aged 0-14 and over 65 do not contribute to the labour force, but still have basic needs, meaning that a high share of young or old people can be a fiscal burden. With a decreasing population growth, the share of people aged 15-64 increased relative to those ages 0-14, meaning that were more workers per young people, thereby decreasing the potential fiscal burden, and providing a demographic 'bonus' (Crafts, 1998).

[8] The factor income is the share of the production attributed to capital and labour if one assumes perfect competition and constant returns to scale.

The second view is called the assimilation view, which claims that the assimilation of technology increased productivity and was, in turn, the primary cause of economic growth in East and Southeast Asia. A number of studies have emphasised that most of the economic growth within a country is caused by increases in TFP (Klenow and Rodriguez-Clare, 1997, Prescott, 1998, Hall and Jones, 1999, Easterly and Levine, 2002, Caselli, 2005). For instance, Madsen and Islam (2012) assume that capital is endogenous to the state of technology. Expected returns increase if the level of technology is higher, meaning that the incentives to invest are higher with improvements of technology. East and Southeast Asian economic growth was, according to them, driven primarily by increased technological progress. The main channel was through increased human capital and R&D, which caused increases in productivity. However, the assimilation view, similarly to the accumulation view, relies heavily on the assumptions of the researcher.

The assimilation view, however, gives a more accurate picture of East and Southeast Asian economic growth. There have been huge improvements in various technology indicators, such as education, patents, and research and development, indicating an East Asian convergence, not only in income, but also in terms of technology. There is a common perception that when developing countries are far from the technological frontier, the primary driver behind technological progress is the adaptation of already existing technologies from advanced economies. When a country is close to—or even at—the technological frontier, new technologies have to be invented and applied, meaning that invention and innovation become the primary drivers of technological progress. If true, the degree of innovation should increase with the level of technology.

As a measure of technology input, one can use research and development (R&D) expenditure as a share of GPD. R&D is both used to apply existing technology to domestic purposes (learning) and to develop new technologies (innovating). Figure 1 presents R&D (as a share of GDP) compared to the US level:

$$Share\ Compared\ to\ US(\%) = \frac{R\&D\ East\ Asian\ Country\ (\%\ of\ GDP)}{R\&D\ USA\ (\%\ of\ GDP)} \tag{1}$$

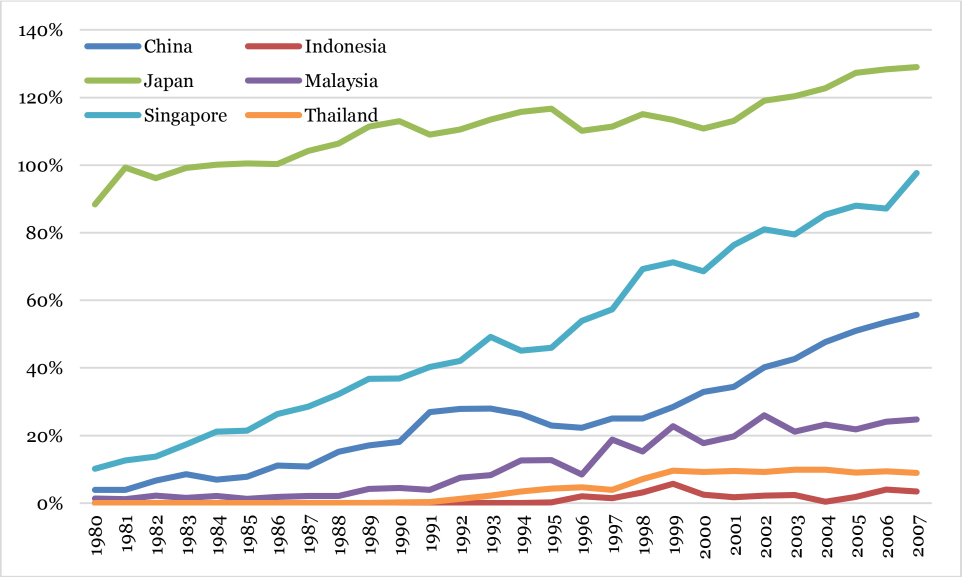

Figure 1: Percentage Share of R&D as a Share of GDP (US Share = 100)
Source: Castellacci and Natera (2011)

Figure 1 shows that Japan has had a higher expenditure on R&D as a share of GDP than the US since 1985. Singapore R&D expenditure has also been growing steadily over the period, while Chinese R&D is increasing at a fast pace. However, Indonesia, Malaysia and Thailand invest a considerably smaller share of GDP in R&D than the US.

To measure innovation, figure 2 shows the share of patents per capita compared to the US:[9]

$$Share\ Compared\ to\ US(\%) = \frac{Patents\ per\ Capita\ East\ Asian\ Country}{Patents\ per\ Capita\ USA} \qquad (2)$$

Figure 2 shows that Japan lies well ahead of the other East and Southeast Asian economies. In 2008, Japan had more US patents per capita than the US itself. Singapore and South Korea also made huge advances, with especially the latter increasing the number of patents relative to the US. However, figure 2 also indicates a huge gap within East and Southeast Asia, with China, Indonesia, Malaysia and Thailand lagging (the four are virtually overlapping in figure 2).

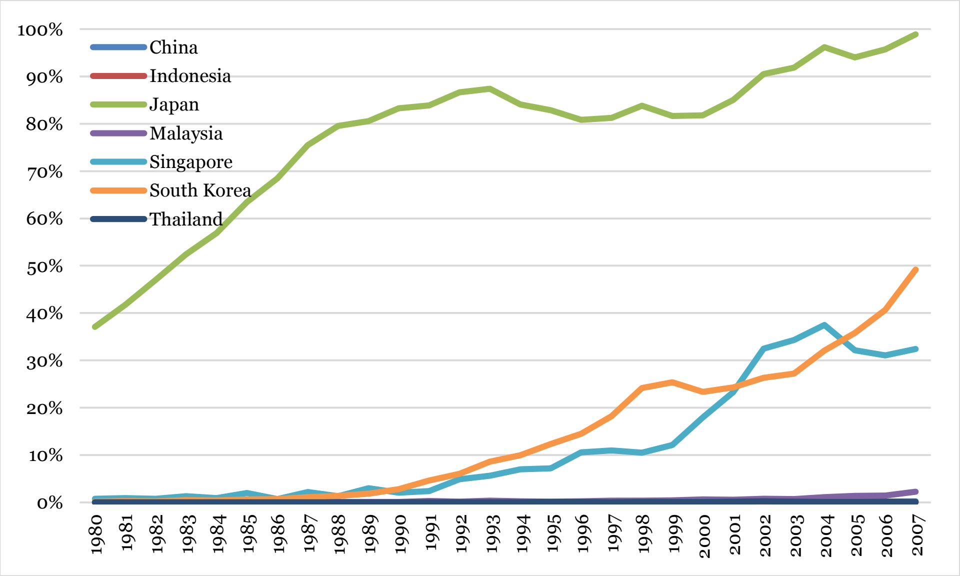

Figure 2: Percentage Share of Patents per Capita 1980-2007 (US Share = 100)
Source: Castellacci and Natera (2011)

The evidence for the assimilation view is therefore quite strong. This thesis therefore assumes that the assimilation view holds. The analysis in the present thesis considers the relationship between technological progress and the upgrading of the production structure. One popular theory of East and Southeast Asian development has been the ‘flying geese formation’ of development originally developed by Akamatsu (1962).[10] The flying geese theory states that there is a lead goose, a technological leader, while the other countries follow the technological leader like a formation of flying geese. In the flying geese theory, late-comers successfully enter new sectors using technology imports from mature economies to upgrade their production structure. The industry typically has a declining advantage in the mature economy from which the technology is being imported (Rana, 1990, Geda and Meskel, 2008). There are two interrelated processes present.

The first process is at the micro-level and involves an industry going through three phases; (i) Import, (ii) Production and (iii) Export (there might also be a potential fourth phase, Re-import). The second process is on the macro-level in which industries become increasingly more diversified, with an upgrade occurring over time from simple consumer goods, to capital goods and further, to more sophisticated goods. The flying-geese

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[9] Patents are measured as US patents.
[10] For more recent contributions see for instance Kojima (2000), Ozawa (2002) and Cutler *et al.* (2003).

theory, with its dynamic comparative advantage, is different from the traditional static comparative advantage of the Heckscher–Ohlin model. The flying geese theory has more in common with the product cycle theory of Vernon (1966) and is compatible with the new trade theory of Krugman (1991).

Empirically, there is strong evidence to suggest that the export structure of a country's economy is important for its subsequent economic growth. Hausmann *et al.* (2006) found that a higher value-added content of exports was a clear predictor of subsequent economic growth. They also found that globalisation since 1990 had increased specialisation into countries' comparative advantage, as traditional trade theory suggests. This increasing specialisation might, however, have slowed economic growth in Latin America and Sub-Saharan Africa. The reason, suggested by Hausmann *et al.* (2006), was that Latin America and Sub-Saharan Africa had a comparative advantage in agriculture, and an increased specialisation in agriculture led to an export structure consisting of lower value-added products leading to a decline in economic growth. Geda and Meskel (2008) argued that increased diversification of the export structure was important for East Asian economic growth. In particular, they concluded that vertical diversification was more important than horizontal diversification in explaining the differences between East Asian and Sub-Saharan African countries.[11]

A country's export structure can therefore be thought of as a function of the level of technology. If one assumes that the level of technology is given by the symbol A, one can schematically classify the East Asian economies as having gone through three different phases as illustrated in figure 3.

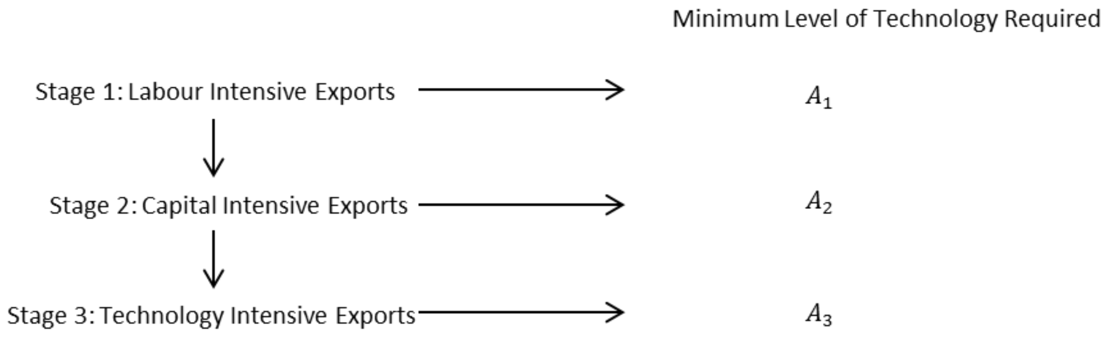

Figure 3: Minimum Level of Technology for Different Types of Export

Figure 3 shows that a country needs to reach certain thresholds of technology to be able to be competitive in the international market. To be able to compete in labour-intensive exports such as textiles, a country needs to reach a technology level of A_1. As highlighted by Amsden (1989), to be able to compete in labour-intensive manufacturing exports, one does need a level of technology that is beyond the present reach of many developing countries. To be able to be competitive at capital-intensive and technology-intensive production, countries need even higher levels of technology, which few countries outside the Western economies have managed. In fact, apart from the Western economies, Japan, Singapore, South Korea and Taiwan are currently the only countries that truly have gone beyond the first stage.

2. Industrial Policy

The first major subtopic of this PhD thesis is industrial policy. As mentioned, technological progress occurs through industrial upgrading. It is important to understand whether this upgrading happens through a market-

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[11] Horizontal diversification broadens the number of products which have a similar value-added, while vertical diversification broadens the products with different degrees of value-added.

driven process, or if such upgrading requires government assistance in the form of industrial policy. One key feature in most East and Southeast Asian countries has been the use of industrial policy to a varying degree.

It is important to understand the meaning of industrial policy. No universally accepted definition of industrial policy exists. One common view is to use 'industrial policy' to describe the government intervention to promote certain manufacturing sectors with the explicit aim of increasing the value-added activities of production to defy an economy's comparative advantage (Amsden, 1989, Chang, 2002, Lin and Chang, 2009). Others attempt to differentiate so-called 'selective' industrial policy from 'functional' industrial policy (Lall, 2004, Naudé, 2010). Selective policies promote certain industries, while functional policies might increase the entire supply side of the economy.[12] A third view is that industrial policy is a 'dialogue' between the private sector and the state in how to overcome barriers to economic growth (Rodrik, 2008). The definition employed in this context is that employed by Pack and Saggi (2006, pp.1-2): 'any type of selective government intervention or policy that attempts to alter the structure of production in favour of sectors that are expected to offer better prospects for economic growth that would not occur in the absence of such intervention.' In table 4, I provide a summary of the main focus of industrial policy loosely based on Naudé (2010).

Table 4: Industrial Policy

Focus	Purpose	Examples of instruments
Technology	1. Promoting science and innovation 2. Increase learning and technological capabilities 3. Improve productivity	- Funding of research activities - R&D subsidies - Education and training policies - Incentives for foreign direct investments - Upgrading of economic infrastructure - Creation of venture capital funds
Market	1. Economic signals and incentives 2. Selective industrial policy 3. Selection mechanisms	- Price regulations - Intellectual property rights - Imposition of import tariffs - Providing export subsidies - Entry and exit regulations - Preferential access to finance
Communication	Distribution of information	- Marketing of export industries - Encouraging firm cooperation - Dissemination of successful experiences

Source: Partly based on Naudé (2010)

Industrial policies caused a large debate in the 1980s and 1990s, and whether East and Southeast Asian countries grew because of or in spite of their industrial policies. The general view today is that industrial policy probably did help to promote economic growth in East Asia. However, critics have pointed out that industrial policies might not be an adequate solution for other developing countries, as industrial policies in Latin American and Sub-Saharan Africa in the 1950s to 1970s have failed. The reason for this, as claimed by those in favour of industrial policies, is that the types of industrial policies conducted were inadequate for these economies.

The critics of industrial policy have been more subdued in recent years. One reason is the failed attempts at market liberalisation in Latin America and Sub-Saharan Africa. Another reason is the increased realisation that developed countries themselves engage in industrial policies, both in the past and presently (Chang, 2002). Great Britain used industrial policies during the industrial revolution to promote its industries. Likewise, starting in the 1850s, Germany and the US used industrial policies to catch up with Great Britain.

Even today, advanced economies continue to use industrial policies. The US is among those that frequently use industrial policies. This involves both so-called 'disguised' industrial policies, such as the promotion of industries through government contracting, and the more direct industrial policies, for instance,

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[12] In practice, differentiating between functional and selective industrial policy is problematic. If the government attempts to construct a functional industrial policy, for instance, by promoting tertiary education, the main beneficiaries will be industries that are human capital intensive at the expense of industries that employ mainly workers with lower levels of education. In practice, most functional industrial policy will benefit certain industries better than others (Lin and Chang, 2009).

government support to Boeing (Chang, 2009). The evolution of the debate regarding industrial policy is crudely summarized in table 5.

Table 5: Summary of the Evolution of Theory and Practice of Industrial Policy

Phase	Industrial Policy and Technology	Representative contributors
1940s to 1960s	- Industrialization is necessary for development	Rosenstein-Rodan (1943)
	- Industrial policy needed, particularly infant industry protection, state-ownership and coordination	Myrdal (1957)
	- Imitation of advanced countries will increase the level of technology	Hirschman (1958)
	- Economies-of-scale important	Prebisch (1959)
1970s to 1990s	- Practical obstacles to industrial policies are considered significant	Baldwin (1969)
	- Trade liberalisation necessary for increased technological progress	Krueger (1971; 1990)
	- Free market the optimal solution for increasing efficiency and thereby long-term economic growth	Pack (1993; 2000)
2000s to present	- Market and government failures are both present	Amsden (1989)
	- Institutional setting matters but design difficult: Need to understand political context	Nelson (1993)
	- Flexibility in the practice of industrial policy is important	Chang (2002; 2003; 2009)
	- Differences exist with respect to the extent to which comparative advantage needs to be defied	Lall (2004)
	- Innovation and technological upgrading should be a central objective of industrial policy	Rodrik (2008)
		Cimoli *et al.* (2009)
		Lin and Chang (2009)
		Robinson (2009)

Source: Partly based on Naudé (2010)

If one takes a crude view of the level of technology, similarly to that of figure 4, a developing country's level of technology might be below the sufficient level to be able to compete in manufacturing products. If a country should start to export labour-intensive exports, it must reach the level A_1; industrial policies can be used as illustrated in figure 4. South Korea began exporting labour-intensive manufacturing exports such as textiles in the 1960s. According to Amsden (1989), South Korean exporters did not have a sufficient level of technology to be competitive in the international market. Instead, the government pursued an active industrial policy through subsidies, trade barriers and export targets to increase South Korean exports. The foreign currency earned was used to purchase capital goods that increased the level of technology of South Korean producers.

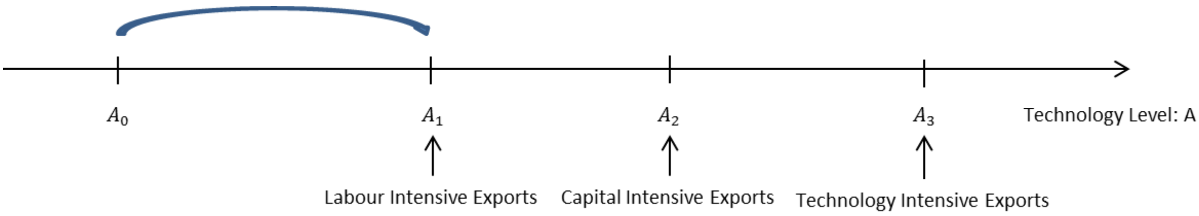

Figure 4: Increase in Technology to Reach Minimum Levels for Various Exports

The present thesis analyses various instances of such upgrading to better understand how industrial policy has worked. Essay 1 focuses on the industrial policy during the establishment of the shipbuilding sector in South Korea, 1970-1990. The literature contribution of the essay lies in its focus on the interplay between domestic and international factors. Essay 2 focuses more specifically on the industrial policy in the Malaysian palm oil sector, and the period 1970-1990 in which the higher value-added segments of the palm oil sector were established. Essay 3 highlights how differences in industrial policies in similar resource-based manufacturing sectors can lead to different outcomes. It adds to the literature by analysing whether industrial policies in resource-based sectors have comparable effects for Indonesia and Malaysia 1960-2010, as it did for Finland and Sweden 1860-1910.

3. Natural Resources

The second major subtopic is natural resources and its relationship with technology. A key difference between the Northeast Asian economies such as Japan, South Korea and Taiwan, and the Southeast Asian economies of

Indonesia, Malaysia and Thailand is that the former are resource-poor while the latter are resource-rich. Economic growth, technological progress and industrial upgrading have been faster in Northeast Asia than in Southeast Asia.

The question is to what extent this difference can be attributed to natural resources. If South Korea had Malaysia's natural resources, would South Korea have had a growth rate similar to Malaysia? The answer is most likely 'no'. Institutions, the colonial heritage, the cold war support, the ethnic composition and their geographical location all differ, and all of these factors are mentioned in the literature as having aided South Korea's economic growth. To ask whether Malaysia could have been a new South Korea is therefore fruitless, since such questions are impossible to answer. It is more fruitful to analyse whether natural resources have contributed to economic growth in Malaysia.

Much research has focused on the link between economic growth and natural resources, with a new wave of interest following Sachs and Warner (1995) who indicated that resource-abundant countries might have achieved lower economic growth. Still, there is considerable debate about whether natural resources affect economic growth positively or negatively. The evidence depends on: (i) how natural resources are measured; (ii) the time period for analysis; and (iii) the econometric specification, in particular, whether cross-section or panel data is used.

Equally debated are the potential economic mechanisms associated with natural resources. One of the most popular early explanations was the long-term decline in terms of trade of primary goods exporters. Other much-researched effects were the so-called Dutch disease effects. Natural resources lead to higher wages, an appreciation of the exchange rate and in some models, a decline in productivity. The literature has greatly increased since the 1990s, with more mechanisms coming into consideration. In order to illustrate these different mechanisms, I present some of those proposed in the resource literature in table 6.

Technology is an important part of a number of these mechanisms. Some advanced countries had a large degree of natural resources and managed to generate high economic growth in the late 19th century. The US is the most studied example, and economic historians emphasise that the emergence of the US as the world's leading manufacturing producer is a result of its abundance of natural resources (Wright, 1990 and David and Wright, 1997). These studies claim that successful resource-led growth came through an upgrading of the level of technology. Furthermore, Wright and Czelusta (2006) claimed that the mechanisms that drove resource-led growth in the 19th century are still present today, and that the failure of some resource-abundant countries to achieve economic growth lay not in the natural resources themselves, but in the failure to upgrade the level of technology.

Table 6: Some Economic Mechanisms Proposed in the Resource Curse Literature

Key Mechanism	Focus
Dutch disease	Van Wijnbergen (1984): The presence of a natural resource sector increases the demand for labour and increases wage rates and the increased natural resource exports make the exchange rates appreciate. The increasing wage rates and exchange rate leads to fewer exports in the 'traditional' export sector. Matsuyama (1992), Sachs and Warner (1995) and Gylfason (2001): Natural resource sectors have lower productivity growth and less technological learning than the manufacturing sector and the labour and capital diverted to the natural resource sectors lowers the overall productivity of the economy and reduces economic growth in the long-term.
Economic policy	Sachs and Warner (1995): Natural resources lead to more protectionist policies and increased protectionism impedes economic growth. Manzano and Rigobon (2006): Government debt increases in times of commodity price booms, as the government treats an upward shift in prices as permanent and increases their debt by borrowing abroad. Once the commodity prices decline, the government cannot repay the debt leading to a macroeconomic crisis. Auty (2001) and Atkinson and Hamilton (2003): Those that control the natural resources promote anti-developmental policies by protecting their own interests.
Exploitation pattern	Auty (1997): Type of land hold system (plantation or small-holder) crucial for how resources affect the political system. Ross (1999): Government ownership over resources could have adverse effects on economic growth. Papyrakis and Gerlagh (2004), Isham *et al.* (2005) and Stijns (2006): Agriculture/Mineral and Point/Diffuse resources with different effects on economic growth.
Export diversification	Hausmann *et al.* (2006) and Lederman and Maloney (2006): The real problem is not natural resources per se, but the lack of export diversification that results from natural resource exports which leaves natural resource exporting countries more sensitive to demand and price conditions in world commodity markets.
Institutions	Leite and Weidmann (2002): Rent-seeking institutions could cause a resource curse as revenues are not re-invested in the economy but consumed by those in control of the institutions. Sala-i-Martin and Subramanian (2003), Bulte *et al.* (2005), Mehlum *et al.* (2006) and Norman (2009): 'Bad' institutions defined and measured in various ways, causing revenues to be poorly utilised.
Human capital	Gylfason (2001): More natural resources lead to less investment in education because the natural resource sectors are less knowledge-intensive than manufacturing. Stijns (2006): More natural resources lead to increased government spending on education. Bravo-Ortega and De Gregorio (2006): Large stocks of human capital could offset the negative effects of the resource curse.
Linkages	Hirschman (1958), Seers (1964) and Baldwin (1966): If the natural resource sectors expanded, it would have less of an impact on the economy because of their enclave structure, thereby an economy would experience a lower growth rate compared to a situation with a similar expansion in manufacturing. Roemer (1970), Lewis Jr (1989) and Cramer (1999): Processing of natural resources is a feasible and desired way forward for many developing countries.
Political stability	Baland and Francois (2000); Le Billon (2001); and Collier (2005): Increased presence of natural resources might cause more political instability, which hampers economic growth.
Prices	Prebisch (1950) and Singer (1950): Long-term price decline of primary goods relative to manufacturing leads to decreasing terms-of-trade for primary goods exporters. Atkinson and Hamilton (2003), Bleaney and Halland (2009) and van der Ploeg (2011): High volatility of primary good prices leads to unstable income, which might lead to unpredictability of long-term fiscal policy.

The industrial policy literature rarely explicitly includes natural resources, and natural resources do not feature in the flying geese theory of structural change. However, it is easy to extend the flying-geese argument to Malaysia, for instance, which hopes to industrialise in the phases illustrated in figure 5.

Figure 5: Resource-Intensive Exports as a Preliminary Stage

Prior to 1985, much of the economic growth in Malaysia was resource-led, with industrial policy promoting increased processing in a number of resource-based industries such as forestry, palm oil and rubber, which could be a part of the preliminary stage in figure 5. From 1985 and onwards, Malaysia increasingly started to export labour-intensive exports such as textiles, as is indicated in 'stage 1' in this diagram. Rather than a 'big push' from A_0 to A_1, a country might have two 'smaller pushes', from A_0 to A_R and from A_R to A_1 as indicated in figure 6.

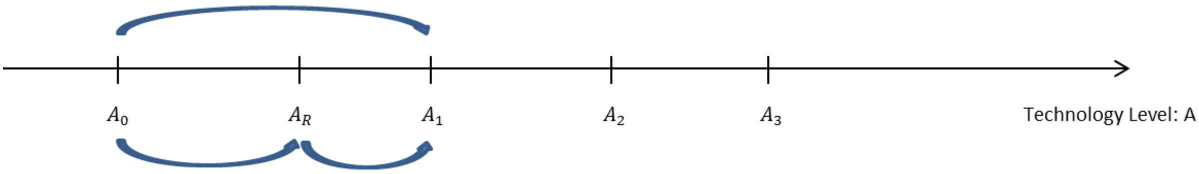

Figure 6: Increase in Technology to Reach Minimum Levels for Various Exports

The increased income from resource-intensive exports could provide increased foreign currency, which can be used to import more advanced technology though licences and machines, which in turn would increase the level of technology. Therefore, resource-based industrialisation could potentially be the first stage of a country's industrialisation path. However, resource-based industrialisation need not be seen as an earlier stage, but rather, an alternative or a complementary path to industrialisation, as indicated in figure 7.

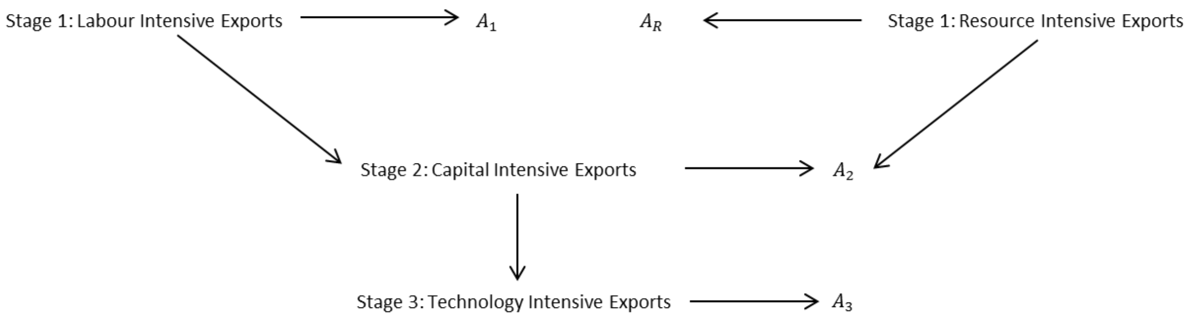

Figure 7: Two alternative 'routes' to higher value-added production

It is not clear whether the level of technology needed to process natural resources into resource-based manufacturing products is lower or higher than the technology level needed for labour-intensive manufacturing products. As figure 7 indicates, a resource-abundant country might skip the stage of labour-intensive exports and move directly to stage 2. The increased presence of China in international markets for labour-intensive goods such as textiles means that other possibilities for increased technological upgrading might, in fact, be welcome.

Natural resources can, according to this model/scheme, potentially provide the basis for industrialisation. Essay 2 takes a micro-perspective and analyses how the Malaysian palm oil sector became a good example of successful South-South trade. This essay attempts to add to the literature by analysing the link between the productivity of the natural resource sectors and the higher levels of processing explicitly, which has not been done previously in the literature. Essay 3 explores this further by analysing how natural resources aided structural change and increased value-added activities in Finland and Sweden in the period of 1870-1910, explicitly comparing these processes with Indonesia and Malaysia 1970-2010. No study, to my knowledge, has conducted a similar analysis across periods. Essay 4 explores the contribution of natural resources and technology to economic growth. This essay contributes to the literature by analysing how the effect of natural resource can vary based on the level of technology and vice versa.

4. Methodology

The thesis uses different methodologies for the various essays. Essay 1, co-authored with Stig Tenold, analyses the shipbuilding industry in South Korea. The analysis is divided into three main parts. In the first part, the international market conditions are analysed, and are compared to the period when other leading countries established their shipbuilding industries. In the second part, the approach to upgrading is studied in detail, in particular, the sources of the technology acquired. Finally, these two parts are put together to examine how the combination of international market conditions and the technological upgrading worked together.

Essay 2 is a case study in which the palm oil sector in Malaysia is analysed. The essay examines the development of productivity over time for palm oil plantations. The standard method for a sector productivity analysis is to employ a total factor productivity analysis, but data quality limitations did not allow such an approach. The methodology in this essay is a partial productivity analysis using (i) Land; (ii) Labour; and (iii) Unit costs. The official productivity measure, the oil yield, was found to have a number of inconsistencies, and was subsequently re-estimated.

In essay 3, where two sets of countries in different periods are analysed through a simple time-series approach and a cross-country comparison of different cases of resource-led growth. The two methods are intended to complement each other.

Essay 4 applies econometrics, employing both a cross-sectional and a panel data approach. The objective is to make the analysis more robust by using different estimation techniques. The essay employs both a pooled OLS and a fixed-effects approach in the panel data analysis, the latter to control for unobserved heterogeneity.

5. Thesis Essays

Essay 1: Shipbuilding South Korea[13]

The South Korean shipbuilding sector is the largest in the world, and can be seen as a symbol of the rising economic presence of East Asia in the world economy. However, its establishment was, and to some extent still is, controversial because South Korea did not have a comparative advantage in capital-intensive exports, but decided to promote shipbuilding nevertheless. In hindsight, the industrial policy was successful but remains

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[13] This essay is already published, see Bruno and Tenold (2011).

controversial mainly because it defied the market signals. The promotion of the shipbuilding sector was part of the Heavy and Chemical Industries' (HCI) drive to increase the value-added activities of the South Korean production structure by targeting six industries.

The timing of the promotion of the shipbuilding industry in the 1970s coincided with a global shipping crisis with falling demand for ships worldwide. Intuitively, such a crisis should make establishment more difficult. Essay 1, however, asks the question whether South Korea actually benefitted from establishing themselves in a declining market.

Emphasis will be on the industrial policy part of the PhD thesis. In particular, the focus is on why the industrial policy was successful, and whether the international market conditions helped rather than hindered establishment. The essay also highlights the role of industrial policy in the establishment of the South Korean shipbuilding sector and discusses whether it is feasible for a shipbuilding sector to be established without industrial policy, especially as shipbuilding receives much state support in Japan and in a number of European countries. In addition, the technological learning and the importance of catching up with the industry's technological standards are emphasised.

This essay adds to the literature in at least two ways. First, it explicitly considers how international demand conditions may be important for the establishment of sectors with higher value-added production. Second, it looks at the combination of international market conditions and industrial policy.

Essay 2: Productivity growth in the Malaysian palm oil sector

The Malaysian palm oil sector has been a massive success story in terms of a developing country managing to establish not only a world leading agricultural product, but also a world leading food-processing industry. The strong industrial policy is most likely a reason for the success of the palm oil sector. These policies included tax incentives, an export tax on crude palm oil and a focus on technological upgrading that led to the establishment of a large refinery sector, which produced the higher value-added processed palm oil.

However, the productivity growth at the plantation level, the first stage of production, has been stagnant since the 1970s, according to official figures. This is puzzling, as an increase in value-added activity intuitively should have been preceded by an increase in productivity at the lower stages of production. This essay discusses how productivity at the plantation level affected the growth of the higher-valued added production in the Malaysian palm oil sector.

Within the framework of the PhD thesis, this essay looks explicitly at the link between productivity growth and increased value-added activity. The focus is mainly to obtain a clearer picture of how productivity evolved in the 1970-1990 period, and how this development affected the establishment of higher value-added production. The essay also looks at the industrial policy used in the Malaysian palm oil sector, and the importance of this policy in the establishment of the higher value-added segment. In addition, the essay highlights how an agricultural product can be used as a part of a resource-based industrialisation.

The essay adds to the literature in five ways. First, it re-estimates the official productivity figures, which are inconsistent or implausible when compared with other official data. Second, to my knowledge, no study on the Malaysian palm oil sector has analysed the labour and cost productivity in this period explicitly. Third, no study has studied the link between plantation productivity and the establishment of the Malaysian palm oil sector explicitly. Fourth, it adds to the resource curse literature as an example of how a plantation crop can contribute to economic growth. Finally, it adds to the resource-based industrialisation literature by analysing the determinants of increased domestic processing of agricultural goods in the Malaysian case.

Essay 3: Resource-Led Growth Past and Present

This essay asks the question whether natural resources have the same effect on economies today as they did in the late 19th century when the present-day advanced countries were industrialising. This essay elaborates on the different links between natural resources and economic growth and compares these with four different resource-abundant countries. Finland and Sweden (1860-1910) are compared to Indonesia and Malaysia (1960-2010).

This essay fits the overall framework of the PhD thesis by looking at the process of resource-based industrialisation in two different periods. Resource-based industrialisation increased the value-added of the production and export structure, and thereby contributed to technological progress in Finland and in Sweden. Regressions also indicate that the main natural resource sectors contributed positively and that the resource share in GDP was important for economic growth.

In Indonesia and Malaysia, natural resources had positive impact on the economy. However, the share of the natural resource sector in GDP was not correlated with increased economic growth, indicating that natural resources were less important than for Finland and Sweden. In addition, the international market in the two periods differed, which probably affected the countries in question.

This study adds to the literature in at least three ways. First, it adds to the industrial policy literature as no study, to my knowledge, explicitly explores difference in industrial policy in resource-based sectors across time periods. Second, it adds to the economic history literature by showing which processes are similar and dissimilar in the two periods. Finally, it adds to the resource curse literature by showing that factors at the micro-level might help explain to what extent countries manage to exploit their natural resources.

Essay 4: Natural Resources, Technology and Production

Essay 4 asks the question whether technology affects production in a resource-abundant country. This link is analysed by adopting an econometric approach, using both cross sectional and panel data. To limit the scope of the study, only fuels and minerals were considered, since these resources are the ones most associated with the so-called resource curse.

The findings indicate that resource abundance is positively correlated with GDP per capita in some specifications, while natural resources lower the effect of technology on GDP. No such links were found for resource dependence, which was not statistically significant.

Within the PhD thesis framework, this essay explores the link effect of natural resources and technology on GDP per capita. There are few stylized facts in the literature on this link, and the results of this essay indicate that in resource-abundant countries, technology contributes less to GDP per capita than in resource-poor countries. Given the positive contribution of natural resources to GDP per capita and the findings in essay 3, it is likely that these results are caused by the decreasing relative contribution of natural resources (or technology) when the other increases. This means that natural resources becomes less important for GDP per capita when the level of technology is high and vice versa.

Industrial policy is not explicitly explored in this essay, but can easily be drawn into the discussion as the findings support the idea that a higher level of technology both increases GDP per capita and lowers the effect of natural resources on the economy. This gives support to the general claim that the government should improve the level of technology in the economy.

The study adds to the literature in at least three ways. First, it adds by conducting an explorative study of the relationship between natural resources and technology. No previous study has used several indicators of the level of technology when measuring the effect of resource abundance. Second, differences between the effect of technology on resource abundance and on resource dependence is explored, which no study as I am aware of has done. Finally, the essay adds to the literature on resource-based industrialisation, as it highlights the fact that the contribution of natural resources and technology might be interdependent.

Conclusion

This PhD thesis studied two interrelated questions: (i) What was the importance of state support in promoting technological progress and increased value-added in individual sectors in selected East and Southeast Asian countries?; and (ii) How does technological progress affect economic growth in resource-abundant countries in East and Southeast Asia and beyond?

It is obvious that both questions are too large to tackle in one PhD thesis, and my aim is merely to contribute to answering them, rather than providing the definitive solution.

Regarding the first question, state support was vital for technological progress and industrial upgrading. For the natural resource sectors in Indonesia and Malaysia, the increase in productivity and linkages is a vital component of successful resource-led growth. The state played a vital role in providing the institutional framework and conducting an industrial policy with the explicit aim to contribute to the establishment of resource-processing manufacturing sectors.

This goes especially for the Malaysian palm oil sector, in which both the increased productivity at the plantation level and the industrial policy conducted were crucial for the establishment of the food-processing industries. In addition, the South Korean shipbuilding sector was crucially dependent on state support, and it is unlikely to have been established without this support.

The contribution of this thesis in relation to the first question is that state support is a vital component for our understanding of how East and Southeast Asia improved its level of technology and thereby had such high economic growth rates. In addition, it is found that industrial policy was as vital in the resource-based manufacturing sectors studies as other manufacturing sectors.

Regarding the second question, the thesis attempts to identify key determinants of successful resource-led growth, and focused explicitly on technology as a key potential component. The presence of natural resources is found to be positively correlated with GDP per capita, and so is technology. The contribution of natural resources was also lowered with a higher level of technology. This finding suggests that improving the level of technology is a potential way to reduce the importance of natural resources in the economy.

In Indonesia and Malaysia, this pattern is also present as natural resources were found to be relatively less important than for Finland and Sweden a century ago. As technological upgrading is faster, because of a larger potential catch-up effect to the US, for instance, natural resources would therefore play a lesser role. However, natural resources were still found to be important in absolute terms, meaning that the promotion of resource-based industries such as the Malaysian palm oil sector can still be important for present-day resource-abundant countries.

The literature contribution of this PhD thesis with regard to the second question is achieved by an examination of the interplay between natural resources and technology more closely than previous studies. Most likely, there is a connection between the two and this interrelationship warrants more study.

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Essay 1: The Basis for South Korea’s Ascent in the Shipbuilding Industry, 1970–1990[*]

Lars Bruno and Stig Tenold

Abstract

The last 50 years have seen a dramatic shift in the hegemony of the shipbuilding industry. Today more than 90 per cent of the world’s new building orders have been placed at yards in South Korea, China and Japan. South Korea emerged as a major shipbuilding nation in the period from 1970 to the late 1980s, when world shipping was in crisis. The aim of this paper is to explain how the country managed to gain this position.

After a presentation of world shipbuilding in general, and South Korean shipbuilding in particular, the paper analyses domestic and international factors that can explain South Korea’s growing market share. At the domestic level, we consider the interplay between the country’s comparative advantages, technological learning and a conscious industrial policy aimed at escalating shipbuilding capacity. At the international level, we suggest that the severe crisis in shipping and shipbuilding might in fact have been beneficial for South Korea’s ability to grab market shares.

Introduction

One of the most striking features of Asia’s increasingly important position in the global economy is the region’s crucial role in the shipbuilding market. Today, more than 90 per cent of the world’s orders for new ships have been placed with Asian yards, more specifically with shipbuilders in China, Japan and South Korea. When Japan became the world’s leading shipbuilding nation in 1956, European yards still held a market share of around 75 per cent. Subsequently competition from Japan, then South Korea and latterly China seriously eroded and then ended Europe’s once leading position. Whereas the declining fortunes of the European shipbuilding industry – and to some extent the rise of Japan – are well-covered in the literature, the rise of South Korea has received little attention.[14]

This article looks at the formative period of South Korean shipbuilding, the period from 1970 to 1990, which appears to be an unlikely time for the escalation of shipbuilding activities. The period was initially dominated by a major crisis in world shipping and shipbuilding consequent upon first, the tripling, and then quadrupling, of oil prices by OPEC in 1973/4 and the consequent slump in demand, and in its later stages resulted in massive yard closures in Europe. Our main question is how South Korean yards managed to build up a substantial market share in a period where the shipbuilding industry was in distress. Our explanations are based on both international and domestic factors, with specific emphasis on the role of state policy and technological learning.

There is a substantial body of literature looking at the promotion of the heavy and chemical industries (HCIs) in South Korea, but few studies have focused solely on shipbuilding. Cho and Porter looked at the entrance

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[*] We thank the anonymous referees for their helpful comments and suggestions.

[14] The overall shift in shipbuilding market shares is eminently discussed in D. Todd, Industrial Dislocation: The case of global shipbuilding (London, 1991) and, with a specific focus on the shift to Asia, D. Todd,‘Going East: Was the shift in volume shipbuilding capacity from Britain and continental Europe to the Far East and elsewhere during the latter half of the twentieth-century inevitable?’ Mariner’s Mirror 97:1 (2011), 259–61. For a concise analysis, see D. S. Cho and M. E. Porter, ‘Changing Global Industry Leadership: The Case of Shipbuilding’, in M. Porter, Competition in Global Industries (Boston, 1986). More comprehensive presentations of the decline of European shipbuilding can be found in B. Stråth The Politics of De-Industrialisation: The Contraction of the West-European Shipbuilding Industry (Beckenham, 1987) and, on Britain, L. Johnman and H. Murphy, British Shipbuilding and the State since 1918: A political economy of decline (Exeter, 2002). The rise of Japan is covered by T. Chida and P.N. Davies, The Japanese Shipping and Shipbuilding Industries: A History of Their Modern Growth (London, 1990). With regard to the growth of the South Korean shipbuilding industry, two works stand out: A. Amsden, Asia’s Next Giant: South Korea and Late Industrialization (New York, 1989) and G. Jonsson, Shipbuilding in South Korea: A Comparative Study (Stockholm, 1995).

of South Korea in the world shipbuilding market. Amsden used Hyundai Heavy Industry (HHI), the main South Korean company exporting ships during the 1970s, to analyse the breakthrough of the country's shipbuilding in the international market. However, the most comprehensive analysis is the study by Jonsson, where South Korea's experience is compared with developments in Japan, the United Kingdom and Sweden.

The three studies above emphasize four factors that enabled South Korea to become an important producer of ships: government support, low labour costs and the repression of labour, favourable access to international and domestic funds, and assistance in technology transfer. This paper adds to the literature by introducing two new dimensions. First, we put the development of South Korean shipbuilding into a wider international context. Second, we address the question whether the difficult conditions in the markets for ships and shipbuilding may in fact have been an advantage for the ascendancy of South Korean shipyards.

1. South Korean and world shipbuilding, 1970–90

South Korea's advance within shipbuilding in the period 1970 to 1990 was spectacular. The period was turbulent, as the shipping crisis led to a dramatic decline in demand for new tonnage from the middle of the 1970s onwards, sparking a global shipbuilding slump. The response in Western Europe was based on a number of ingredients; nationalization, rationalization, subsidization, specialization and, ultimately, massive disinvestment and downscaling. By 1990 the Western European merchant ship completions had been reduced by around 75 per cent relative to the peak of the mid-1970s – from more than 12 million gross register tons (grt) in 1975 to less than 3 million grt in 1990. The South Korean completions on the other hand multiplied by a factor of more than eight over the same period.[15] Indeed, while South Korea's production in 1975 was less than a sixth of West Germany's, by 1990 its output was larger than that of all European yards put together.

The crisis of the 1970s and 1980s was a watershed in the post-war shipping market. Following the OPEC oil price increases, the rapid growth of tanker demand was replaced by stagnation and then absolute reduction. When the market collapsed, there was a substantial overhang of ordered, non-delivered vessels, and the second half of the 1970s and first half of the 1980s were characterized by overcapacity, substantial lay-ups and a massive reduction in the amount of new tonnage launched.[16] As a result of huge demand for tonnage and long order books, the production capacity of the world's shipyards had increased tremendously in the late 1960s and early 1970s. Ironically, when the production capacity reached a historically high volume, the market collapsed.

Historically problems in the shipping industry have rapidly spilled over into the shipbuilding sector. Owing to the strong growth of the fleet before the freight market breakdown, from 1974 onwards, new orders were virtually absent and large amounts of tonnage were cancelled. Figure 1 shows the fluctuations in tonnage completed, as well as South Korea's increasing market share. The more than ten-year glut and the massive South Korean expansion are evident from the data.

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[15] Unless otherwise stated, data on shipbuilding are taken from Lloyd's Statistical Tables, various years, and refer to vessels completed, measured in gross register tons.

[16] See S. Tenold, Tankers in Trouble – Norwegian shipping and the crisis of the 1970s and 1980s (St Johns, NL, 2006) for an overview of the problematic period 1973–87.

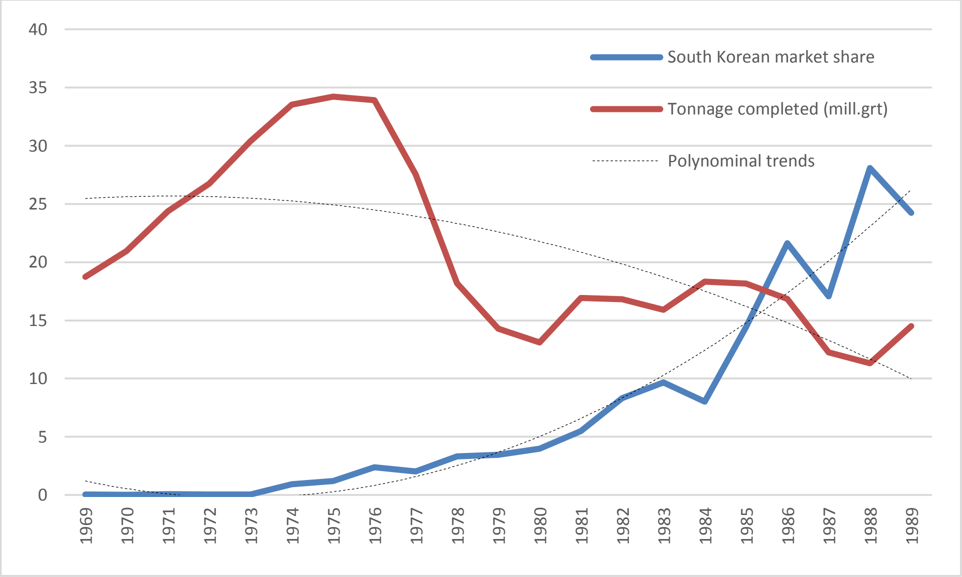

Figure 1 Tonnage completed (million grt) and South Korea's share (per cent), 1969-89
Source: Lloyd's Statistical Tables, various years

The basis for South Korea's growth in the shipbuilding market should be sought in a combination of international and domestic elements. Although these are closely intertwined, this article looks at the two factors separately. However, we initially indicate why it is necessary to take both aspects into account, and why we have taken a 'two-stage' approach in our analysis.

Few sectors are as 'international' in their character as the shipping industry. The majority of shipowners sell their services in a global market, where the nationality of the service provider for all practical purposes is irrelevant, and purchase their ships in an international market as well, either second-hand or as new buildings. While there are some links between shipping and shipbuilding at the national level, this is far more important with regard to, for instance, warship building, than with regard to merchant shipping.

The fact that the shipyards' customer base is international does not imply that the influence of national governments is unimportant. On the contrary, governments in all major shipbuilding nations have interfered with the market mechanism, providing direct subsidies, easy financing, preferential orders, etc.[17] Thus, while the state of the international market is undoubtedly important, the domestic dimension has to be considered in order to understand fully the rise and fall of shipbuilding nations. Conditions in the international market determine the room to manoeuvre, but domestic policies and possibilities determine the actual movement.

Table 1 is a schematic presentation of the factors underlying the ascendancy of the three nations that have been leaders within world shipbuilding. This table is testament to the relative strength of the dominant shipbuilding nations across time. Since the second half of the nineteenth century there have only been three market leaders in peace-time: Great Britain, Japan and South Korea.[18] However, the factors on which their positions were based varied along several dimensions. The table presents elements that were particularly important when the countries gained large market shares. As the countries' shipbuilding industries matured, other factors gained prominence.

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[17] Stråth, The Politics of De-Industrialisation, 14 refers to government efforts to secure ship-building activity as 'the "obscure jungle" of subsidies'.
[18] The role of US shipbuilding during periods of war, and their immediate aftermath, should of course be mentioned. However, during periods of uninterrupted market conditions, the triumvirate above have an impressive pedigree. Britain was the world's main shipbuilder from the mid nineteenth century until the late 1950s, before Japan established the dominant position it held until eclipsed by South Korea around the turn of the millennium. Exactly when South Korea overtook Japan, depends on the measure; gross tonnage, compensated gross tonnage, tonnage launched, tonnage completed or the size of the order book. For the rise of Asian shipbuilding, see Todd, 'Going East'.

Table 1: Advantages of leading shipbuilders during their initial period of growth

	Great Britain *1850s-1880s*	*Japan* *1950s-1970s*	*South Korea* *1970s onwards*
Demand factors			
Shipping market	Booming	Booming	Volatile
Shipbuilding market	Increasing	Increasing	Declining (temporarily)
Market focus	Domestic	Initially domestic	Export market
Supply factors			
Relative labour costs	High	Low	Low
Unionization	Limited	Repressed	Repressed
Technology	Domestic	Foreign	Foreign
Resources	Iron & coal	Steel	Steel
State support	Limited (indirect)	Yes	Yes

Both Great Britain and Japan established their positions in periods where demand for transport and ships was growing rapidly, while South Korea progressed under more difficult demand conditions. Moreover, while British yards had the advantage of a large home market and Japan used domestic owners as a base for subsequent export orders, the South Koreans relied on foreign demand.

The differences are evident when we look at the supply factors as well, although here the two Asian nations share the same properties, with different timing. Great Britain's supremacy was built on bespoke production, entailing relatively high labour costs, but initially occurred in a period where labour unionism was limited. The dominance within shipbuilding technology and marine engineering gave an advantage that was enhanced by abundant supply of iron and coal. Direct state support was very limited, compared with the post-war period, but the role of the Empire, and the country's position in international trade had important indirect effects. Moreover, postal subventions to liner shipping companies and Admiralty support also helped British shipbuilding.[19]

The initial phases of Japanese and South Korean shipbuilding growth were characterized by relatively low wages and repressed unions. Moreover, production technology was 'imported' – and only subsequently refined – while the role of the state was substantial. The authorities had detailed plans for the expansion of the industry, working closely with major business interests to ensure that the goals were met.

2. The international development

The world shipbuilding glut weighed down the industry, affecting all major shipbuilding nations adversely. Some countries – France, Norway, Sweden and the UK – reached a peak in the mid 1970s, after which shipbuilding fell by 90 per cent or more. The Netherlands and Spain experienced lower, but still substantial, decline. Only Denmark, Germany and Japan saw acceptable production figures, at least in relative terms, though even here output in 1990 amounted to as little as 35 to 40 per cent of the peak production.

The massive decline happened despite substantial efforts at maintaining activity. A huge arsenal of support was employed; financial credits and direct transfers to yards and shipowners, tax concessions, equity from state funds, naval and other public orders, etc. Nevertheless, the forces of the market were so strong, and the overcapacity so large, that a downscaling was inevitable. Intuitively, this makes South Korea's performance even more remarkable. However, as we will argue later, South Korea might have had some benefits from entering a sector in which the market mechanism was strangled and a return to 'normalcy' appeared impossible.

Table 2 shows some support measures[20] put in place to secure employment at the yards in the major shipbuilding countries. In addition to the nation-specific measures mentioned below, the period saw the closure

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[19] Johnman and Murphy, British Shipbuilding and the State since 1918, 1.

[20] For a concise introduction to strategic measures, see for instance J. Oakes, 'Shipbuilding in W. Europe', Seatrade, July/August (1986), 19–24. For development in individual countries, see, for Denmark, R. T. Poulsen and H. Sornn-Friese, 'Downfall delayed – ownership structures and maritime deindustrialization in Danish shipbuilding, 1975–2009', forthcoming, Business History (2011), for Germany and the Netherlands, see, C. de Voogd, 'Shipbuilding in West Germany and the Netherlands, 1960–1980', International Journal of Maritime History 19:1 (2007), 63–86, and for Britain, Johnman and Murphy, British Shipbuilding and the State.

of several yards, capacity reduction in others and massive lay-offs in most countries. More than a hundred yards were closed, and employment was halved in Western Europe and Japan between 1975 and 1987. In 1975 more than 325,000 people were employed at shipyards in Western Europe. By 1983 the figure was down to around 155,000.[21] There was a substantial reduction of employment in Japan as well, from 150,000 in 1975 to 85,000 in 1983.[22]

Table 2: Production 1975 and 1990 ('000 grt) and strategic support measures

	1975	1990	Change	Strategic measures
Denmark	969	407	-58 %	Tax concessions, owners' orders
France	1,149	63	-95 %	Massive subsidies, specialization
Germany	2,499	874	-65 %	Restructuring, mergers, state owners, naval orders
The Netherlands	1,028	184	-82 %	Massive subsidies, the RSV-scandal
Norway	1,052	88	-92 %	Offshore focus, subsidies, specialization
Spain	1,593	367	-76 %	Restructuring, nationalization, naval orders
Sweden	2,188	27	-99 %	Subsidies, nationalization, full withdrawal
United Kingdom	1,169	127	-89 %	Nationalization, privatization, naval orders
Japan	16,991	6,661	-61%	Rationalization, cross-subsidization
South Korea	410	3,440	+740%	Capacity increase, state support
World	34,203	15,995	-54%	

Most support measures were futile and only contributed to prolonging the decline of European shipbuilding. The fundamental problem, lack of competitiveness, was not properly addressed. European costs, in particular wages, were too high, and the strategic measures did not lead to a sufficiently large improvement in productivity and production costs. In addition to South Korea, Brazil and Taiwan tried to break into the market, as seen in figure 2. In 1979 and 1980, the Brazilian output even exceeded that of South Korea.

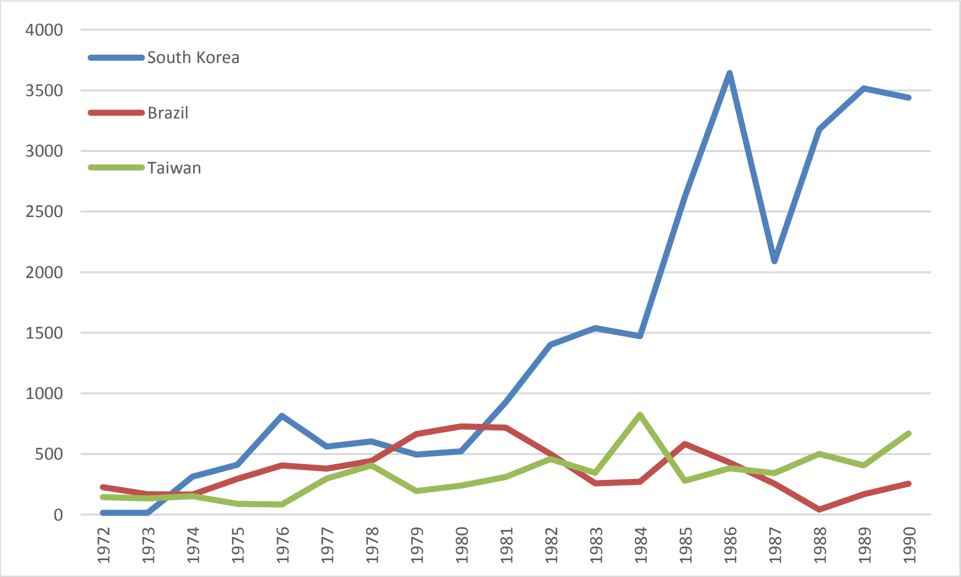

Figure 2 New competitors: tonnage completed in Brazil, South Korea and Taiwan, 1970-90
Source: Lloyd's Statistical Tables, various years

The Brazilian drive imploded in the first half of the 1980s: as Pires noted, 'The shipbuilding industry is now almost totally idle'.[23] Taiwan was a more viable competitor, but never managed to get the volumes that South Korea

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[21] Data from Institute of Shipping Economics, Shipping Statistics, 28:5 May (1984), 47. Considering shipbuilding only, and excluding ship repair and conversion, employment in the European Union countries declined from 209,000 in 1975 to 65,700 in 1991; see D. Glen, 'Shipbuilding disputes: the WTO panel rulings and the elimination of operating subsidy from shipbuilding', Maritime Policy & Management 33:1 (2006), 5.
[22] The Japanese data refer to the members of the Shipbuilding Association of Japan, which includes the 23 leading shipbuilding companies.
[23] F. M. Pires, 'Shipbuilding and shipping industries: net economic benefit cross-transfers', Maritime Policy & Management 28:2 (2001), 157.

gained. The basis for the emergence of the three developing country producers was more or less the same – an initial focus on price competitiveness, helped by strong government support. However, South Korean shipbuilders appear to have succeeded better in the second phase of the shipbuilding drive, when low wages could no longer be the only means of competition.

The competitive costs of South Korean and Taiwanese yards, and the low productivity of Brazilian shipyards, are evident from table 3. The table is based on data on production, measured as compensated gross tonnage (cgt), which take into account variations in the labour necessary to construct different vessels. The table, based on data for production and employment 1979 to 1981, coupled with compensation per worker in 1982, shows dramatic differences in productivity. For instance, the average shipyard worker in Great Britain produced only marginally more than the average South Korean, but received more than three times the compensation.

Table 3: Productivity – Annual output and compensation, 1982

	Output cgt	Workforce	Output/worker	Comp./worker	Comp./ cgrt
Northern Ireland	47,625	5,769	8.26	11,451	1,387
Belgium	119,917	5,904	20.31	21,860	1,076
Brazil	398,333	30,000	13.28	12,800	964
Great Britain	355,414	20,982	16.94	14,039	829
Portugal	62,808	9,233	6.80	5,524	812
Italy	239,370	14,483	16.53	13,313	805
Germany	719,334	24,819	28.98	20,079	693
Denmark	279,836	10,127	27.63	18,577	672
AWES	4,427,142	194,697	22.74	15,130	665
France	434,709	17,067	25.47	16,543	649
Spain	557,082	33,507	16.63	10,665	641
Norway	436,318	14,480	30.13	18,548	616
Finland	464,739	16,600	28.00	14,860	531
Sweden	409,708	12,300	33.31	17,478	525
Netherlands	300,282	9,426	31.86	16,384	514
Taiwan	148,924	12,000	12.41	5,185	418
Japan	4,461,282	115,598	38.59	15,209	394
Poland	405,688	43,650	9.29	3,190	343
South Korea	469,200	31,053	15.11	4,600	304

Note: AWES is an acronym for the Association of West-European Shipbuilders. Data from Nederlands Economisch Instituut, reprinted in Institute of Shipping Economic (1984 p.47)

South Korea succeeded in establishing a position as a low-cost provider of new tonnage. According to Graham Day, CEO of the nationalized British Shipbuilders plc: ‘if […] a Japanese shipbuilder […] said the price was 10, all you would have to do is produce that to a South Korean yard and they will bid 9 without looking at the specification or anything else’.[24]

By the mid 1980s, South Korea had become the most important competitor to Japan in the high-volume shipbuilding market. Some European yards focused on more advanced purpose-built vessels, but in aggregate, European shipbuilding was dramatically reduced. For the largest vessels, it was now a two-horse race between Japan and South Korea. In the mid 1980s currency fluctuations improved South Korea’s competitiveness further. The appreciation of the yen eroded the Japanese advantage of higher productivity; ‘the price differential with the Koreans this time a year ago was between 5–10%. Now, though, since the won is linked to the dollar, the gap is anything up to 50%’.[25]

3. Domestic development

South Korea’s road to dominance of the world shipbuilding industry had a meagre starting point. Although the country had more than a hundred shipyards in the 1960s, only nine were producing steel vessels.[26] The major

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[24] Johnman & Murphy, British Shipbuilding and the State since 1918, 231.

[25] P. Bartlett and H. Asami, ‘Japanese report’, Seatrade, July/August (1986), 133.

[26] Our presentation of the early shipbuilding industry in South Korea draws heavily upon Jonsson, Shipbuilding in South Korea.

yard in 1970 was the state-owned Korea Shipbuilding and Engineering Corporation (KSEC), which received its first international orders for six tankers in the 20–30,000 ton range from Gulf Oil in 1970 and 1971.[27] Although KSEC thus was responsible for South Korea's first stab at the international market, the real expansion came through Hyundai.

Hyundai Construction Company (HCC) applied for a licence to construct ships in June 1970 and the government approved it in September. The construction of Hyundai's huge shipyard at Ulsan commenced in March 1972 and was completed in June 1974.[28] HCC established the shipbuilding company Hyundai Heavy Industries (HHI) on 23 March 1972. The establishment and early operations of HHI depended upon state support. In brief, the state supported HHI by giving access to domestic and foreign funds with preferential interest rates; helping in obtaining and providing financial guarantees; making complementary investments in facilities and complementary industries, such as steel; and providing support for technology acquisition. It is a testimony to the rapid expansion that HHI became the world's leading shipbuilder in 1983, only one decade after its establishment. This position is still held today.

The entries of two other chaebols (family-owned conglomerates) Daewoo and Samsung into shipbuilding were also based on state support. In December 1978 the Daewoo group took over a 25 per cent completed shipyard at Okp'o, originally built by KSEC, and following complementary investments by Daewoo the shipyard was finally finished in January 1981.[29] Samsung acquired Geoje Shipyard through the purchase of Koryô Shipbuilding, the operations of which started in September 1979.

Table 4 shows the production of the four big shipyards from 1973 to 1986. Hyundai dominates in the 1970s, while Daewoo and Samsung increase their market shares in the 1980s. In the crucial years 1979 to 1985 production increased more than five-fold, marking South Korea's transition from a developing shipbuilder to a leading player. South Korean shipyards, especially the big four, were favourably positioned to exploit the short-lived international boom in 1979–80 to fill their order books.

Table 4: Principal shipbuilders' production (grt) 1973-1986

Year	Hyundai	KSEC	Daewoo	Samsung	Big four (BF)	Total	BF/Total
1973	126,000	2,980	0	0	128,980	163,474	78.9 %
1974	451,700	2,980	0	0	454,680	561,870	80.9 %
1975	512,000	75,400	0	0	587,400	612,460	95.9 %
1976	573,500	52,450	0	0	625,950	683,973	91.5 %
1977	505,568	76,322	0	0	581,890	648,523	89.7 %
1978	614,790	116,694	0	0	731,484	775,800	94.3 %
1979	383,763	103,060	0	0	486,823	555,639	87.6 %
1980	518,565	60,448	0	13,858	592,871	684,931	86.6 %
1981	907,040	137,655	21,500	52,000	1,118,195	1,219,932	91.7 %
1982	861,206	186,988	148,329	126,000	1,322,523	1,479,367	89.4 %
1983	864,782	129,573	128,270	73,400	1,196,025	1,328,246	90.0 %
1984	1,320,904	152,781	571,800	123,974	2,169,459	2,313,565	93.8 %
1985	1,423,378	124,484	929,600	273,074	2,750,536	2,813,920	97.7 %
1986	1,262,478	186,535	722,101	378,100	2,549,214	2,730,147	93.4 %

Note: G. Jonsson, Shipbuilding in South Korea: A Comparative Study (Stockholm, 1995), 83

Two factors, one economic and one political, motivated the authorities to promote heavy industries in general, and shipbuilding in particular.[30] The economic argument was that light manufacturing exports could not be sustained in the long run, and South Korea had to gain a competitive edge in more heavy manufacturing to

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[27] H. Nam, Building Ships, Building a Nation: Korea's democratic unionism under Park Chung Hee (Seattle, 2009), 201.

[28] According to figures from Jonsson, Shipbuilding in South Korea, 78, South Korea's total production capacity measured in grt increased from 187,000 ton in 1970 to 250,000 ton in 1973, followed by huge leaps to 1,100,000 ton in 1974 and 2,390,000 ton in 1975.

[29] Jonsson, Shipbuilding in South Korea, 82.

[30] S. C. Lee, 'The Heavy and Chemical Industries Promotion Plan (1973-1979)', in L. J. Cho and Y. H. Kim (eds), Economic Development in the Republic of Korea: A Policy Perspective (Honolulu, 1994), 438, adds a third; the confidence the government got from successful planning in the 1960s. President Park had a high regard for the Japanese model which he saw as a rough blueprint of how to develop South Korea.

maintain economic growth. The basis for the reduced competitive advantage within labour-intensive production was increasing labour costs, increased international competition and growing trade restrictions on textiles.[31]

The political motive was national security. In 1971 Nixon withdrew one third of all US troops from South Korea. Five years later, the Carter administration announced a full troop withdrawal.[32] The decreased US military presence, along with the communist military threat from China and North Korea, forced South Korea to upgrade their own military. President Park Chung-Hee (1917–79), who had come to power a decade earlier in a military coup d'état and had nationalized the banks and the steel industry, therefore saw the promotion of the defence industry as a necessary step in maintaining national security. Park's dogged promotion of the heavy industries in the late 1970s, with an overheated economy and clear signs of overcapacity, indicates that political concerns might have dominated economic ones.

In the 1980s state support was less extensive, but could be easily defended, as long as shipbuilding was expanding. However, towards the end of the decade, several shipbuilding companies started to struggle and the state provided bailouts as they believed the crisis was temporary. This indicates that shipbuilding had become both an economic and politically sensitive sector and could be considered to be too big to fail.

Shipbuilding generally depended on the state for at least three reasons. First, high fixed costs make the establishment of shipbuilding capacity virtually impossible without government support, especially as competitors from other countries also rely on subsidies. Second, shipbuilding companies are important employers in regions where job opportunities are limited. If shipbuilding is a declining domestic industry, restructuring is costly as employment is substantial and sector specific capital stock, with few alternative purposes, is high. Finally, the shipbuilding sector is sensitive partly because of national security. National companies are thus sometimes forced to choose more expensive domestically built ships. A supportive government is a major component in successfully establishing and maintaining a viable shipbuilding industry.[33]

South Korea's first attempt to promote shipbuilding was the Shipbuilding Promotion Law from 1958, the scope of which was increased in 1967.[34] The main vehicle of promotion had been the then state-owned KSEC, but progress was slow. The 1969 Nixon doctrine and the 1972 Yushin constitution, which suspended democracy and gave Park more direct power, made more aggressive promotion possible.

The first detailed reference to the future expansion of the HCIs was in the Third Five Year Development Plan (1972–6).[35] The real promotion of the HCI sectors came with the HCI plan in 1973. As part of that, the Shipbuilding Development Plan was announced in March 1973 by the Ministry of Trade and Industry (MTI). The plan had several objectives. First, South Korea would be self-sufficient in vessels by 1980. Second, shipbuilding exports should reach 1 billion US$ (3.2 million grt) by 1980 and 2 billion US$ (6.2 million grt) by 1985. Third, nine shipyards should be constructed by 1980 and another five by 1985. The main means of production would be Hyundai Heavy Industries (HHI).[36]

The Fourth Five Year Development Plan (1977–81) included several objectives for the shipbuilding sector. One was the commencement of the production of shipping components domestically. Another was the Planned Shipbuilding Programme, which gave guidelines to the sector. Much of the finance would come from the National Investment Fund and foreign loans. Also, government procurement would be used to overcome depressed

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[31] See W. McClenahan, 'The Growth of Voluntary Export Restraints and American Foreign Economic Policy, 1956-1969', Business and Economic History 20 (1991), 189, and Lee, 'The Heavy and Chemical Industries Promotion Plan', 438.

[32] Carter's policy was eventually suspended in July 1979; see L. Niksch, 'U.S. Troop Withdrawal from South Korea: Past Shortcomings and Future Prospects', Asian Survey 21:3 (1981).

[33] For a good introduction to this topic, see Cho and Porter, Changing Global Industry Leadership.

[34] Jonsson, Shipbuilding in South Korea, 70–4. The Shipbuilding Promotion Law from 1958 included subsidies of 40 per cent of construction costs, and allowed for generous loan repayments. The availability of public funds was limited, and shipbuilding output only grew from 4,525 grt in 1959 to 4,674 grt in 1961. The 1967 Law established an inquiry commission and set up a plan to provide capital and implement government-aid projects. However, previous subsidies were abolished, repayment periods shortened and interest rates increased.

[35] An overview of the HCI policies is provided by Lee, 'The Heavy and Chemical Industries Promotion Plan'.

[36] Park's close ties with Hyundai's owner Chun probably played a major part when Hyundai became the instrument of promotion of the South Korean shipbuilding industry.

international shipping markets. The plan also made the first major revisions in shipbuilding targets following the shipping crisis: the number of planned shipyards was reduced from nine to two.

The HCI drive provided shipbuilding and other preferred sectors with capital incentives, complementary investments, trade incentives and tax holidays. The capital incentives included preferential rates from state-owned banks with low nominal rates. Due to high inflation real interest rates were negative for most of the 1970s. A related method for capital access was government guarantees for foreign loans; see table 5. The government complementary investments included large infrastructure programmes for new facilities, both industrial complexes for shipbuilding at Ulsan, Okp'o and Chukdo, and the steel industry.[37]

Table 5: Major Commercial Projects, Shipbuilding, 1971-1985

Loan Recipient	Projects	Country Providing Loan	Contract Value (Million)	Year of Contract Validation
Hyundai Heavy Industry	Ulsan Shipyard construction	UK, Germany, Spain, France & Sweden	50 USD	1971-72
Daewoo Shipbuilding & Heavy Machinery	Okp'o Shipyard construction and machine purchase	UK, Sweden, Denmark & Finland	30 USD; 3 SEK	1978
Daewoo Shipbuilding & Heavy Machinery	Okp'o Shipyard construction and machine purchase	Hong Kong	30 USD	1980
KSEC	Construction of export ships	Hong Kong	31 USD	1981

Note: Based on data from Jonsson, *Shipbuilding in South Korea*, p.80 and T. Harrori, '*Chaebol-style enterprise development in Korea*', The Developing Economies 35:4 (1997 pp.460-463).

Following the assassination of President Park Chung-Hee in mysterious circumstances in October 1979 and the ascendancy of the Chun regime in May 1980, the economic policy changed. Selective targeting was replaced by a more functional industrial policy, with support given to research and development (R&D) and training. Moreover, the protection of shipbuilding was reduced, but did not disappear. In 1986, the Industry Development Law replaced the Shipbuilding Promotion Law from 1967.[38]

State support in shipbuilding was often targeted at the company level. The government played a large role in the establishment of South Korea's most important chaebol, Hyundai Heavy Industries.[39] One important element was the government's guarantees for foreign loans for the construction of the Ulsan shipyard. The construction of which required a budgeted 67 million US$, with 40 million supplied through foreign loans. Foreign lenders were sceptical, but the South Korean government was able to raise 50 million US$. The basis for this was HCC's proven ability in construction, with projects completed both domestically and abroad, and the fact that Hyundai had managed to get a first customer in Greek shipowner, George Livanos and could start production as soon as the facilities were constructed.

Government support was important in winning the first order from Livanos in 1971. The order was for two very large crude carriers (VLCCs) of 259,000 dead weight tons (dwt) each. The ships were sold at a price 16 per cent below the world market price and were exact replica of a ship that had been built at the Scott Lithgow shipyard in Scotland.[40] The learning-by-doing and the implementation of foreign technology were useful, but problems in production delayed delivery of the ships. After Livanos, and Japanese and Hong Kong shipowners

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[37] H. Kang, 'The Development Experience of South Korea – The Role of Public Policy', in P. K. Wong and C. Y. Ng, Industrial Policy, Innovation and Economic Growth: The experience of Japan and the Asian NIEs (Singapore, 2001), 353.

[38] The 1986 Law called for 'balanced development' with promotion of technology, increased productivity, efficient allocation of resources, training of labour and higher self-reliance. This was partly due to foreign pressure regarding state support, where shipbuilding had to follow OECD guidelines.

[39] Amsden, Asia's Next Giant, 275.

[40] For Scott Lithgow, see, L. Johnman and H. Murphy, Scott Lithgow: Déjà vu all over again. The rise and fall of a shipbuilding company (St John's, NL, 2005).

cancelled orders, the government assisted in the establishment of the Hyundai Merchant Marine Company in 1976, which took over the ships.

The state also intervened directly in the 1980s when Daewoo and KSEC had severe losses and were threatened by bankruptcies. The government arguments for supporting Daewoo rested on protecting jobs and communities. KSEC was eventually bought by the conglomerate Hanjin in May 1989 and renamed Hanjin Heavy Industries. The intervention was based on the government's expectancy that the recession in the world shipbuilding market would be short-term. The government, as it turned out, were right and shipbuilding markets started to recover in the 1990s.

4. Technology

The South Korean shipbuilding sector was technology-dependent in the 1970s, but managed to learn quickly and over time became a technologically innovative market leader. Technological development is a key component in explaining South Korea's importance in the world shipbuilding market. Three factors are particularly important: first, technological learning and adoption, in particular HHI's learning by doing at an early stage. Second, development of human capital, and third, the building of networks, in terms of better vertical integration with suppliers and the sharing of technology among shipbuilders.

South Korean shipbuilding in the 1970s lacked the technological know-how to be competitive in international markets and therefore sought foreign technological assistance.[41] HHI got four types of technological assistance from abroad for the Ulsan yard: dockyard designs from the English company, A&P Appledore; ship designs and operating instructions from Scott Lithgow; European shipbuilders who worked for HHI during the first three years of operations; and production know-how from Kawasaki Shipbuilding.[42] Hyundai had to pay 1.7 million US$ to Appledore and Scott Lithgow for the technology acquired. The link between the South Koreans and Scott Lithgow went back to a previous order of South Korean ships at the yard, 'so we [Scott Lithgow] were the logical choice when Hyundai and their consultants looked around for help. They bought the plans of our current quarter-million-tonner and signed a contract to train their key men.'[43]

At HHI, production know-how improved relatively fast, while design technology took longer to master. Production know-how increased, again, through learning-by-doing in producing multiple types of ships. As the market for VLCCs collapsed in 1974, HHI received orders for medium and small sized vessels and managed to accumulate production know-how in the building of crude oil tankers, roll-on–roll-off ships, multipurpose cargo vessels, bulk carriers and container ships. Regarding design technology, HHI was dependent on foreign designs for most of the 1970s although the company started to acquire basic design abilities from as early as 1974.[44] In 1978 a Basic Design Department was set up within the company. HHI's first self-designed ship was a 25,000 dwt bulk carrier ordered by Hyundai Merchant Marine in 1979. From 1978 to 1983, Hyundai was actively purchasing ship designs from other companies to improve their technology; see table 6.

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[41] Y.-H. Bae,'Shipbuilding Technology Development in Hyundai Heavy Industries Co., Ltd. (HHI)', in Y.-H. Bae *et al.*, Case Study on Technological Innovation of Korean Firms (Seoul, 2002) claims that Hyundai initially wanted to establish a joint venture with Mitsubishi in January 1969, but could not agree on the terms. Hyundai also sought joint ventures with the Aker group from Norway and Pan Maritime from Israel in October 1969, but these efforts eventually failed.

[42] Amsden, Asia's Next Giant, 276.

[43] Glasgow University Archives, Scott Lithgow company magazine, no. 10 (1972), 18. The previous order was for two 130,000 dwt tankers, Gold Star and King Star for Samyang Navigation Company originally placed in May 1967 for delivery in 1969, however, contractual negotiations rumbled on and delivery was put back until 1970 and 1971, see Johnman and Murphy, Scott Lithgow, 183, 192 and 198.

[44] Bae, 'Shipbuilding Technology Development in Hyundai Heavy Industries', 144–5.

Table 6: Hyundai's purchased design technology from abroad

Design technology	Purchased from	Time of purchase	Price
80,000 dwt tanker	Naiereorm (Germany)	02/1979	281,000 DM
40,000 dwt bulk carrier and 130,800 dwt bulk carrier	B&W (Denmark)	03/1982	11,110,000 USD
45,000 dwt OBO	B&W (Denmark)	10/1982	51,000 USD
170,000 dwt bulk carrier and 80,000 dwt bulk carrier	BWS (Denmark)	11/1983	100,000 USD
Multipurpose cargo carrier	NVLaskey (Canada)	11/1983	60,000 USD

Note: HHI (1992), 549–50; paraphrased from Bae, 'Shipbuilding Technology Development in Hyundai Heavy Industries', 145.

As one company representative pointed out, 'Hyundai Heavy Industries has made strenuous efforts to develop specific expertise and technology for the construction of gas carriers, and since 1978 has made license agreements with consultant companies to enhance its technological capability in cargo tank systems'.[45] Other shipbuilders also chose licences as a mean for acquiring technology, see table 7 for Samsung. In all 159 licences were purchased by South Korean shipbuilders in the period 1962 to 1987, at a total of 117 million US$.[46]

Table 7: Samsung's purchased technology licences from abroad

Technology/Areas	Partner	Period	Details
Managing shipyards	B&W (Denmark)	3/78-12/84	Management
Managing shipyards	B&W (Denmark)	3/81-12/87	Techno. consulting/ Design contract
Managing shipyards	IEC (Japan)	9/87-11/90	Management of production process
Design/Manufacturing	AUTOKON (Norway)	10/82-11/90	Computer programmes for design
Design/Manufacturing	MARCON (Germany)	4/83-8/89	Design technology
Design/Manufacturing	MONNECKE (Japan)	4/83-1/92	Design technology
Design/Manufacturing	IHI (Japan)	6/86-6/89	Consulting production technology
Design/Manufacturing	Sanoyath (Japan)	12/86-12/96	Technological Training

Note: R. Hassink and D. H. Shin, 'South Korea's Shipbuilding Industry: From a Couple of Cathedrals in the desert to an Innovative Cluster', *Asian Journal of Technology Innovation* 13:2 (2005 p.145).

The internal organization of HHI also improved. The Department of Quality Control was established in 1973. By 1983 HHI had managed to get three quality assurance certificates, respectively from Lloyd's Register of Shipping, Det Norske Veritas and the American Bureau of Shipping. Internationally, only four shipyards were approved by Lloyd's and only two shipyards were approved by Veritas at the time. HHI's quality standard had therefore reached an internationally accepted level. In November 1983 the Hyundai Welding Research Institute was set up to improve production technology. Another 1983 establishment was the Hyundai Industrial Research Institute (HIRI which aimed at improving productivity and quality and conducted research on, for instance, material processing and protective coatings. In 1984 a tank experiment station was set up to allow in-house testing and Hyundai Merchant Research Institute was established to research core technologies, for instance ship resistance; propulsion and manoeuvring; engine combustion, performance and durability; and hull form.

The second element crucial to technological development was human capital. An increase in the number of engineers is considered vital for technological catch-up. As Amsden and Jonsson show, the number of shipbuilding engineers had been growing since the 1950s, but many of these were not employed in shipbuilding. Despite having sufficient unskilled workers in the 1970s, there was a shortage of skilled workers. HHI, however, could recruit shipbuilding engineers from KSEC, obtained skilled labour from similar positions from Hyundai

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[45] C. H. Lee, 'Advanced gas tankers', Shipbuilding Technology International 4:1 (1989), 20-1.
[46] B. Gomes-Casseres and S. J. Lee, 'Korea's Technology Strategy', Harvard Business Case Study 9-388-137, (Bosten 1989), 18.

Construction Company and Hyundai Motors, and managed to find shipbuilding engineers that were 'under-employed' elsewhere. This was, however, not enough to meet HHI's demand at that stage.

There were however, three main sources for the increase in human capital. One was expatriates, such as the European engineers who worked at Ulsan in the first three years of operation. This included the Dane, Kurt J. Schou from Odense shipyard, who became the first president of the shipyard. In addition to numerous European engineers, there were also more than 30 Japanese engineers from Kawasaki Heavy Industries.[47]

A second way to increase human capital was to send personnel abroad for training. In accordance with the deal signed with Appledore and Scott Lithgow, 60 engineers and administrative staff received overseas training in shipbuilding technology and management abilities.[48] This was particularly useful, as the Livanos order was built on the basis of a Scott Lithgow blueprint.[49] In addition HHI dispatched personnel to learn design at the Sakaiide shipyard and shipyard construction technology at Kashima Construction in Japan. Given that Japan had 'state-of-the-art' technology, HHI could leapfrog others and acquire global competitiveness quickly.

A third way to increase human capital was by in-house training of personnel at HHI. In the short-term, engineers from various backgrounds came to the yard and brought with them their own standards and procedures. A small training centre was set up, and foremen were sent there for one to three months to increase uniformity.[50]

In September 1972 the company opened up a training centre and Robert L. Wilson from Appledore became the director. Upon opening, HHI trained 324 people in welding and cutting, plumbing, sheet metal work, electrical work, heavy and light machinery work, technical drawing and management. By the end of 1975 a total of 3,636 personnel had been trained, and by 1990 the total was an impressive 35,234.[51]

Another South Korean example of human capital development was at Daewoo Shipbuilding and Heavy Machinery (DSHM), which in 1987 was plagued by falling demand and substantial labour unrest. Heavy losses led to government assistance. However, the effects of the 1987 labour dispute, in hindsight, might have speeded up technological development. New labour measures were implemented, improving technological learning, labour cohesion and management-worker relationships.[52] Small groups of 10 to 15 workers went through training programmes and were sent to Japanese manufacturers to learn more efficient production. Labour schedules were reorganized to increase flexibility, which improved efficiency.

The building of industrial linkages was also important for technology promotion. Companies either created their own backward linkages or used subcontractors. In the 1970s and in the beginning of the 1980s, most key components were imported; towards the end of the 1990s between 70 and 80 per cent of the supply was purchased domestically.[53] One example was the Hyundai Engine and Heavy Machinery Manufacturing Company (HEMCO), established in 1978 to make engines and other components for ships.[54] HEMCO learned through foreign technical assistance, overseas training and licences. Moreover, while most shipyards have to buy their electronics ship navigation systems in the market, Samsung, with a strong electronics division, was able to purchase these components from within the group.

In the 1980s private R&D increased, both through increased policy loans and through changes in the internal organization of shipbuilding companies. This led to increased technological co-operation between South Korean shipbuilders, universities, other research institutions and suppliers. Moreover, South Korean shipbuilders formed their own trade association. The Korea Shipbuilders' Association (KOSHIPA) was founded in 1977 and functioned as an organized lobby group to promote shipbuilders' interests.

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[47] HHI (1992), 344; paraphrased from Bae, 'Shipbuilding Technology Development in Hyundai Heavy Industries', 150.
[48] Bae, 'Shipbuilding Technology Development in Hyundai Heavy Industries', 151.
[49] Scott Lithgow company magazine, no. 10 (1972), 18.
[50] Amsden, Asia's Next Giant, 281.
[51] Bae, 'Shipbuilding Technology Development in Hyundai Heavy Industries', 152.
[52] D. Upton and B. Kim, 'Daewoo Shipbuilding and Heavy Machinery', Harvard Business School Case Study 9-695-001 (Boston, 1994).
[53] Hassink and Shin, South Korea's Shipbuilding Industry, 146–8.
[54] Amsden, Asia's Next Giant, 279–80.

5. Rising in a sunset industry

What was the basis for the success of the South Korean shipbuilding industry? Three important points emerge from the analysis above. First, South Korea managed to acquire a large share of the world shipbuilding market, expanding rapidly in a period when capacity was reduced in all major shipbuilding nations. Second, the influence of the State was substantial, with the industry placed prominently in government plans for long-term economic development. Third, South Korea managed to continuously develop and upgrade production processes, sustaining initial cost advantages through rationalization and innovation. We can combine these elements to discuss to which extent the shipping glut and the plight of the yards in traditional shipbuilding nations might have been beneficial for the South Korean shipbuilding industry.

Four elements are likely to have affected the ascendancy of South Korean shipbuilding beneficially. First, the shipping crisis of the 1970s and early 1980s led to increased emphasis on the price of new ships. Second, the crisis enabled South Korean yards to gain market shares by offering novel financing solutions. Third, the large amount of subsidies prevalent in Western Europe strained the willingness of the authorities in traditional shipbuilding countries to compete with the newcomers. Finally, the crisis improved the South Korean yards' access to technology and know-how.

Subdued freight rates in the shipping market preoccupied owners in reducing costs. During a shipping depression, the market for ships is a buyers' market. Low freight rates implied that shipping companies could not justify paying extra for tonnage from old business relations, making it easier for newcomers to enter. Moreover, price was the one factor that determined where shipowners ordered vessels, an element that helped South Korean yards. Similarly, uncertainty regarding yards' ability to deliver the ships on time is something shipowners are willing to pay a lot to avoid during booms. In a depressed market delays are much less costly for shipowners, thus again having an adverse effect on the owners' willingness to pay extra to order at established yards.

The difficult financial situation of many shipping companies made novel financing solutions a necessity. Several owners were able to acquire new tonnage by entering into bareboat charters with South Korean yards (the legal owners of the vessel), and combine this with a purchase option. Thus, the owners' need for financing was limited, but they controlled the tonnage and could purchase it 'properly' when the market and the financial situation had improved.[55] An added bonus for shipowners was the fact that the ships could utilize low-cost foreign labour, which would have been impossible in several European countries. Table 8 shows that such arrangements were fairly common.

Table 8: South Korean vessels on bareboat charter with purchase options, 1984

	General cargo	Container ships	Log carriers	Bulk carriers	Chemical tankers	Oil tankers	Sum
Number	21	6	4	20	4	4	59
Grt	176,882	80,420	14,819	359,436	6,163	364,607	1,002,327

Note: Institute of Shipping Economics, *Shipping Statistics* 28:5 May (1984).

The subsidizing of Western European yards by governments at the earlier stages of the crisis was enormous. This is important for three reasons: first, the support stifled efficiency improvements and enabled European yards to maintain their relatively low productivity. Second, the expensive subsidies occurred against a backdrop of reduced activity, and cash-strapped governments were unlikely to provide even more financial support to the sector. Third, extensive use of subsidies in traditional shipbuilding nations implies that criticism of government support in South Korea was much more muted than would otherwise have been the case. Moreover, the crisis

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[55] A. Thowsen and S. Tenold, Odfjell: The history of a shipping company (Bergen 2006), 447–8.

may have hindered South Korean costs from escalating, as the low price of new buildings led to a clear focus on productivity.[56]

Finally, the availability of technology and competence may have been improved due to the crisis. European yards, unable to build ships at a profit, were able – and willing – to sell their services. As such, technology transfer from traditional yards might be considered a reflection of the fact that although they were unable to secure orders for new ships, at least they had something – knowledge – to sell.

The length of the shipping crisis of the 1970s and early 1980s was a blessing in disguise for South Korea's shipbuilders. Had the crisis been shorter, the reduction of production capacity in Europe, and the amount of support to European yards, would have been lower. If this were the case, it is likely that South Korean yards would have faced much more fierce competition, both during the temporary improvement of new building orders in 1979 to 1980, and in the second half of the 1980s.

Conclusion

The aim of this article has been to look more closely into the factors that enabled South Korea to grasp substantial market shares in the shipbuilding industry in the 1970s and 1980s. The role of the South Korean government in supporting the venture was crucial, but we have also emphasized that the scale and the length of the shipping and shipbuilding crisis was beneficial. Traditional shipbuilders in Western Europe were beset by high wages, relative to productivity, which, over time, sounded the death-knell of most of the European shipbuilding. Consequently, European shipowners' shift of focus from Europe to Asia was encouraged by lower prices, better delivery times and more beneficial financial terms.

Today it seems likely that the shipbuilding sector again is suffering from substantial overcapacity. The development has been much the same as that of the 1970s: rapid growth of shipyard capacity, linked to a boom in the shipping market, followed by a collapse of shipbuilding orders among historically high order books. This time around, however, the low labour cost, government-sponsored challenger is China, while South Korea's position is similar to that of the established builders – Japan and Europe – in the 1970s.

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[56] There is of course also the possibility that by investing heavily in new capacity and accepting losses through aggressive pricing, the Asian yards were able to see off their European competitors.

Essay 2: Malaysian Palm Oil Refineries and Plantation Productivity[*]

Abstract

The Malaysian palm oil sector is an example of how a developing country can manage to establish itself as a world leader in the production and processing of an agricultural crop. This paper examines how the productivity at the plantation level, the first level of production, influenced the establishment of the higher value-added refineries. The official productivity figures are inconsistent; therefore new productivity figures are estimated. The findings indicate that the improvements in plantation productivity were crucial for the refinery sector.

Introduction

Plantation agriculture has developed a bad reputation in recent years. The natural resource curse literature claims that negative associations exist between point sources, such as plantations, and economic growth.[57] However, some plantation crops, such as palm oil, have contributed to economic growth in both Indonesia and Malaysia.[58] In fact, palm oil has become the leading vegetable oil in terms of production and trade in the course of the past 50 years, increasing its share of global trade in vegetable oils from 16.2 % in 1962 to 59.2 % in 2008.[59] Palm oil is an example of how South-South trade can contribute to economic growth.

The palm oil sector is also an example of a sector that contributed to economic growth through the processing of primary commodities. Cramer (1999) is one of many to emphasise that such processing could contribute to industrialisation in other developing countries, as well. Understanding how this process occurred in Malaysia might therefore yield some useful insights for other developing countries attempting a similar strategy. The key to palm oil's success was the development of an internationally competitive food processing industry in the form of the Malaysian palm oil refineries. These refineries had strong government support in terms of industrial policy and through institutions that helped important functional areas such as research. Palm oil plantations are the first level of the value-chain and provide the palm oil refineries with the necessary input material. However, the puzzle in the case of the Malaysian palm oil industry is that the first stage of production, the plantations, showed little to no increase in productivity according to the official figures, which go back to 1975.[60] This article therefore re-examines the productivity figures and analyses the role of productivity at the plantation level during the period in which palm oil established itself as a major agricultural product in world trade.

The Malaysian palm oil sector has attracted much research, with two types especially relevant. The first deals with the establishment of the palm oil sector, with the PhD thesis by Gopal (2001) as the most extensive work. Gopal focuses on the establishment of the palm oil refineries, and how the industry overcame the common barriers to entry that developing countries face when establishing food-processing industries. However, Gopal to

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[57] For a discussion of plantation-based agriculture and economic growth, see Auty (1997), Woolcook *et al.* (2001), Isham *et al.* (2005) and Boschini *et al.* (2007).

[58] Palm oil is a typical plantation-based crop. It has high establishment costs, high labour requirements and fluctuating (exogenous) world market prices (Fold, 1998 p.400). Interestingly, Isham *et al.* (2005) instead classified it as a diffuse resource.

[59] Figures based on Basiron *et al.* (2004) and MPOB (2009). From 1962 to 2008, the export volume of all vegetable oils increased annually by 6.3 %, while the similar figure for palm oil was 9.4 %. In fact, these figures underestimate the influence of the palm oil sector. Palm kernel oil, an important by-product of the palm oil sector, by itself accounts for around 5 % of vegetable oil exports in 2008.

[60] The most common productivity indicator is the oil yield, which measures the amount of crude palm oil (metric tonnes) per mature area (hectare). I will come back to these productivity figures later.

a lesser extent focused upon the development of productivity at the lower stages of production. The second type of research deals with the reasons for the lack of productivity growth.[61] This lack of growth has been persistent despite large efforts to increase productivity levels. The primary reason behind this lack of growth might be the lack of implementation of new technology. However, the consequences of the lack of productivity growth for palm oil refineries is rarely considered. In fact, no study, to my knowledge, has explicitly looked at the relationship between plantation productivity and the establishment of palm oil refineries. This paper attempts to fill that gap.

The research question is 'How did the development in plantation productivity affect the establishment of the palm oil refinery sector?' This paper adds to the literature in two ways. First, the paper aims to increase our understanding of the importance of plantation productivity during the formative years of the palm oil sector. Specifically, I provide new estimates of productivity for the first and second level of processing and analyse their importance for the refinery sector. Second, the paper aims to increase our understanding of how plantations can contribute to the economic growth process by increasing the value-added of the production structure.

1. The Malaysian Palm Oil Sector

The palm oil sector has three levels of processing. *Plantations* produce the palm oil fruit from the palm trees; these fruits are called fresh fruit bunches (FFB). Following detachment from the palm tree, processing of FFBs must take place within 24 hours to have sufficient quality. *Mills*, the second level, process FFB to produce crude palm oil (CPO), and as a by-product, palm kernel (PK).[62] As the processing of FFBs has to be quick, mills are located close to or even on the plantations. *Refineries*, the final level, process CPO to produce various products called processed palm oil (PPO). CPO, PK and PPO products can also be used as inputs in other industries such as the oleochemical industry.[63] During the 1970-90 period, the higher value-added refineries and the linkages to other industries were established. Figure 1 presents a schematic summary of the industry with some of its forward linkages. To limit the scope of the paper, I do not consider palm kernel or palm kernel oil, but focus on crude palm oil. In addition, as plantations and mills are highly integrated, this paper looks at the productivity of both plantations and mills and how it affects the palm oil refineries.

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[61] See among others Jalani *et al*. (2002); Soh and Goh (2002), and Wahid *et al*. (2005).

[62] Crushing factories process palm kernel to produce crude palm kernel oil, which is an important by-product of the palm oil sector.

[63] For good introductory overviews of the palm oil sector, see Moll (1987), Teoh (2002) and Rasiah (2006).

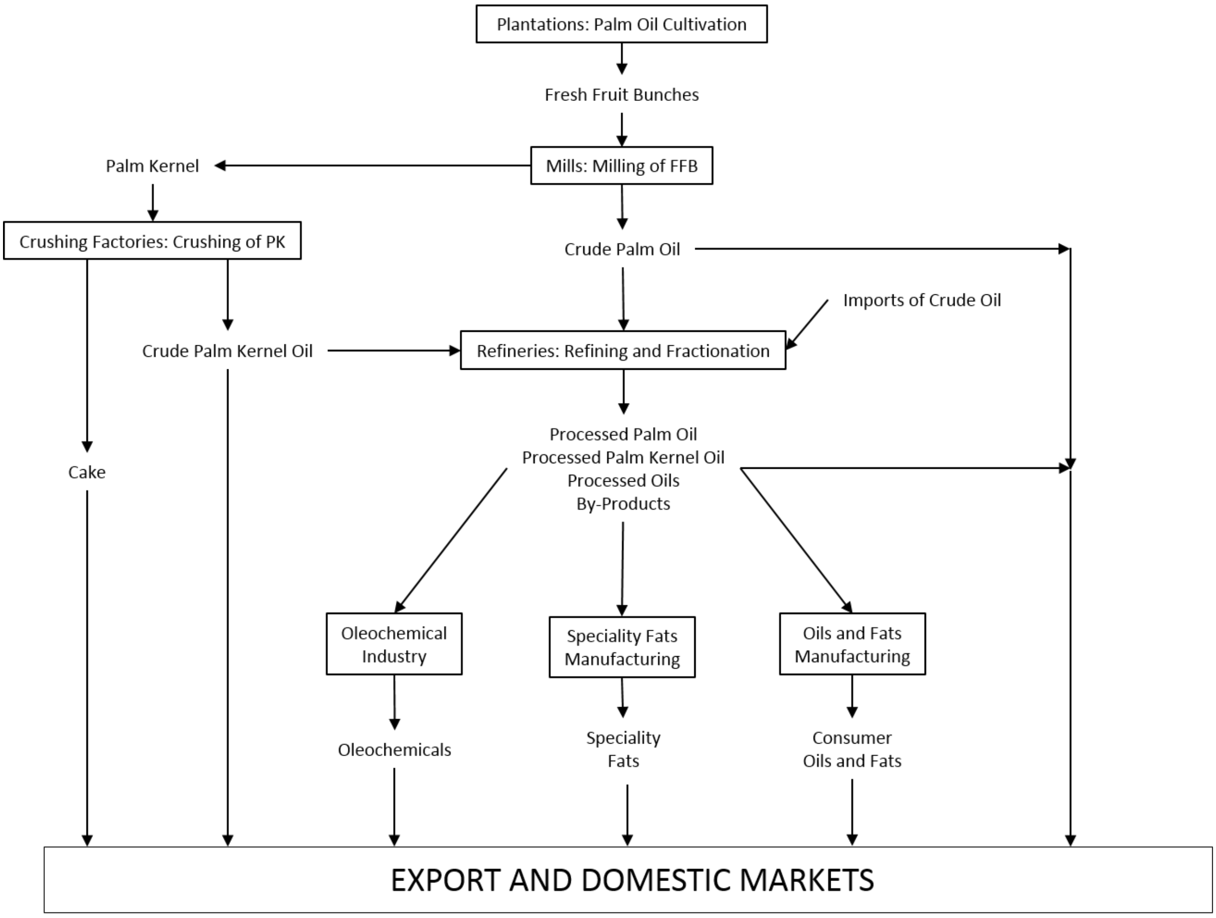

Figure 1: Schematic Summary Malaysian Palm Oil Industry
Source: Gopal (2001 Figure 3.1 p.131)

The modern expansion of the sector started in the 1960s, though commercial production of palm oil first started in 1917 (see table 1). In colonial times, the palm oil sector was slow to develop, with production and exports increasing only modestly.[64] In the 1960s, the government strongly promoted palm oil as part of a strategy of reducing the Malaysian dependence on rubber and tin.[65] Favourable prices and operating costs that were potentially lower than rubber made palm oil a natural long-term replacement for rubber.

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[64] Pletcher (1990 p.329).

[65] Substantial replanting grants were given for planters shifting from rubber to palm oil (Pletcher, 1990 p.337).

Table 1: Phases of development in the Malaysian palm oil sector

Phase 1: Colonial times (1875 to 1957)	The introduction of palm oil in the 19th century and its first commercial exploitation from 1917: - Slow growth in crude palm oil production and exports
Phase 2: Promotion of palm oil production (1957 to 1973)	Government promotion of palm oil: - Investment and tax incentives - High growth in crude palm oil production and exports
Phase 3: Promotion of refineries (1973 to 1986)	Government promotion of increased value-added: - Investment and tax incentives - Increased institutional support - Export tax on crude palm oil - High growth in crude palm oil production - High growth in processed palm oil production and exports
Phase 4: Promotion of upstream and downstream activities (1986 onwards)	Government promotion of backward and forward linkages: - Investment and tax incentives - High institutional support - Continued high growth of processed palm oil production and exports - Continued high growth of crude palm oil production - Establishment of the oleochemical industry with subsequent high growth

Following the rapid increase in crude palm oil production and exports in the 1960s and early 1970s, the structure of the industry changed. The government believed that a continued increase in exports hinged on increasing the value-added of production. To increase the value-added, the government promoted the establishment of the refinery sector through investment and tax incentives, and most importantly, an export tax on crude palm oil starting in 1973. The export tax increased the cost of crude palm oil for European refineries and led to increased investments in palm oil refineries in Malaysia. The World Bank opposed the export tax, as Malaysia did not have a comparative advantage in capital-intensive production.[66] British plantation owners in Malaysia also opposed the tax, as they preferred to have palm oil processed in Europe.[67]

Despite the initial scepticism, the palm oil refinery sector in Malaysia enjoyed high export growth for its products and increased competitiveness over time. Refineries increased their processing capacity from below 0.1 million tonnes in 1971 to close to 10.5 million tonnes in 1990, see table 2. Table 2 also reveals that the average size of refineries gradually increased over time; since it was a capital-intensive industry, it had considerable economies-of-scale to exploit. In addition, most of the oil processed at the refineries came from domestic producers, as the expansion of the processed quantity was closely correlated with increases in local production from 1980 and onward. There was a dramatic change during the 1970s, when CPO processed compared to CPO production was only 4 %, but this figure increased to 95 % by 1980 and has since been at a minimum around 90 %. Figure 2 presents more evidence of the increased importance of refineries as processed palm oil replaced crude palm oil as the main palm oil export product in the 1970s and has kept this position ever since. Gopal (2001) analysed the competitiveness of the palm oil refineries by comparing the profit margins between Malaysian refineries and European ones in the time period 1980 to 1994. Gopal's analysis strongly indicates that the Malaysian refineries became more competitive than the European ones towards the end of the 1980s.[68]

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[66] Note that I used the phrase 'comparative' rather than 'competitive' in this sentence, with comparative advantage meaning the access to resources. Through the rest of the paper, I use the term 'competitive', with competitive meaning the creation of a strategic advantage. See for instance Neary (2002) for a discussion of these concepts.

[67] According to Bek-Nielsen, the founder of United Plantations, the British plantation owners were afraid of upsetting Unilever, their biggest customer, who preferred to process the vegetable oils in Europe (Fold, 1998 p.401).

[68] Earlier studies by Todd (1978) and Lim (1979) had concluded that the Malaysian palm oil refinery industry was not competitive at the end of the 1970s.

Table 2: Palm Oil Refineries Capacity in Operation Malaysia 1971-2010

Year	Capacity in operation Million metric tonnes	Palm oil refineries in operation No.	Average refinery size in operation Million metric tonnes	CPO Processed at Refineries/CPO Production Percentage
1971	0.08	2	0.04	4 %
1975	0.80	10	0.08	21 %
1980	2.88	45	0.06	95 %
1985	5.35	38	0.14	89 %
1990	10.45	37	0.28	106 %
1995	10.15	41	0.25	100 %
2000	14.60	46	0.32	93 %
2005	17.31	48	0.36	94 %
2010	22.89	51	0.45	93 %

Source: Gopal (2001) Table 4.1 for 1971-1995; and MPOB (2000; 2005) Table 2.14 and MPOB (2010) Table 2.17 for 2000-2010

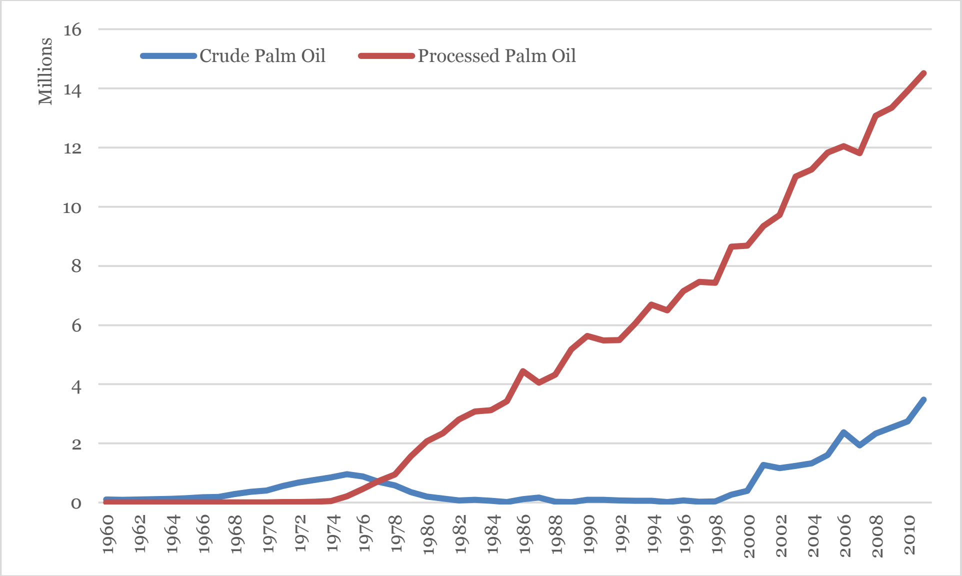

Figure 2: Exports (Metric Tonnes) 1960-2011

Source: Gopal (2001) Table 4.4 for 1960-74; and MPOB (2012) Table 4.1 for 1975-2011

Several factors contributed to the increased competitiveness of the palm oil refinery sector. The most important factor is probably that cost efficiency at Malaysian refineries increased through learning-by-doing. In addition, the refineries went through two restructuring processes in which ineffective refineries went bankrupt. Another important point is that Malaysian refineries had a higher degree of specialisation than those in Europe. European refineries used various vegetable oils to produce processed oil products; Malaysian refineries almost exclusively used palm oil. Such specialisation did create technological challenges, as Malaysia developed new technology to treat large volumes of palm oil. Malaysia increasingly became the main innovator within the industry as it met the challenge of creating palm oil-specific technology. The refineries probably benefited from this development, as the specialisation led to efficiency gains over their European rivals.

By the second half of the 1980s, the palm oil industry had matured and was increasing its backward and forward linkages to other industries. The most important of which has probably been the oleochemical sector. Industry patterns were, however, largely a continuation of the previous period with processed palm oil being the industry’s driver. To understand the establishment of the palm oil sector, it is therefore important to look at the 1970-90 period.

The state played a decisive role in the development of the palm oil sector. Through government schemes, the state was directly involved in production. The most important of these schemes was the Federal Land Development Authority (FELDA), which changed its focus during the period from being a purely poverty reducing institution to becoming a commercially active state company.[69] The state also purchased most of the foreign-owned companies to increase the equity share of indigenous ownership as a part of the New Economic Policy.[70] In addition to direct involvement in production and industrial policy, the state institutions' support was important. The Palm Oil Registration and Licensing Authority (PORLA) was responsible for giving licences and controlling prices in the palm oil sector. The Palm Oil Research Institute of Malaysia (PORIM) was responsible for conducting public research in palm oil. Following a rationalisation process in 1998, PORLA and PORIM merged to form the Malaysian Palm Oil Board (MPOB). The government is also the main owner of the current Malaysian Palm Oil Council (MPOC); a private company that promotes palm oil by launching marketing campaigns and trade missions. Direct government involvement in agricultural markets has been much criticised. However, in the case of the Malaysian palm oil sector, heavy government involvement has been compatible with high growth. Pletcher (1991) mentions two factors that he believes have been important for successful state intervention. The first is that the price mechanism, though influenced, was never controlled. The second is that the policies that helped shape the palm oil sector were internally consistent and consistent across time.

The paradox addressed in this paper is that the most common productivity indicator for the palm oil sector, the oil yield, has been virtually constant since 1975 (see table 3. The oil yield measures crude palm oil production per mature area (area which is harvested) and is a joint productivity indicator of both plantations and mills. For an industry that became increasingly competitive internationally, one would expect productivity to have increased at all levels of production.[71] According to Jalani *et al.* (2002), the reasons for the stagnation of yields are: (i) Expansion into marginal areas; (ii) Inadequate agronomic inputs; (iii) Ineffective and inadequate management; (iv) Shortage of skilled labour; (v) Low replanting rate; (vi) Inadequate extension capability; and (vii) Combination of low fresh fruit bunch yields at plantations with low oil extraction rates at mills. A major concern is that the yields do not reflect the breakthroughs made by research, implying that the major failure was the lack of implementation of new technology.[72]

Table 3: Main Official Productivity Indicator Palm Oil Sector

Year	Oil Yield: Crude Palm Oil Production (tonnes)/Mature Area (hectare)
1960	3.75*
1965	3.75*
1970	3.68*
1975	3.66
1980	3.78
1985	4.33
1990	3.64
2010	3.69

Source: Jalani *et al.* (2002); MPOB (2010)
*Estimates from MPOB personnel

The large expansion of crude palm oil production, which was crucial for the establishment of the palm oil refineries, might therefore have been a pure input-driven process. There are several arguments that could support this interpretation. The most convincing argument would probably be that productivity, despite not increasing, was higher than for other vegetable oils. Even as late as in 2009, the oil yield for soya bean oil was

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[69] On the evolution of FELDA regimes, see Pletcher (1991 pp.628-630). See also Simeh and Ahmad (2001 pp.2-4) for an overview of the government institutions in the palm oil sector.

[70] See Pletcher (1991 pp.630-631).

[71] Exporting firms have, in general, a higher productivity than comparable non-exporting firms do. However, it is still debated whether this occurs through self-selection of the most productive firms into the export market or as a result of the fact that international trade provides the competition that makes firms more competitive. See for instance Aw *et al.* (2011), Bernard and Jensen (1999), and Giles and Williams (2000a, 2000b).

[72] See among others Jalani *et al.* (2002), Soh and Goh (2002), and Wahid *et al.* (2005).

0.3, rapeseed 1.3 and sunflower oil 0.8.[73] The competitive pressure to increase the oil yield might therefore have been limited as profit margins continued to be high. However, productivity might in fact have increased. As, the land with the highest quality is taken into production first, future expansion into new areas increasingly meant that land decreased in quality. Producing the same quantity despite a decrease in the quality of inputs would be a *de facto* productivity increase. Another argument is that increased market entry caused the average productivity to decline. New plantations would initially be less productive, as productivity first increases through learning-by-doing.[74] If a sufficient number of new plantations were established, the average productivity levels might decrease.

A second possibility is that the official productivity figures do not give an accurate picture of the development of productivity. The oil yield is a partial productivity measure that combines land and process productivity. Partial productivity analysis does not take into account the effect of other inputs, or how other partial productivity measures have developed. In the next section of the paper, I explore this possibility further, and I do find inconsistencies in the official productivity measures indicating that these do not give an accurate picture of the evolution of productivity.

As Cramer (1999) mentions, not much is understood of how food processing industries are established in developing countries. If increased productivity at the plantation level is an important precondition for developing a downstream food processing industry, the policy implications might be to increase the productivity in agriculture as a means to promote industrialisation. The Malaysian palm oil sector might then yield some important lessons for other developing countries to follow. However, if the Malaysian palm oil sector is unique, and purely a product of favourable geographical conditions, the potential lessons for other developing countries lessen.

2. Productivity Measures in the Palm Oil Sector

The main challenge in measuring productivity is to choose the appropriate methodology given the research question and the data availability. The main indicator of productivity has been the previously mentioned oil yield, which is a mixed land and processing productivity measure. The most commonly used methodology in the productivity literature is a total factor productivity analysis. However, data limitations, especially the lack of capital data for the 1970s, hinder such an analysis.

Since the 1960s, there has been much research on palm oil production by the government and private plantations, which had several priority areas. The most relevant priority areas for plantations and mills have been (i) increasing the amount of oil produced per hectare; (ii) decreasing production costs; and (iii) increasing labour productivity. I therefore look into each of these to assess overall productivity.

2.1 Oil Yield

To assess the actual oil yield, one has to assess the sources and the collection methods. The oil yield, as mentioned before, measures the amount of crude palm oil in tonnes per mature area in hectare per annum. Two agencies collected the official data from 1961 until present. From 1961 to 1988, the Department of Statistics of Malaysia collected the data, mainly through annual surveys. From 1989 until the present, the Palm Oil Registration and Licencing Authority (PORLA) had the responsibility for data collection. In 1998, PORLA merged with two other institutions to form the Malaysian Palm Oil Board (MPOB). Another major source of agricultural

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[73] The US for soya bean, the European Union for rapeseed and Argentina for sunflower; figures from FAO (2014). Palm oil needs a tropical climate to achieve high yields, while the other vegetable oils are close substitutes more adapted to other climates. The various vegetable oils, despite some different properties, compete more or less directly in the international market.

[74] Differences in productivity among different plantations and mills are huge; see for instance Basiron (2007).

data is the Food and Agricultural Organization Division of the United Nations (FAO), which also has data on the Malaysian palm oil sector.

The oil yield data taken directly from the MPOB differs from the FAO data. According to MPOB data, the oil yield increased from 3.7 metric tonnes per hectare (mt/ha) in 1975 to 3.9 mt/ha in 2009, an annual compound growth rate of 0.2 %. However, according to FAO data, yield increased from 3.5 mt/ha in 1975 to 4.3 mt/ha in 2009. The FAO data give an annual compound growth rate of 0.6 % in the same period. The FAO data thus shows a growth rate that is three times as high as the MPOB data. Fry (2009) also noted the difference, which he attributed to the unreliability of the FAO data. Fry believed that yield estimates based themselves on the assumption of an automatic increase over time. Fry's assessment comes from the analysis of the yield of other vegetable oils. However, Fry's conclusions are probably not correct, as the yields from other non-vegetable crops do not show an increasing trend. In addition, both production and end of year mature areas are identical for both the official MPOB data and the FAO data for the period 1975-2011. The difference in the yield figures has an easier explanation, since the formulae for calculating oil yields differ, as illustrated in equations (1) and (2):

$$MPOB\ CPO\ Yield = \frac{Yearly\ CPO\ Production}{Average\ Mature\ Area\ in\ Production\ During\ the\ Year} \tag{1}$$

$$FAO\ CPO\ Yield = \frac{Yearly\ CPO\ Production}{Mature\ Area\ at\ the\ End\ of\ the\ Year} \tag{2}$$

Normally, this difference would be unproblematic as the trends would be approximately the same. However, the trends are not the same, meaning that one of these is probably inconsistent. Palm kernel (PK) is, as mentioned, a by-product of the palm oil sector. Both CPO and PK are produced from fresh fruit bunches (FFB), and therefore, both use the same mature area. The MPOB has official figures for both the CPO yield and the PK yield. One can estimate the average amount of mature area in production as production and yield data are available. Using the yield figures to estimate mature area gives inconsistent results. Area estimates using CPO yield differ from the estimates using PK yield prior to 1984. In addition, for most of the 2000s, the official MPOB figures imply that nearly 100 % of all planted land was in production, while the official MPOB figures for mature area at the end of the year show that this is implausible. Appendix 1 explains these inconsistencies further and shows the estimation of average mature area for all years in more detail.

To get a more plausible estimate of oil yield, I use yearly CPO production and end-of-year mature area data, which are the same for 1975-2011, regardless of whether FAO or MPOB figures are used. For the years 1961-1974, production and mature area data are available from the FAO, which are broadly similar to earlier PORLA publications. Figures for the 1950s are estimated using data from Gopal's (2001) PhD dissertation, and are the least accurate. The yield figures for the 1950s are therefore those with the highest degree of uncertainty. To get a better measurement of land used in production, I use the average amount of mature land during the production year as shown in equation (3):

$$Average\ Mature\ Area_t = \frac{Mature\ Area\ End\ of\ Year_t - Mature\ Area\ End\ of\ Year_{t-1}}{2} \tag{3}$$

The oil yield is the CPO production divided by the average amount of mature area as shown in equation (4):

$$CPO\ Yield_t = \frac{CPO\ Production_t}{\left(\frac{Mature\ Area\ End\ of\ Year_t + Mature\ Area\ End\ of\ Year_{t-1}}{2}\right)} \tag{4}$$

For more details, and calculations for each individual year, see appendix 1. Figure 3 presents the results; to smooth out short-term fluctuations, I present only the five-year moving average.

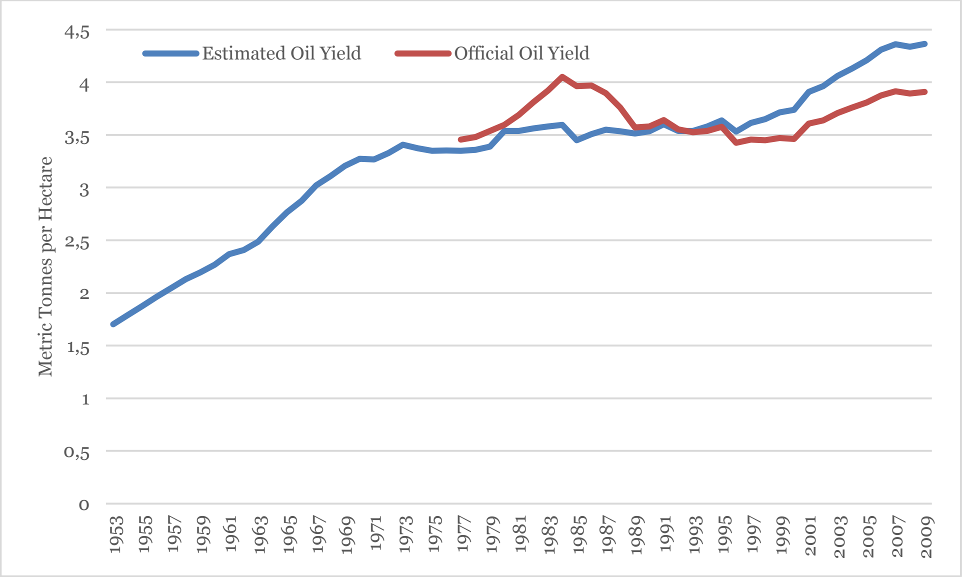

Figure 3: Oil Yield Crude Palm OIl (metric tonnes)/Average Mature Area (ha) 1953-2009 (Five-Year Moving Average)
Note: For sources and a more detailed explanation of the estimation, see appendix 1

The results in figure 3 show that the official MPOB oil yield figures were probably too optimistic in the 1980s and too pessimistic in the 1990s. Taking the estimated figures, the oil yield increased from 1.4 t/ha in 1950 to 2.3 t/ha in 1960, and even further to 3.7 t/ha in 1975; several authors, among them Gopal (2001 table 3.8 p.125), report similar figures. There has also been a considerable increase in long-term yields in the period since the mid-1970s. However, the increase was slow up until the mid-1990s. It is important to analyse the potential reasons for this pattern. To examine the underlying process, I divide the production process into its two stages; figure 4 shows a rough schema of this two-stage process.

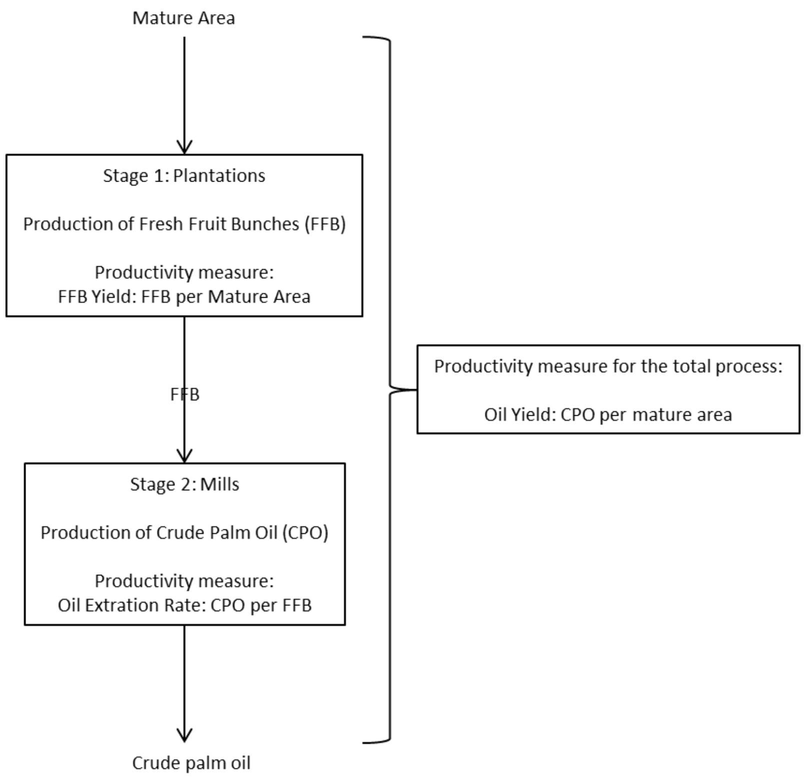

Figure 4: Production process of Crude Palm oil

The productivity of crude palm oil can therefore be divided into two components as shown in equation (5a), with equation (5b) showing the same two components defined:

$$\frac{Yearly\ CPO\ Production}{Average\ Mature\ Area} = \frac{Yearly\ Fresh\ Fruit\ Bunches\ Production}{Average\ Mature\ Area} \times \frac{Yearly\ CPO\ Production}{Yearly\ Fresh\ Fruit\ Bunches\ Production} \quad (5a)$$

$$Oil\ Yield = FFB\ Yield \times Oil\ Extraction\ Rate\ (OER) \quad (5b)$$

To calculate these separate ratios, I had to make some assumptions. Time-series on fresh fruit bunch production suffer from a lack of time consistency as the collection of official data was changed in 1989. The Department of Statistics and the MPOB used different ways of collecting the data, thus, the time series are not comparable. Therefore, I used the FAO time-series on fresh fruit bunch production as these are consistent over time.[75] In appendix 1, I show the results for individual years. In figure 5, I show the five-year moving average to smooth out short-term fluctuations, and I have also indexed the figure to 1963 to enable an easier analysis of relative changes over time.

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[75] For estimating the Oil Extraction Rate, the preferred measure is FFB processed and not FFB produced, as some of the FFBs are used for seed production. However, the difference between the two is small and I assumed that the relative share was constant over time.

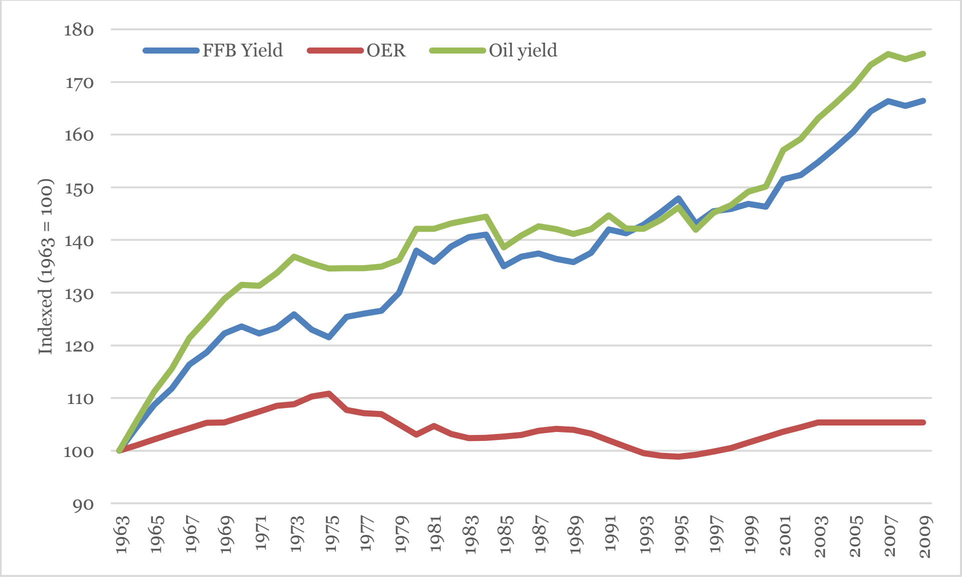

Figure 5: Oil Yield, FFB Yield and OER 1963-2009 (Five-Year Moving Average)
Note: For sources and a more detailed explanation of the estimation, see appendix 1

The results show that the growth in the yield of fresh fruit bunches (FFB) is the main contributor to the growth in the oil yield. FFB yield grew fast in the three short periods, 1963-69, 1975-81 and 1999 until the present. These 'leaps' were followed by more modest growth. The most relevant 'leap' for the topic of the paper is the 1975-81 one. The oil extraction rate (OER) contributed to the growth in oil yields from 1963 to 1975, but then entered a period of long-term decline, which lasted until the mid-1990s. Since 1995, the OER has again increased, but has still not come back to the levels of the mid-1970s. If true, it would imply that the main driver for increasing oil yields were productivity improvements at the plantation level. It would also imply that mill productivity held oil yields back.

To find the reason for the increase in oil yields, one has to find the reason for an increase in FFB yields. One potential reason is the increased amount of palm oil research. Several palm oil companies improved their research through the creation of the Oil Palm Genetics Laboratory.[76] In addition, the Malaysian Department of Agriculture launched a research exchange programme with West Africa. The most important technological change has been the improvement of the palm trees through the introduction of new species. The introduction of the DxP variety in the late 1960s and early 1970s, which led to more FFB per hectare, is probably the main reason behind the large leap in FFB yields from 1975 to 1981. As can be seen in figure 6, the DxP variety of oil palm quickly replaced the less efficient DxD and other oil palm species. Since it takes three years from a tree is planted until it reaches harvesting maturity, and a further five years for the highest yield, one would expect yields to increase approximately eight years following the planting of a new DxP tree. There is a lagged correlation between the share of DxP palm trees and the increase in FFB yields eight years later. Data from the Department of Statistics (1969-1988) show that plantations that have the DxP variety of oil palm trees have a higher yield than plantations with a different palm oil species. However, there are too few observations, and a large selection bias issue, which means that any kind of econometric specification would not yield reliable results.

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[76] See for instance Hartley (1988) and Kajisa *et al.* (1997).

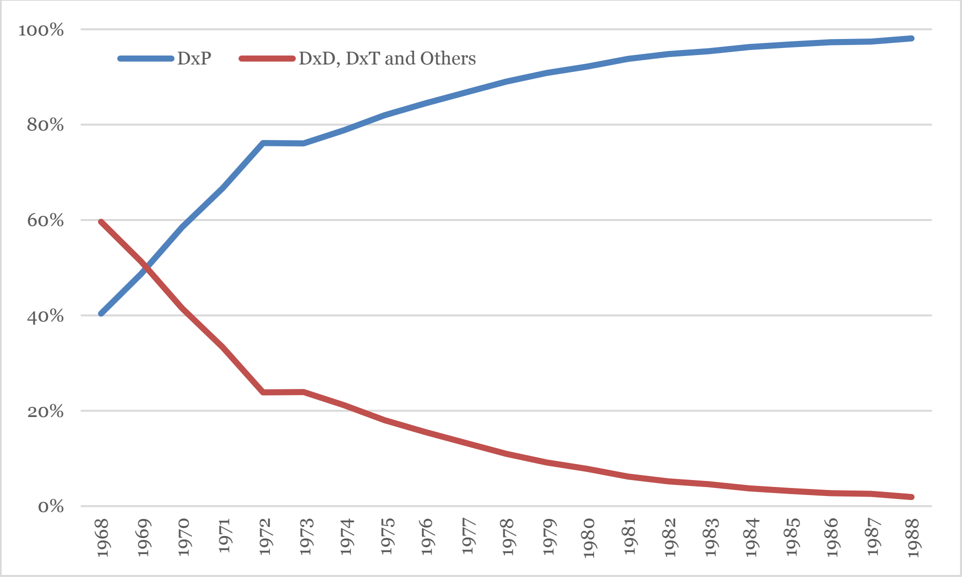

Figure 6: Planted Palm Oil Species, Share (%) of Total Planted Area Peninsular Malaysia 1968-1988

Source: DoS (1968) Table 25; DoS (1969) Table 26; DoS (1970-1971) Table 29; DoS (1972) Table 30; DoS (1973-1981) Table 31; DoS (1982-83) Table 29; DoS (1984-1988) Table 6.1

A second reason for improvements in FFB yields is the increased productivity in the government schemes. As mentioned previously, the Federal Land Development Authority (FELDA) was the largest government scheme in Malaysia.[77] FELDA increased its ownership share of oil palm planted area from less than 5 % in 1970 to around 30 % in 1990.[78] Plantations expanded on good soil, and often shifted from rubber to palm oil. FELDA expanded on virgin soil, often considered of 'secondary suitability' in terms of soil quality and topography.[79] FFB yields of the FELDA programme increased from 13.9 FFB per ha in 1975 to 18.1 FFB per ha in 1985.[80] Private estates only managed an increase from 18.0 to 18.6 FFB per ha the same years. FELDA's improvements in management and the private incentives for smallholders that took part in the programme probably led to the increase in FFB yields.[81]

The oil extraction rate (OER) has not shown clear progress for the period as a whole. The major reason mentioned for the lack of increase in OER is that FFBs do not have a proper degree of ripeness, which lowers OER.[82] One potential reason for this lack of ripeness is the high competition among mills, especially those without their own plantation.[83] The competition, coupled with the pressure to increase production, might have caused a decline in harvesting standards and the quality of FFBs. Another reason for the lack of ripeness has been the increasing shortage of workers at plantations. This meant that detached FFBs are lying on the ground too long before being transported to mills.

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[77] The private plantations have the best FFB yield. Government schemes, sometimes called organized smallholders, have a lower FFB yield than private plantations. FELDA has had periods with highly centralised management on the different schemes in an attempt to benefit from economies-of-scale. The different farmers resisted such attempts, as these preferred more independence in how to manage their own plots. The independent smallholders, or true smallholders, have the lowest FFB yield among oil palm growers. For the role of independent smallholders, see for Rahman *et al.* (2008).

[78] Data based on Simeh and Ahmed (2001). Other public schemes accounted for a further 16 % of total planted area in 1990.

[79] Fold (1994 p.76).

[80] DoS (1975 Table 32); and DoS (1985 Table 6.2).

[81] Palm oil was the most profitable of the government schemes with FELDA settlers growing palm oil earning 765 RM per month, compared to 484 RM for rubber schemes and 148 RM for padi rice cultivators.

[82] Chan and Lee (1993 p.11).

[83] In 1988, 45 mills were located on estates and 58 mills were owned by estates. The remaining 119 mills are 'independent' in the sense that they are owned by smallholders or (local) state organisations or linked to comparatively small private estates (Fold, 1994 p.76). Mills that do not have their own plantations are fully 'supply-dependent'. An estimate made by Thiran (1984) claims that 29 of 171 mills in 1981 were fully 'supply-dependent'.

Large private firms owning both plantations and mills in general have higher OERs than the industry average.[84] This might be the result of (i) better labour saving technologies at plantations; (ii) private research which is more directed at firm-specific problems and therefore more likely to be relevant for the firm; and (iii) a tighter integration between plantations and mills, meaning that there are better routines to get FFBs quickly to the mills, thereby increasing their ripeness. However, the OER in private plantation firms, despite being higher, did have the same trends as the rest of the industry.[85]

2.2 Labour productivity

SInce plantations are labour-intensive, labour productivity has special importance. Employment data are taken from '*The Oil Palm, Coconut and Tea Statistics Handbook*' published annually by the Department of Statistics. The data from the Department of Statistics show end of year employment for 1969-88. Having only one observation per year could potentially be problematic because of the seasonal nature of production. However, the correlation between annual production and employment in December is high, which makes the indicator plausible.[86]

To analyse the labour productivity for the period 1969-88, I estimate two labour productivity measures shown in equations (6) and (7):

$$Labour\ Productivity\ Plantation_t = \frac{Fresh\ Fruit\ Bunch\ Production_t}{\left(\frac{Employment\ End\ of\ Year_t + Employment\ End\ of\ Year_{t-1}}{2}\right)} \tag{6}$$

$$Labour\ Productivity\ Mill_t = \frac{Crude\ Palm\ Oil\ Production_t}{\left(\frac{Employment\ End\ of\ Year_t + Employment\ End\ of\ Year_{t-1}}{2}\right)} \tag{7}$$

To estimate the input, the employment during the year, I estimate the average employment by dividing the two end-of-year figures. The input estimation measure for employment is similar to the input measure for land for oil yields. In addition, I had to adjust the data to make sure they were consistent over time. Workers were categorized into (i) Directly employed; and (ii) Contract workers. While the share of directly employed on plantations was available for the whole period, the share of contract workers employed on plantations was only available for 1979-1988. Therefore, the share of contact workers employed on plantations and those employed in mills in the period 1969-1978 had to be estimated using the trend in the share 1979-1988. It is important to stress that the results do not hinge on these assumptions. Appendix 2 shows the calculation and data issues more extensively.

The first labour productivity measure is for the plantations. As the employment figures were only for plantations in Peninsular Malaysia, I excluded FFB production from Sabah and Sarawak, as well as from government schemes. The production data for FFB is the same as for FFB yields, from the FAO (2014), adjusted to make sure that the production figures were only for Peninsular Malaysia plantations. For more details on the estimations, see appendix 2.

The evidence indicates that labour productivity increased strongly for plantations (see figure 7). Better equipment might explain the increase in labour productivity meaning that capital per worker increased. However, the mechanisation of production of palm oil first started in the 1980s. Anecdotal evidence from the 1970s

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[84] Chang *et al.* (2003 p.28) shows that the OER is highest for plantation-based mills. The 'supply-dependent' mills came out second, with the government mills having the lowest OER.

[85] See for instance Gan *et al.* (1993) for Sime Darby; Lee and Shawaluddin (1993) for Golden Hope; and Toh and Tan (1993) for United Plantations.

[86] This correlation is sufficient, as I am interested in trends rather than absolute values.

indicates that there was no large increase in the capital per worker in this decade.[87] Figures from the Department of Statistics indicate that real capital per worker was actually decreasing. It is therefore unlikely that an increase in capital caused the increase in labour productivity. The evidence indicates that better organisation and improvements in management probably were the keys to increasing productivity. Mature land per worker in 1970 was 3.3 ha; by 1988, this figure had increased to 8.8 ha. It is not possible to cover an increasing land area without an improvement in the organisation at the plantations.

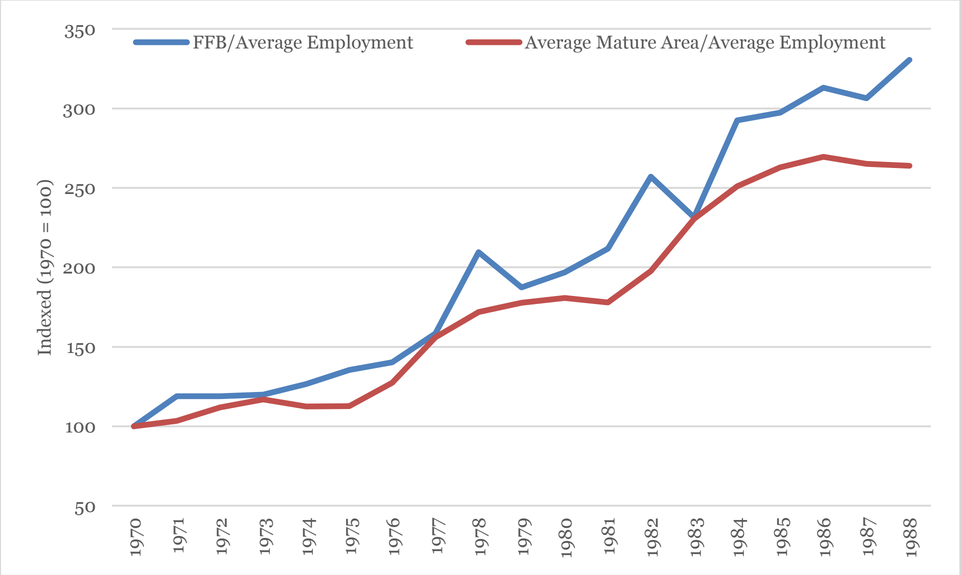

Figure 7: Labour Productivity and Land per Labour Ratio Plantations Peninsular Malaysia 1970-1988 (1970 = 100)
Note: For sources and a more detailed explanation of the estimation, see appendix 2

The labour situation does deserve a special comment, since the 1980s started to see the first signs of problems with labour shortage. Following the introduction of manufacturing free trade zones and the higher wages offered there, Malaysians became increasingly unwilling to work on plantations. This created a labour shortage in the palm oil industry. This situation is a chronic problem for the industry, which, despite attempts to raise labour productivity and mechanisation, refuses to go away. Since 1986, the inflow of foreign workers, especially from Indonesia, is meeting the palm oil industry's need.[88]

For plantation mills, labour productivity increased from 1970 to 1986 (see figure 8). The problem is that plantation mills are unlikely to be representative for mills in general. Figure 8 shows that the share of mills that are located on plantations was a declining share of overall mills, declining from 58 % in 1970 to 17 % in 1988. Chang *et al.* (2003 p.28) shows that plantation mills are more productive, as the oil extraction rates differ between plantation types. Less data are available for mills compared to plantations, so no quantitative assessment on the causes of the increase in labour productivity is possible. Mills are capital-intensive and labour productivity is therefore not likely to be as important for plantations.

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[87] Company records from United Plantations show no clear trends in the capital at plantations. The problem is that these records include capital invested in mills and refineries, and these explain the large 'leaps' in the records. The trend apart from these 'leaps' is non-increasing.
[88] For the labour constraints in the plantation industry, see Amatzin (2006).

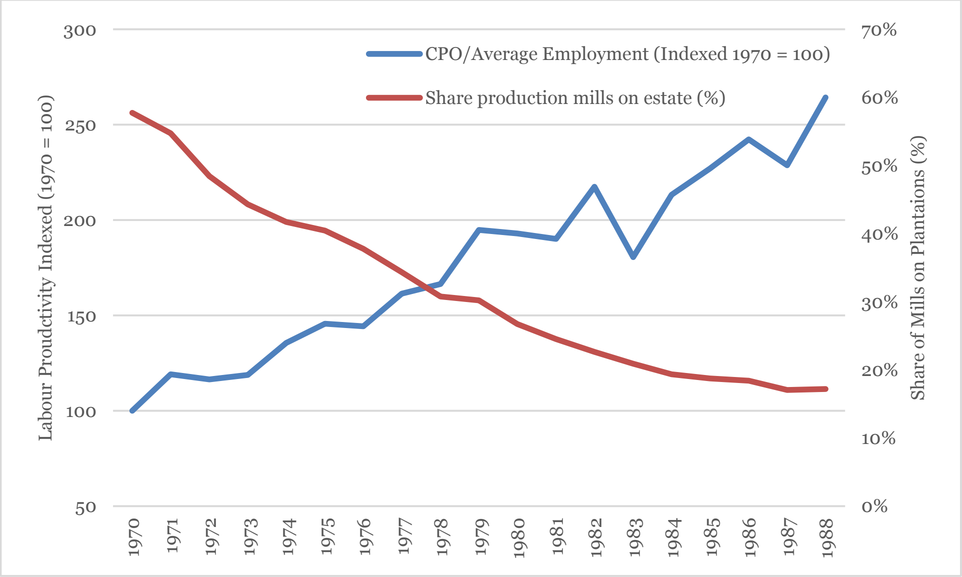

Figure 8: Labour Productivity Mills on Plantations and Production Share of Mills on Plantations 1970-1988
Note: For sources and a more detailed explanation of the estimation, see appendix 2

2.3 Cost of production

A pragmatic view of productivity is to look at real production costs, as plantations aim to minimise these. The source of the cost data is the Department of Statistics of Malaysia's annual survey, published in '*The Oil Palm, Coconut and Tea Statistics Handbook*'. The average annual response rate is around 75 %, with the lowest response rate being two-thirds for two separate years. These data are not part of the current official MPOB data. The reason appears to be a lack of communication between the Department of Statistics and the MPOB, rather than unreliable collection methods. These annual surveys are also the only source that has reported the costs on an industry-wide basis. However, I do have cost data for the same period for a single market-leading palm oil company, United Plantations. Comparing the production cost from the Department of Statistics with the production costs from the United Plantations will give an indication of the data's validity.

Cost data is published for 1980-88 and for individual cost categories for the years 1969-88.[89] Approximately 80 % of total production costs are accounted for by three cost categories: wages, fertilizers, and total immature area upkeep costs. It is therefore possible to estimate costs for the 1970s. For a detailed description of the costs estimated, see appendix 3. The production data are the same as those used for the labour productivity on plantations. Figure 9 presents the unit cost estimates:

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[89] The cost data is for plantations that have a planted area of 200 ha and above. These figures are representative as these plantations account for 93.3 % of all fresh fruit bunch production of all plantation production in the period 1981-87.

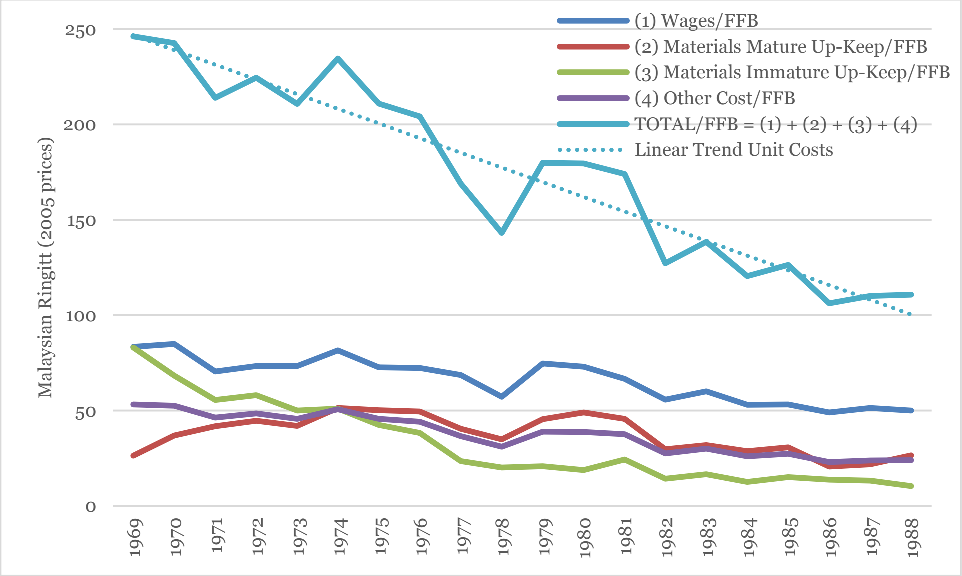

Figure 9: Palm Oil Plantations Peninsular Malaysia: Real Production Costs 1969-88 (2005 prices)/Fresh Fruit Bunch Production (tonnes)
Note: For sources and a more detailed explanation of the estimation, see appendix 3

According to figure 9, plantations' cost efficiency increased in real terms. The largest cost share was wages, in which wages for harvesters had the highest cost share. The materials for immature area up-keep were large at the start of the period, which is not surprising. As mentioned above, oil palm trees takes three years to mature, and during the first three years prior to harvesting the area is immature. Oil palm trees have a lifespan of about 20-30 years before replanting (Ismael and Mamat, 2002). Once planted, it takes a long time until the next replanting. Immature area as a share of total planted area decreased from 42.6 % in 1970 to 14.0 % in 1990.[90] In the 1960s and 1970s, oil palm expanded into many new areas and the costs naturally declined during the 1980s and 1990s as more area became mature.

As mentioned, United Plantations publishes annual reports, which present time-series cost data all the way back to 1966. Taking the cost of production for crude palm oil (CPO) and converting it into real figures shows a clear downward trend since the end of the 1970s (see figure 10). The level of cost per CPO is not comparable with the cost per FFB in figure 9, as the United Plantation figures include both plantation and milling costs. However, the trend is the same for both figures 9 and 10, in that unit costs are declining. This similarity increases the plausibility of the cost data based on the Department of Statistics data. For the cost data for individual years, see appendix 3.

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[90] Figures from FAO (2014) and MPOB (2011).

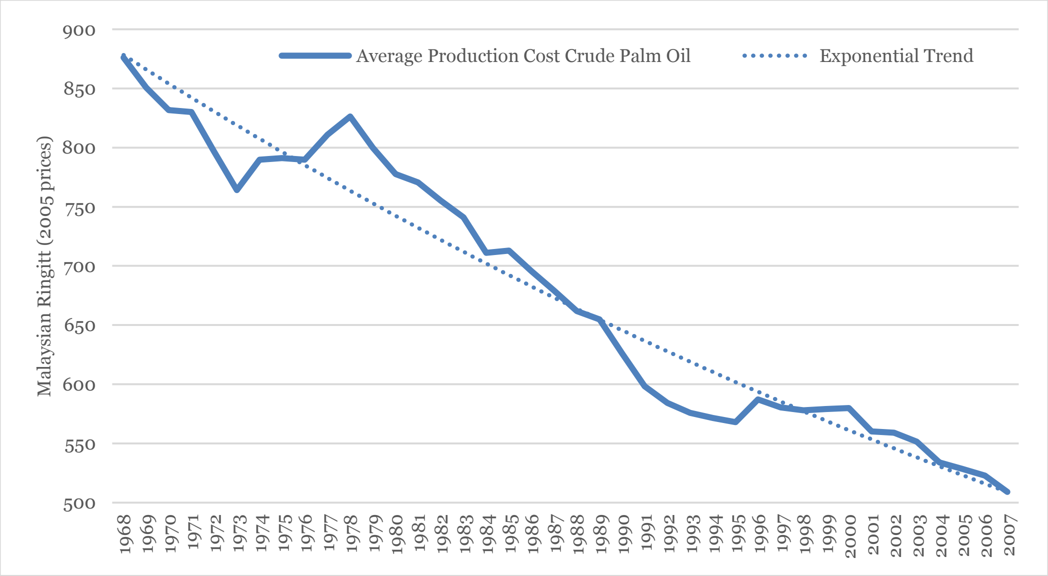

Figure 10: United Plantations: Real Average Production Costs 2005 prices Crude Palm Oil 1968-2007 (Five-Year Moving Average)
Note: For sources and a more detailed explanation of the estimation, see appendix 3

There are several reasons for the decline in unit costs. Evidence presented by Noor *et al.* (2004 pp. 36-37) strongly indicated that cost per FFB decreases with plantation size. The same study found similar results for mill size and cost efficiency. There was a large concentration of ownership in the palm oil industries, dominated by large private plantation companies and government schemes. Large plantation companies, such as United Plantations, owned plantations, mills and refineries.[91] The integrated production structure meant that a decrease in plantation and mill costs increased the competiveness of the refineries. For the government schemes, there were private incentives to decrease operation costs. Each settler has a plot of land, at the expense of a loan with a maturity of 20 years. Since settlers are organised smallholders, rather than a collective, settlers have an incentive to maximise profits in order to repay their loans. Private plantations that did not own their own refineries also had incentives to become more profitable.

3. The role of plantations in the establishment of the refineries

The results of the previous section show that productivity, measured in various ways, probably did increase at plantations and mills. However, was the increase in productivity important for the establishment of the palm oil refinery sector? Oil palm is the most profitable vegetable oil crop, as shown in table 4.[92] If the palm oil sector had the same oil yield in 2007 as in 1963, it would still be the highest among all vegetable oils. An increase in palm oil productivity, measured by the oil yield, would perhaps not have been necessary for the establishment of the palm oil refineries.

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[91] Simeh (2002) found that the OER, together with the productivity of palm kernel, were important for the mills' profits. Differential gains in these productivity measures were used to offset the mill's operating cost. Fold (1994) looked at the origins of the concentration of plantation ownership, which was caused by an increase in centralisation in the 1950s in a period when plantations were sold to agency houses as Malaysian independence seemed imminent. In 1974, the five largest companies controlled 45 % of the total oil palm planted area, and together with a dozen other plantation groups, they controlled about 70 % of the planted area.

[92] Among the four major agricultural crops in Malaysia measured by planted area, palm oil had the highest growth in yield meaning tonnes per hectare. From 1961 to 2008, palm oil yield increased by an annual compound growth rate of 1.3 % compared to padi rice the similar figure was 1.1 %, rubber 0.7 %, and coconuts declined -1.4 %, all data from FAO (2014). Had crop prices been included, the difference would be even larger.

Table 4: Value per ha (nominal values based on a three-year moving average)

	1962-64	1984-86	2006-08
Crude Palm Oil – Malaysia			
Oil Yield*	2.40	3.31	4.29
Price – USD**	237	466	662
Value per ha	569	1,545	2,844
Rapeseed Oil – European Union			
Oil Yield*	0.58	0.90	1.16
Price – USD**	245	467	924
Value per ha	141	421	1,069
Soyabean Oil – USA			
Oil Yield*	0.18	0.17	0.31
Price – USD**	243	499	826
Value per ha	45	85	259
Sunflower Oil – Argentina			
Oil Yield*	0.20	0.47	0.69
Price – USD**	268	535	942
Value per ha	54	251	651

Source: Calculations based on FAO (2014) and MPOB (2011)

*Oil Yield is calculated as the three-year moving average of production (tonnes) per harvested area (ha) using FAO data

** Prices are three-year moving averages of annual average prices in dollar per metric tonne registered on the North West Europe Market

Based on the evidence in the previous section, plantations probably did increase their FFB yield, cost efficiency and labour productivity. As mentioned, there is no evidence that capital otherwise increased to drive these results. The amount of land per worker did increase, and this points to better organisation and learning-by-doing as one of the most important reasons for increased productivity. The introduction of the DxP variety of oil palm trees also seems to have had an important say in increasing the overall productivity of plantations

The evidence for mills is far weaker and hampered by a lack of data. The OER was stagnant, with the decrease in ripeness of FFBs being the most probable cause. There are no cost efficiency figures for mills, but the United Plantations figures do indicate that mills increased cost efficiency. However, there is no sure way of telling whether this decrease was similar in magnitude to plantations. The labour productivity figures only existed for the mills at plantations, and did show that labour productivity increases were lower for mills than they were for plantations.

These increases in productivity probably allowed for a long-term decline of domestic real palm oil prices from 1975 to 1990 (see figure 11). These prices show the same trends as the international prices for crude palm oils.[93] The decline from 1975 to 1990 followed the introduction of export tax on crude palm oil in 1973; the domestic sale of crude palm oil to refineries increased. The refineries are organised through the Palm Oil Refinery Association of Malaysia (PORAM).[94] Being organised through PORAM meant that the refineries could coordinate decisions collectively, giving them a high degree of market power. For instance, PORAM imposes strong quality requirements on crude palm oil in order to increase the quality of processed palm oil. Another example is how PORAM attempts to lower market prices on inputs to be able to compete on the world market.

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[93] By using data from the Department of Statistics, and MPOB, one can compare the locally delivery prices of crude palm oil (converted to US dollars) with the international prices in US dollars on the Western European market. For the years 1960-2008 the correlation coefficient is 0.972. The Malaysian market share of total vegetable oils has been too small to have a direct impact on prices.

[94] Plantations are also organised through the Malaysian Palm Oil Association (MPOA) which had more than 100 members and covered about 70 % of the area under private ownership in 2002 (Teoh 2002 p.37).

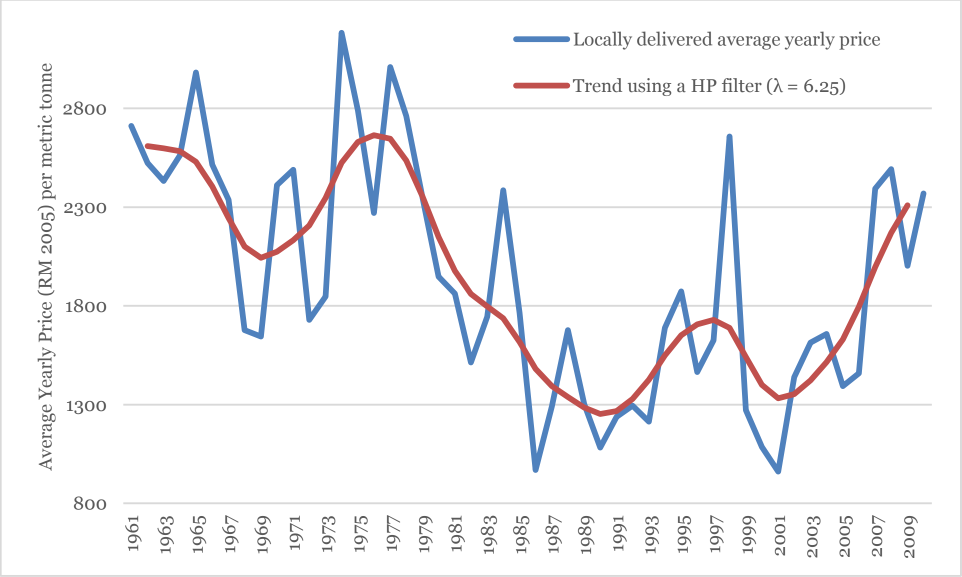

Figure 11: Locally Delivered Average Yearly Price 1961-2010 RM per metric tonne (2005 prices)
Source: DoS (2007) table 10.1 for 1960-1979 prices; MPOB (2011) for 1980-2011 prices Table 5.1; and WDI (2014)

The main relationship between plantations/mills and refineries is that crude palm oil is the major input of the refinery sector. According to Gopal (2001), the main competitive advantage of the Malaysian refinery sector is the cheap supply of crude palm oil. The increase in productivity was probably crucial for the establishment of the refinery sector, for three important reasons.

First, the increased cost efficiency meant that crude palm oil lowered the input costs for the refineries, both for those refineries that produced their own crude palm oil and those that purchased it on the market. Gopal (2001) showed that Malaysian refineries lowered their operating costs during the establishment period of the palm oil refineries, which increased their competitiveness.[95] Costs were binding for the palm oil refineries; the evidence coming from two restructuring processes.[96] In the early 1980s, a number of Malaysian palm oil refineries went bankrupt as there was a restructuring period following a period of overcapacity. At the end of the 1980s and early 1990s, there was a second and far more severe crisis. This crisis coincided with an increase in crude palm oil prices, as figure 11 shows, which increased input costs, indicating that these costs were binding for the refinery sector.[97]

The second reason is that inputs were becoming increasingly scarce. This goes especially for labour. The increase in labour productivity allowed an increase in production in excess of what otherwise would have been possible. Time-series on employment by the Department of Statistics (2007) indicate that labour productivity has not increased since 1986. The reason is that Malaysian labour increasingly refused to work on plantations and went to better-paid jobs in the manufacturing sectors. Increasingly, the palm oil sector became dependent on foreign labour, especially from Indonesia. However, even if labour productivity probably did not increase by much since 1986, it also did not decrease.[98]

The third reason is that the increase in productivity allowed an expansion of the output of mills. The technological development at the mills was important for the competitiveness of the palm oil sector as the

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[95] The profit margins only considered the value-added at the refinery level of production and did not include the cost of crude palm oil.

[96] Fold (1998 pp.401-402).

[97] Government support alone did therefore not guarantee the survival of the palm oil refinery sector. Food processing industries in most countries receive government support and this support is therefore an important competitive advantage. Government support is a necessary but insufficient condition for food processing companies.

[98] Based on FAO figures of fresh fruit bunch production and time-series data on employment from the Department of Statistics, the FFB per employment ratio increased from 51.8 in 1969 to a high of 241.9 in 1989, and has since been relatively stable. In 2006, the figure was 228.3 tonne FFB per employed worker.

quality of crude palm oil increased.[99] This increased quality reduced operating costs for refineries and meant that processed palm oil had a higher degree of quality. Increased controls were vital for this process to occur.[100] Even the smallest of the Malaysian refineries have established their own laboratory facilities to ensure the quality of final products.[101]

Conclusion

This paper found that the official oil yield figures have probably understated the true extent of the productivity growth at palm oil plantations. As the official oil yield figures were inconsistent, new estimates indicate that there has been a considerable increase in oil yields over time. The main source of this increase has been the increase in fresh fruit bunches per hectare, and not the oil extraction rate. Estimates of cost efficiency and labour productivity show a clear increase in productivity levels.

The research question of the paper is 'How did the development in plantation productivity affect the establishment of the palm oil refinery sector?' The increase in productivity was probably crucial for the establishment of the palm oil refinery sector. Despite government protection, the palm oil refinery sector was cost sensitive because of high international competition. The decrease in production costs for those refineries that owned plantations and mills, and a decrease in price for those refineries that had to purchase their crude palm oil were vital for the competitiveness of the palm oil refinery sector. The progress in labour productivity was not only crucial for the increase in the crude palm oil industry in the establishment period 1970-90, but also laid the foundation for the subsequent period. Therefore, it seems likely that the increased productivity was an important part in establishing a higher value-added production structure.

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[99] PORAM (1990) and Fold (1994 p.77).
[100] Fold (1994 p.77).
[101] Maycock (1989).

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Appendix 1: Estimating new yield figures

Stage 1.1: Estimating the Mature Area

Palm oil fruits, fresh fruit bunches, are used to produce a number of different products; the two major ones are crude palm oil and palm kernel, as illustrated in the figure below:

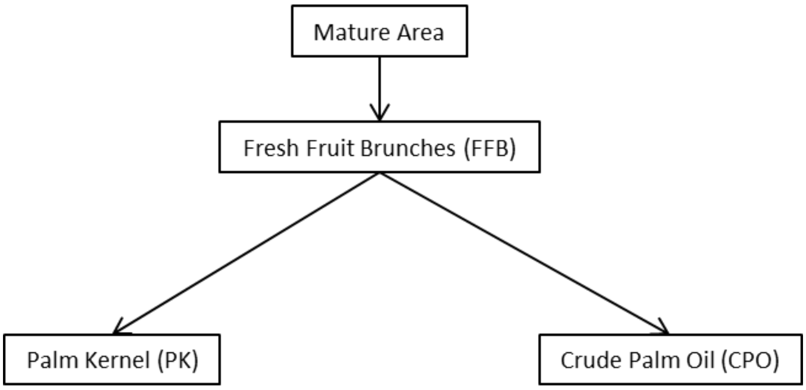

Figure Appendix 1.1: Illustration of the relationship between palm kernel and crude palm oil

To assess the productivity, the Malaysian Palm Oil Board (MPOB) uses two land productivity measures:

$$CPO\ Yield = \frac{Yearly\ CPO\ Production}{Average\ Mature\ Area\ in\ Production\ During\ the\ Year} \tag{A1.1}$$

$$PK\ Yield = \frac{Yearly\ PK\ Production}{Average\ Mature\ Area\ in\ Production\ During\ the\ Year} \tag{A1.2}$$

The MPOB publishes time-series, starting in 1975. Figures available include the CPO yield and the PK yield, along with yearly production of CPO and PK. The only figure not published, which features in the formula above, is the average amount of mature area used in production that specific year. However, this information can be easily obtained by re-arranging the above two expressions:

$$Average\ Mature\ Area_t = \frac{CPO\ Production_t}{CPO\ Yield_t} \tag{A1.3}$$

$$Average\ Mature\ Area_t = \frac{PK\ Production_t}{PK\ Yield_t} \tag{A1.4}$$

Since the average mature area to produce crude palm oil and palm kernel is the same, equations A1.3 and A1.4 should yield the same result. I attempted to estimate the average mature area in production using these two equations in table appendix 1.1:

Table appendix 1.1: Estimated mature area using equations A1.3 and A1.4

Year	CPO Yield	CPO Production	PK Yield	PK Production	Mature Area Equation A1.3	Mature Area Equation A1.4	$\left(\frac{\text{Equation A1.3}}{\text{Equation A1.4}} - 1\right)\%$
1975	3.66	1,257,573	0.74	232,821	343,599	314,623	9.21 %
1976	3.48	1,391,965	0.71	256,015	399,990	360,585	10.93 %
1977	3.54	1,612,747	0.74	334,791	455,578	452,420	0.70 %
1978	2.95	1,785,525	0.68	367,540	605,263	540,500	11.98 %
1979	3.65	2,188,699	0.79	475,039	599,644	601,315	-0.28 %
1980	3.78	2,573,173	0.81	557,066	680,734	687,736	-1.02 %
1981	3.76	2,822,144	0.79	588,783	750,570	745,295	0.71 %
1982	3.83	3,510,920	0.80	909,918	916,689	1,137,398	-19.40 %
1983	3.43	3,016,481	0.72	834,570	879,441	1,159,125	-24.13 %
1984	4.25	3,714,795	1.19	1,045,579	874,069	878,638	-0.52 %
1985	4.33	4,134,463	1.28	1,211,887	954,841	946,787	0.85 %
1986	4.41	4,542,249	1.28	1,336,263	1,029,988	1,043,955	-1.34 %
1987	3.39	4,531,960	0.98	1,311,218	1,336,861	1,337,978	-0.08 %
1988	3.47	5,027,496	1.01	1,473,288	1,448,846	1,458,701	-0.68 %
1989	3.88	6,056,501	1.15	1,793,690	1,560,954	1,559,730	0.08 %
1990	3.64	6,094,622	1.10	1,844,737	1,674,347	1,677,034	-0.16 %
1991	3.48	6,141,353	1.01	1,785,218	1,764,757	1,767,543	-0.16 %
1992	3.43	6,373,461	0.99	1,874,367	1,858,152	1,893,300	-1.86 %
1993	3.78	7,403,498	1.16	2,266,104	1,958,597	1,953,538	0.26 %
1994	3.43	7,220,631	1.05	2,203,929	2,105,140	2,098,980	0.29 %
1995	3.50	7,810,546	1.08	2,395,588	2,231,585	2,218,137	0.61 %
1996	3.55	8,385,886	1.06	2,488,750	2,362,221	2,347,877	0.61 %
1997	3.63	9,068,728	1.06	2,638,068	2,498,272	2,488,743	0.38 %
1998	3.02	8,319,682	0.88	2,429,468	2,754,862	2,760,759	-0.21 %
1999	3.58	10,553,918	1.03	3,025,690	2,948,022	2,937,563	0.36 %
2000	3.46	10,842,095	1.01	3,162,760	3,133,553	3,131,446	0.07 %
2001	3.66	11,803,788	1.05	3,367,710	3,225,079	3,207,343	0.55 %
2002	3.59	11,909,298	0.98	3,268,635	3,317,353	3,335,342	-0.54 %
2003	3.75	13,354,769	1.02	3,627,235	3,561,272	3,556,113	0.15 %
2004	3.73	13,976,182	0.98	3,661,456	3,746,966	3,736,180	0.29 %
2005	3.80	14,961,654	1.01	3,964,031	3,937,277	3,924,783	0.32 %
2006	3.93	15,880,786	1.02	4,125,124	4,040,912	4,044,239	-0.08 %
2007	3.83	15,823,745	0.99	4,096,989	4,131,526	4,138,373	-0.17 %
2008	4.08	17,734,441	1.05	4,577,500	4,346,677	4,359,524	-0.29 %
2009	3.93	17,564,937	1.01	4,500,683	4,469,450	4,456,122	0.30 %
2010	3.69	16,993,717	0.93	4,292,076	4,605,343	4,615,135	-0.21 %
2011	4.01	18,911,520	1.00	4,706,603	4,716,090	4,706,603	0.20 %

Source: Yield and production figures gathered from MPOB (2012) tables 1.17 and 3.2

The differences in average mature area, using the two formulas, were large, especially for the period up until 1983 as illustrated in figure appendix 1.2:

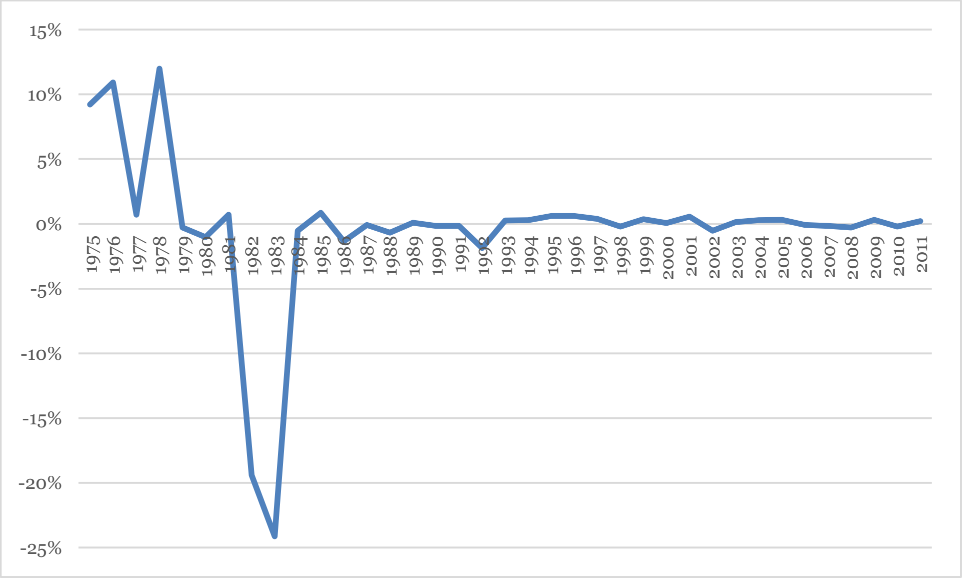

Figure appendix 1.2: Percentage difference in estimated mature area using equations A1.3 and A1.4

As an alternative, one could estimate average mature area by dividing the mature area at the end of year t and the mature area at the end of year t-1:

$$Average\ Mature\ Area_t = \frac{Mature\ Area\ End\ of\ Year_t - Mature\ Area\ End\ of\ Year_{t-1}}{2} \quad \text{(A1.5)}$$

The MPOB published time-series data on the mature area at the end of the year. I have used this somewhat crude measure to compare it with the other two estimates of productivity in figure appendix 1.3:

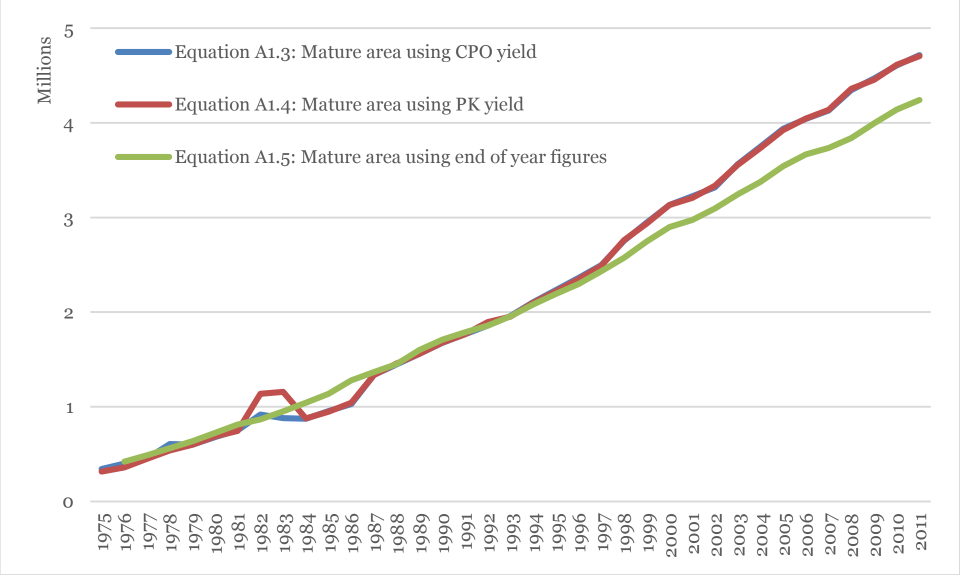

Figure appendix 1.3: Estimated yearly mature area

Source: For equations A1.3 and A1.4 see table appendix 1.1; for equation A1.5 data was gathered from MPOB (2012) table 1.2

According to figure appendix 1.3, the mature area estimates using equations A1.3 and A1.4 are internally inconsistent up until 1983, but have followed each relatively closely since then. However, from 1994 and onwards, equation A1.5 gives a lower estimate of mature area than equation A1.3 and A1.4. This is puzzling, since all the data used come from the same source, namely the MPOB. If true, the figures from 1994 and onward would imply that area considered mature during the production year, is immature at the end of the year. This is plausible for a limited number of years, since an area might need to be re-planted towards the end of the year. However, as oil palm trees take approximately 3 years to mature, the figures could only explain the deviation for 2-3 years at most, while the figures above show that this process then must have occurred 17 years in a row. This is highly unlikely, and is therefore dismissed, which means that equation A1.3 and A1.4 yield implausible estimates for mature area in production. In addition, the increase in mature area using A1.5 shows a smoother trend than equations A1.3 and A1.4. This implies that the trend using A1.5 is more plausible.

The official yield figures, from which A1.3 and A1.4 are derived, is therefore inconsistent. More evidence comes from figure appendix 1.4, which seems to indicate unrealistically large fluctuations in the average mature area using the official figures. In addition, if the official figures are true, then the share of land in production has been close to 100 % during the year since 2000, but between 80-85 % at the end of the same years. In conclusion, despite the average mature area derived by using equation A1.5 is a simple and somewhat crude measure, it provides a more consistent and plausible estimate of average mature areas than do the first two equations derived from the official yield figures. To re-estimate the oil yield, I therefore use the average mature area.

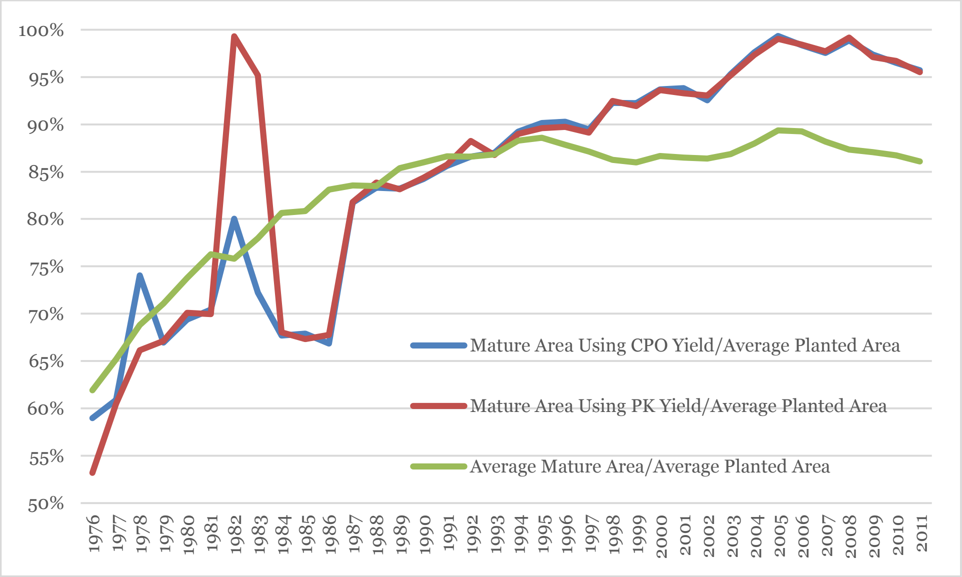

Figure Appendix 1.4: Mature Area as a % Share of Planted Area
Source: Mature area using CPO and PK Yield from table appendix 1.1, end of year figures for mature and planted area are gathered from MPOB (2011) table 1.2

Stage 1.2: Estimating the Oil Yields

To construct the oil yields, production data on crude palm oil (CPO) and mature area 1975- 2011 are from the MPOB (2011). Production data on fresh fruit bunches (FFB) presented a problem as the Department of Statistics, which collected palm oil data up until 1988, reported widely different figures than PORLA/MPOB did following 1989 indicating a measurement change. To avoid internal inconsistency, all FFB production figures from 1961-2011 are from the online FAO (2014) database. Figures for the period 1950-60 are uncertain. The doctoral thesis of Gopal (2001) reported production and oil yield figures for 1950 and 1960, and using these figures, I estimated mature land in these two years. Production and mature area data for 1951 to 1959 is extrapolated separately and must therefore be interpreted with caution. Appendix 1.2 presents the data.

Using the CPO production and the mature area figures from table appendix 1.2, I estimate two separate oil yields:

$$CPO\ Yield_t = \frac{CPO\ Production_t}{Mature\ Area\ End\ of\ Year_t} \qquad (A1.6)$$

$$CPO\ Yield_t = \frac{CPO\ Production_t}{\left(\frac{Mature\ Area\ End\ of\ Year_t + Mature\ Area\ End\ of\ Year_{t-1}}{2}\right)} \qquad (A1.7)$$

The results, from these two equations are compared with the official oil yield in table appendix 1.3

The two components of the oil yield, the FFB yield and the Oil Extraction Rate (OER) are given by:

$$Oil\ Yield = FFB\ Yield \times Oil\ Extraction\ Rate\ (OER) \qquad (A1.8)$$

$$\frac{CPO\ Production}{Mature\ Area} = \frac{FFB\ Production}{Mature\ Area} \times \frac{CPO\ Production}{FFB\ Production} \qquad (A1.9)$$

Using the FFB production, CPO production, and the different measures of mature area, I have estimated the separate components in table appendix 1.4.

Table Appendix 1.2: Production and land data palm oil

Year	FFB Production	CPO Production	Mature Area End of Year	Average Mature Area Equation A1-5
1950		54,100	37,832	
1951		57,870	38,058	37,945
1952		61,640	38,283	38,170
1953		65,410	38,509	38,396
1954		69,180	38,734	38,621
1955		72,950	38,960	38,847
1956		76,720	39,185	39,073
1957		80,490	39,411	39,298
1958		84,260	39,636	39,524
1959		88,030	39,862	39,749
1960		91,800	40,087	39,975
1961	500,000	94,846	43,302	41,695
1962	570,000	108,171	46,175	44,739
1963	662,000	125,691	49,073	47,624
1964	647,000	122,913	52,900	50,987
1965	792,000	150,411	59,000	55,950
1966	949,000	189,687	67,400	63,200
1967	1,129,000	225,758	78,500	72,950
1968	1,415,000	282,984	99,100	88,800
1969	1,761,000	352,096	125,400	112,250
1970	2,155,000	431,069	149,900	137,650
1971	2,902,000	580,389	184,000	166,950
1972	3,422,000	718,580	235,100	209,550
1973	3,870,000	812,614	278,300	256,700
1974	4,981,000	1,045,975	329,800	304,050
1975	6,200,000	1,257,573	385,666	363,809
1976	6,500,000	1,391,965	454,009	419,838
1977	7,500,000	1,612,747	521,486	487,748
1978	9,900,000	1,785,525	603,087	562,287
1979	10,700,000	2,188,699	670,299	636,693
1980	12,800,000	2,573,173	777,388	723,844
1981	14,400,000	2,822,144	848,143	812,766
1982	17,900,000	3,510,920	888,619	868,381
1983	15,400,000	3,016,481	1,010,879	949,749
1984	19,500,000	3,714,795	1,072,451	1,041,665
1985	21,400,000	4,134,463	1,201,010	1,136,731
1986	23,100,000	4,542,249	1,360,579	1,280,795
1987	22,800,000	4,531,960	1,373,147	1,366,863
1988	25,300,000	5,027,496	1,530,906	1,452,027
1989	30,600,000	6,056,501	1,672,096	1,601,501
1990	31,000,000	6,094,622	1,746,054	1,709,075
1991	31,500,000	6,141,353	1,826,267	1,786,161
1992	33,200,000	6,373,461	1,890,268	1,858,268
1993	39,700,000	7,403,498	2,020,516	1,955,392
1994	38,800,000	7,220,631	2,144,080	2,082,298
1995	42,200,000	7,810,546	2,243,065	2,193,573
1996	44,030,000	8,385,886	2,353,147	2,298,106
1997	47,670,000	9,068,728	2,513,183	2,433,165
1998	43,840,000	8,319,682	2,638,020	2,575,602
1999	55,000,000	10,553,918	2,856,701	2,747,361
2000	56,600,000	10,842,095	2,941,791	2,899,246
2001	58,950,000	11,803,788	3,005,267	2,973,529
2002	59,546,000	11,909,298	3,188,307	3,096,787
2003	66,775,000	13,354,769	3,303,133	3,245,720
2004	69,881,000	13,976,182	3,450,960	3,377,047
2005	74,800,000	14,961,654	3,631,440	3,541,200
2006	79,400,000	15,880,786	3,703,254	3,667,347
2007	79,100,000	15,823,745	3,764,389	3,733,822
2008	88,672,000	17,734,441	3,915,924	3,840,157
2009	87,825,000	17,564,937	4,075,702	3,995,813
2010	84,965,000	16,993,717	4,202,213	4,138,958
2011	94,557,600	18,911,520	4,281,837	4,242,025

Source: MPOB (2011) table 1.2 (mature area) and 3.2 (CPO production) for 1975-2011; FAO (2014) for FFB production 1961-2011; CPO production and mature area 1961-1974; 1950 and 1960 figures from Gopal (2001) table 3.8 page 125; 1951-1959 extrapolated

Table Appendix 1.3: Oil yields, official and estimated

Year	Official MPOB Oil Yield	Equation A1.6	Equation A1.7
1950		1.43	
1951		1.52	1.53
1952		1.61	1.61
1953		1.70	1.70
1954		1.79	1.79
1955		1.87	1.88
1956		1.96	1.96
1957		2.04	2.05
1958		2.13	2.13
1959		2.21	2.21
1960		2.29	2.30
1961		2.19	2.27
1962		2.34	2.42
1963		2.56	2.64
1964		2.32	2.41
1965		2.57	2.70
1966		2.88	3.05
1967		3.01	3.20
1968		3.06	3.38
1969		3.01	3.36
1970		3.05	3.34
1971		3.29	3.66
1972		3.33	3.67
1973		3.13	3.42
1974		3.06	3.48
1975	3.66	3.26	3.46
1976	3.48	3.07	3.32
1977	3.54	3.09	3.31
1978	2.95	2.96	3.18
1979	3.65	3.27	3.44
1980	3.78	3.31	3.55
1981	3.76	3.33	3.47
1982	3.83	3.95	4.04
1983	3.43	2.98	3.18
1984	4.25	3.46	3.57
1985	4.33	3.44	3.64
1986	4.41	3.34	3.55
1987	3.39	3.30	3.32
1988	3.47	3.28	3.46
1989	3.88	3.62	3.78
1990	3.64	3.49	3.57
1991	3.48	3.36	3.44
1992	3.43	3.37	3.43
1993	3.78	3.66	3.79
1994	3.43	3.37	3.47
1995	3.50	3.48	3.56
1996	3.55	3.56	3.65
1997	3.63	3.61	3.73
1998	3.02	3.20	3.26
1999	3.58	3.69	3.87
2000	3.46	3.69	3.74
2001	3.66	3.93	3.97
2002	3.59	3.74	3.85
2003	3.75	4.04	4.11
2004	3.73	4.05	4.14
2005	3.80	4.12	4.23
2006	3.93	4.29	4.33
2007	3.83	4.20	4.24
2008	4.08	4.53	4.62
2009	3.93	4.31	4.40
2010	3,69	4,04	4,11
2011	4,01	4.42	4.46

Source: Official MPOB yield gathered from MPOB (2011) table 1.17. The other figures used are data from table appendix 1.2

Table Appendix 1.4: Oil Yield and its separate components

Year	Method 1: End Year Mature Area			Method 2: Average Mature Area		
	FFB Yield	OER	Oil Yield	FFB Yield	OER	Oil Yield
1961	11.55	0.19	2.19	11.99	0.19	2.27
1962	12.34	0.19	2.34	12.74	0.19	2.42
1963	13.49	0.19	2.56	13.90	0.19	2.64
1964	12.23	0.19	2.32	12.69	0.19	2.41
1965	13.53	0.19	2.57	14.21	0.19	2.70
1966	14.41	0.20	2.88	15.26	0.20	3.05
1967	15.03	0.20	3.01	16.02	0.20	3.20
1968	15.29	0.20	3.06	16.88	0.20	3.38
1969	15.04	0.20	3.01	16.80	0.20	3.36
1970	15.27	0.20	3.05	16.69	0.20	3.34
1971	16.46	0.20	3.29	18.29	0.20	3.66
1972	15.86	0.21	3.33	17.46	0.21	3.67
1973	14.89	0.21	3.13	16.27	0.21	3.42
1974	14.57	0.21	3.06	16.55	0.21	3.48
1975	16.08	0.20	3.26	17.04	0.20	3.46
1976	14.32	0.21	3.07	15.48	0.21	3.32
1977	14.38	0.22	3.09	15.38	0.22	3.31
1978	16.42	0.18	2.96	17.61	0.18	3.18
1979	15.96	0.20	3.27	16.81	0.20	3.44
1980	16.47	0.20	3.31	17.68	0.20	3.55
1981	16.98	0.20	3.33	17.72	0.20	3.47
1982	20.14	0.20	3.95	20.61	0.20	4.04
1983	15.23	0.20	2.98	16.21	0.20	3.18
1984	18.18	0.19	3.46	18.72	0.19	3.57
1985	17.82	0.19	3.44	18.83	0.19	3.64
1986	16.98	0.20	3.34	18.04	0.20	3.55
1987	16.60	0.20	3.30	16.68	0.20	3.32
1988	16.53	0.20	3.28	17.42	0.20	3.46
1989	18.30	0.20	3.62	19.11	0.20	3.78
1990	17.75	0.20	3.49	18.14	0.20	3.57
1991	17.25	0.19	3.36	17.64	0.19	3.44
1992	17.56	0.19	3.37	17.87	0.19	3.43
1993	19.65	0.19	3.66	20.30	0.19	3.79
1994	18.10	0.19	3.37	18.63	0.19	3.47
1995	18.81	0.19	3.48	19.24	0.19	3.56
1996	18.71	0.19	3.56	19.16	0.19	3.65
1997	18.97	0.19	3.61	19.59	0.19	3.73
1998	16.88	0.19	3.20	17.16	0.19	3.26
1999	19.25	0.19	3.69	20.17	0.19	3.87
2000	19.24	0.19	3.69	19.52	0.19	3.74
2001	19.62	0.20	3.93	19.82	0.20	3.97
2002	18.68	0.20	3.74	19.23	0.20	3.85
2003	20.22	0.20	4.04	20.57	0.20	4.11
2004	20.25	0.20	4.05	20.69	0.20	4.14
2005	20.60	0.20	4.12	21.12	0.20	4.23
2006	21.44	0.20	4.29	21.65	0.20	4.33
2007	21.01	0.20	4.20	21.18	0.20	4.24
2008	22.64	0.20	4.53	23.09	0.20	4.62
2009	21.55	0.20	4.31	21.98	0.20	4.40
2010	20.22	0.20	4.04	20.53	0.20	4.11
2011	22.08	0.20	4.42	22.29	0.20	4.46

Source: Calculated using data presented in table appendix 1.2.

Appendix 2: Labour productivity

Data on employment is available for 1969-1988 in the Department of Statistics '*The Oil Palm, Coconut and Tea Statistics Handbook*'. For the years 1969-1978, information is available on three categories: (1) Directly employed; (2) Contract workers; and (3) Other workers. The first category consists of (a) Administrative staff; (b) Estate workers; and (c) Mill workers. For the years 1979-1988, the third category, (3) Other workers, is incorporated in the figures for various plantation staff. In addition, contract workers for 1979-1988 are subdivided into (a) Estate workers and (b) Mill workers.

To make the figures consistent, I made some modifications. The reason for these modifications is that a small share of the workers is classified differently in the two periods. To be able to compare the data, I had to make three adjustments. First, I added the category (3) Other workers to the (1b) Directly employed estate workers for 1969-1978. Second, I included a residual category called 'unpaid family workers, working proprietors and partners' in the (1b) category for 1979-1988. Finally, as the estate and mill shares for contract workers were unavailable for 1969-78, I estimated these. To estimate the respective shares of estate and mill workers, I used the 1979-1988 data. Estimating the share of the estate workers as a share of total workers from 1979 to 1988 yields the following trend:

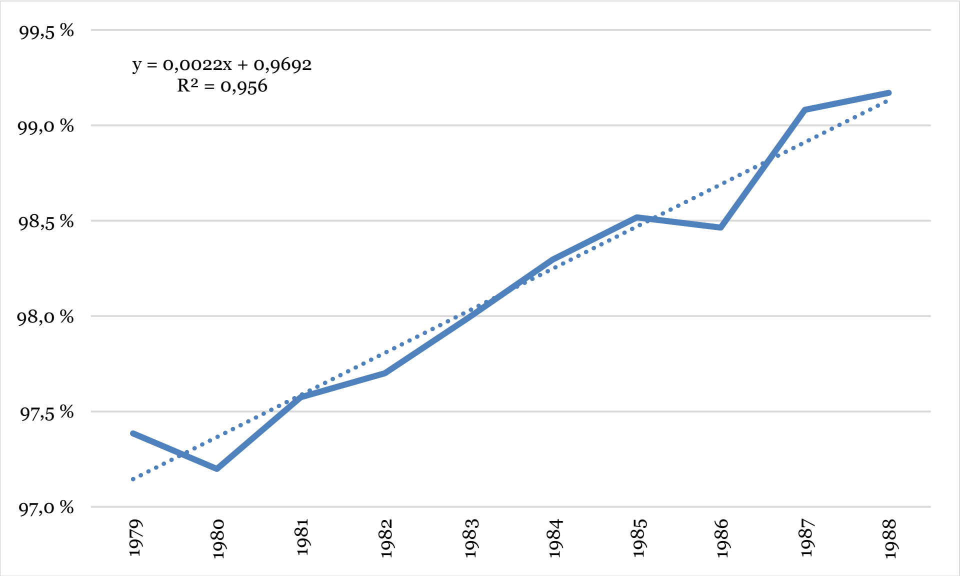

Figure Appendix 2.1: Number of Estate Workers as Share of Contract Workers 1979-1988

To estimate the share from 1969-78 I assume the same linear trend. The linear trend gave the highest R^2 and is found appropriate as the period estimated is short. It is important to emphasise that the results in this paper do not hinge on these assumptions, since the results are the same if only directly employed figures were employed, whether all contract workers were assumed to be working on plantations or using these estimated figures.

Table appendix 2.1 Employment Palm Oil Estates by Number at the End of the Year

Year	1. Directly employed				2. Contract workers			TOTAL
	(a) Administrative Staff	(b) Estate Workers*	(c) Mill Workers	Total Directly Employed	(a) Estate Workers	(b) Mill Workers	Total Contract Workers	Total Employed
1969	1,554	19,500	1,778	22,832	**10,572**	**574**	11,146	33,978
1970	1,382	21,302	1,877	24,561	**11,264**	**584**	11,848	36,409
1971	1,471	24,517	2,138	28,126	**12,956**	**640**	13,596	41,722
1972	1,545	25,707	2,057	29,309	**17,600**	**827**	18,427	47,736
1973	1,660	28,958	2,013	32,631	**18,335**	**818**	19,153	51,784
1974	1,993	35,329	2,182	39,504	**22,956**	**969**	23,925	63,429
1975	4,300	33,615	2,412	40,327	**24,510**	**976**	25,486	65,813
1976	4,781	35,174	2,608	42,563	**22,427**	**840**	23,267	65,830
1977	5,040	37,537	2,288	44,865	**22,897**	**803**	23,700	68,565
1978	5,819	39,975	2,382	48,176	**24,808**	**812**	25,620	73,796
1979	6,672	41,965	2,606	51,243	27,158	729	27,887	79,130
1980	7,832	44,527	2,760	55,119	27,000	778	27,778	82,897
1981	8,983	45,719	2,836	57,538	27,721	689	28,410	85,948
1982	9,282	43,776	2,847	55,905	27,784	654	28,438	84,343
1983	9,317	43,434	2,683	55,434	24,213	496	24,709	80,143
1984	10,442	43,290	2,725	56,457	29,369	509	29,878	86,335
1985	10,718	43,775	2,764	57,257	32,830	494	33,324	90,581
1986	10,985	42,874	2,755	56,614	30,511	476	30,987	87,601
1987	11,544	42,535	2,760	56,839	34,209	317	34,526	91,365
1988	12,257	43,133	2,680	58,070	37,982	318	38,300	96,370

Source: For the years 1969-1978: Department of Statistics (1973) Table 43; Department of Statistics (1978) Table 45
For the years 1979-1988: Department of Statistics (1983) Table 42; Department of Statistics (1988) Table 10.1
Figures in bold are estimated using the estimated share of estate and contract workers
* For the years 1969-1978: Includes the category 'other workers'; For the years 1979-1988: Includes the category 'unpaid family workers, working proprietors and partners'

The data on employment back to 1969 was only available for the plantations of Peninsular Malaysia. Employment data for Sabah and Sarawak first became available from 1980 and onwards. Therefore, the production and land figures had to be re-adjusted. I therefore deducted the Sabah and Sarawak production quantity of fresh fruit bunches for 1969-1988; and for the mature area 1969-1974, using Department of Statistics data. As the total production and mature area figures included both plantations and government schemes, I had to adjust for that as well. The problem was that FFB production data for government schemes was missing for 1969-1972, while they were available for 1973-1988. Using the 1973-1988 figures, I estimated a linear trend for both production and land as illustrated in figure appendix 2.2. Again, the linear trend gave the highest R^2 and was chosen, as the time-period estimated for was short.

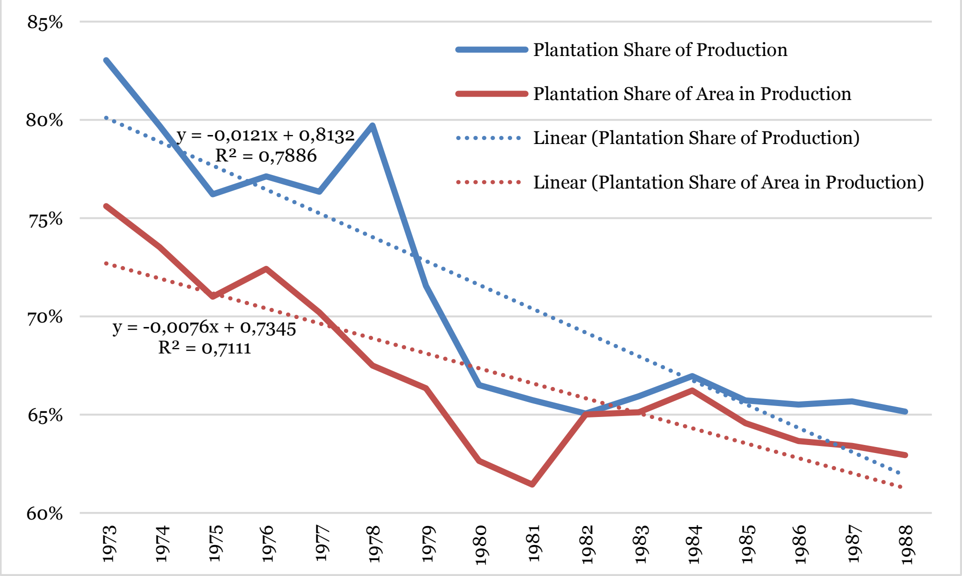

Figure appendix 2.2: Plantation share of production and area in production in peninsular Malaysia
Source: DoS (1973-1981) Table 32; DoS (1982-1983) Table 30; DoS (1984-1988) Table 6.2

The data on employment for mills is only available for those mills that are located on plantations. Data is available for crude palm oil production coming from these mills, and to get a more accurate estimate of the labour productivity of mills, I only use this production figure. I also included data on the share of CPO production coming from mills located on plantations as a share of total CPO production in Peninsular Malaysia. The data used on production and land are presented in table appendix 2.2.

The employment figures are end of year figures; therefore, I take the averages of the two end of year figures to construct labour input. The labour productivity measures for plantations and for mills are estimated by equations A2.1 and A2.2:

$$Labour\ Productivity\ Plantation_t = \frac{Fresh\ Fruit\ Bunch\ Production_t}{\left(\frac{Employment\ End\ of\ Year_t + Employment\ End\ of\ Year_{t-1}}{2}\right)} \quad \text{(A2.1)}$$

$$Labour\ Productivity\ Mill_t = \frac{Crude\ Palm\ Oil\ Production\ Plantation\ Mills_t}{\left(\frac{Employment\ End\ of\ Year_t + Employment\ End\ of\ Year_{t-1}}{2}\right)} \quad \text{(A2.2)}$$

For the calculation of labour productivity at the plantation level, I use workers from categories (1a), (1b) and (1c). For the calculation for labour productivity at the mill level, I use workers from categories (1c) and (2b). I also measure the amount of land per employee by estimating equation A2.3:

$$Land\ per\ Employee_t = \frac{\left(\frac{Mature\ Area\ End\ of\ Year_t + Mature\ Area\ End\ of\ Year_{t-1}}{2}\right)}{\left(\frac{Employment\ End\ of\ Year_t + Employment\ End\ of\ Year_{t-1}}{2}\right)} \quad \text{(A2.3)}$$

Table appendix 2.3 shows the estimated labour productivity and land per employee.

Table appendix 2.2 FFB, CPO production and mature area, all figures for plantations located in Peninsular Malaysia

Year	FFB Production (metric tonnes)	Mature Area (Hectare)	CPO Production Mills (metric tonnes)	CPO Production Share Mills on Plantations
1969	1,713,911	104,841	192,585	59 %
1970	1,689,418	114,681	232,318	58 %
1971	2,234,850	137,746	301,385	55 %
1972	2,565,746	176,206	318,237	48 %
1973	2,898,678	190,697	327,667	44 %
1974	3,563,765	220,882	391,531	42 %
1975	4,280,113	248,556	459,814	40 %
1976	4,507,975	299,733	476,094	38 %
1977	5,220,453	334,392	509,685	34 %
1978	7,346,168	373,747	505,011	31 %
1979	7,069,063	408,867	614,137	30 %
1980	7,870,750	449,514	640,369	27 %
1981	8,830,108	483,936	648,348	25 %
1982	10,810,010	525,095	737,172	23 %
1983	9,415,567	601,292	582,059	21 %
1984	12,066,568	645,607	659,938	19 %
1985	13,051,008	703,246	711,288	19 %
1986	13,849,386	784,680	759,063	18 %
1987	13,633,600	774,665	696,453	17 %
1988	15,472,856	896,205	774,990	17 %

Source: The production and mature area figures for FFB are from the same source as in Appendix 1.2 with two deductions.

The mature area for peninsular data for 1975-1988 are from MPOB (2011) table 1.2. The first the deduction by the FFB production (1969-1988) and mature area (1969-74) from Sabah and Sarawak using data Department of Statistics (1974; 1975; 1976; 1977; 1978; 1979; 1980; 1981) Table 51; Department of Statistics (1982; 1983) Table 49; Department of Statistics (1984; 1985; 1986) Table 12.6; Department of Statistics (1987; 1988) Table 12.4; and Department of Statistics (1974) Table 46.

The second deduction is by excluding the share of production and mature area of non-plantations. For data on the plantation share of production and mature area in Peninsular Malaysia I used the Department of Statistics (1973; 1974; 1975; 1976; 1977; 1978; 1979; 1980; 1981) Table 32; Department of Statistics (1982; 1983) Table 30; Department of Statistics (1984; 1985; 1986; 1987; 1988) Table 6.2.

CPO production by mills on estates, and their share, was gathered from Department of Statistics (1969) Table 24; Department of Statistics (1970; 1971; 1972) Table 26; Department of Statistics (1973; 1974; 1975; 1976; 1977; 1978; 1979; 1980; 1981) Table 34; Department of Statistics (1982; 1983) Table 32; Department of Statistics (1984; 1985; 1986; 1987; 1988) Table 6.4.

Table appendix 2.3: Labour Productivity for Plantations and Mills; and Land per Labour Ratio

	FFB Production per Person Employed	CPO Production per Person Employed	Mature Area per Person Employed
1970	52	97	3,3
1971	61	115	3,5
1972	61	112	3,7
1973	62	115	3,9
1974	65	131	3,8
1975	70	141	3,8
1976	72	139	4,3
1977	82	156	5,2
1978	108	161	5,8
1979	97	188	5,9
1980	101	186	6,1
1981	109	184	6,0
1982	132	210	6,6
1983	119	174	7,7
1984	151	206	8,4
1985	153	219	8,8
1986	161	234	9,0
1987	158	221	8,9
1988	170	255	8,8

Source: Calculated with data from tables appendix 2.1 and 2.2

Appendix 3: Cost data

The cost data for 1981-1987 was only available for plantations over 200 hectares. I made the simplifying assumption that these plantations were representative for other plantations. Since these plantations account for 93.3 % of all fresh fruit bunch production from plantations, the assumption does not have large implications. The costs, converted to 2005 Ringgit, are shown in table Appendix 3.1:

Table Appendix 3.1: Share Real Production Costs Measured in Ringgit (2005 = 100)

	1981	1982	1983	1984	1985	1986	1987	SUM	Share
Supervision costs	30,171	35,433	38,005	45,342	47,882	44555	49,592	290,980	3 %
Miscellaneous	51,084	62,004	61,707	66,429	79,054	80653	69,041	469,972	5 %
Transportation costs	87,295	98,519	82,391	104,275	126,583	121697	120,775	741,534	7 %
Repairs and maintenance	69,086	70,963	66,189	74,058	81,531	68599	72,636	503,061	5 %
Mature area up-keep (materials)	371,517	308,120	291,831	335,373	389,550	294495	294,730	2,285,616	23 %
Immature area up-keep (materials)	210,774	157,403	157,574	150,676	196,649	186907	183,598	1,243,582	12 %
Harvesting and collection	34,887	42,997	16,056	24,442	24,321	15715	6,055	164,473	2 %
Salaries and wages	571,807	592,072	548,665	61,5196	667,786	651698	676,548	4,323,773	43 %
TOTAL	1,426,622	1,367,511	1,262,419	1,415,791	1,613,356	1,464,318	1,472,975	10,022,992	100 %

Source: Source: DoS (1985-1987) Table 11.2; Depreciation and taxes are not included; WDI (2014)

There are three main cost categories, with salaries and wages comprising of 43 % of the total production costs; materials for mature area up-keep 23 % and materials for immature are up-keep 12 %. The other cost categories collectively account for 22 % of total production costs. To estimate the total costs for the period 1969-1988, I will therefore look at each of them in turn and consider: (i) Salaries and wages; (ii) Materials for mature are up-keep; (iii) Materials for immature area up-keep; and (iv) Other costs.

3.1 Wage cost

I had to make two adjustments. The first adjustment was to convert those years that only had December figures available to yearly figures. For 1969-79, the wage data is for December while for 1979-1988 there are yearly figures. 1979 is the only year in which these figures overlap, and I assume that the ratio of yearly wages relative to December wages are the same for each individual year 1969-1978 as for 1979. I calculate the ratio between yearly and December wage for each individual wage category, namely (1a) Directly employed administrative staff; (1b) Directly employed estate workers; (1c) Directly employed mill workers; (2) Contract workers; and (3) Other workers. Thereafter, I estimate the yearly wage for each individual year from 1969 to 1978. To get the real wage, I use the consumer price index from WDI (2014).

The second adjustment I had to make was similar to the one in appendix 2. I had to estimate the share of contract workers that were working on plantations and the share working in plantation mills. I use a similar approach by estimating the relationship for the years 1979-1988 as shown figure appendix 3.1:

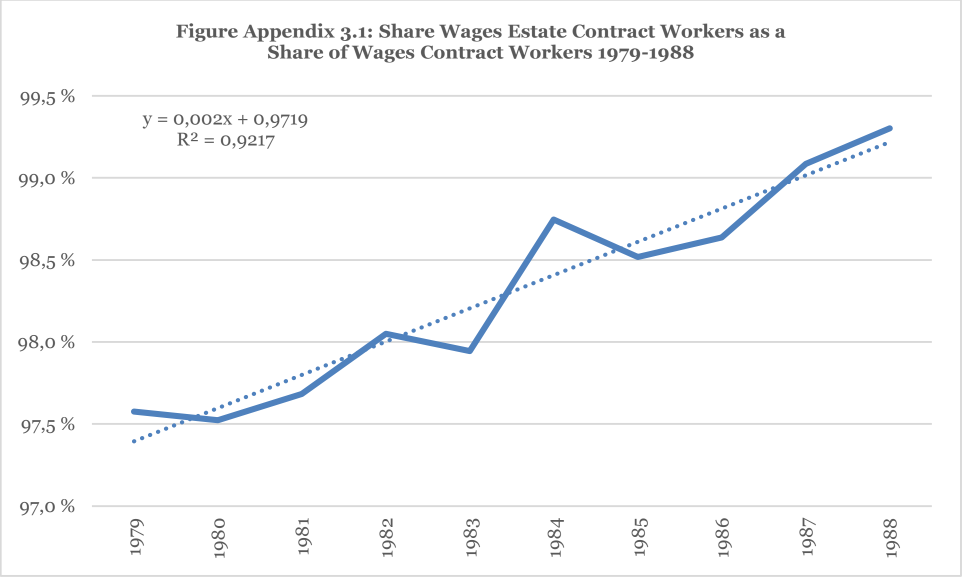

Figure Appendix 3.1: Share Wages Estate Contract Workers as a Share of Wages Contract Workers 1979-1988

I then assumed that the linear relationship to hold for 1969-1978 and used the equation above to estimate the wage costs for estate contract workers. The result of the estimations are shown in table appendix 3.2. When using the cost data as a part of total production costs, I will not include (1c) Directly employed mill workers; and (2b) Contract mill workers as these do not contribute to the production of fresh fruit bunches.

Table Appendix 3.2: Real yearly wages 1969-88 (1969-78 estimated)

Year	1. Wages Directly employed				2. Wages Contract workers			TOTAL WAGES
	(a) Administrative Staff	(b) Estate Workers	(c) Mills Workers	Total Directly Employed	(a) Estate Workers	(b) Mills Workers	Total Contract Workers	Total Employed
1969	29,661,091	63,416,255	7,225,645	100,302,992	49,945,328	5,611,210	55,556,539	155,859,531
1970	25,938,830	65,441,382	8,202,245	99,582,458	51,985,191	5,712,024	57,697,216	157,279,673
1971	28,867,095	74,007,488	9,457,124	112,331,706	54,607,144	5,865,884	60,473,028	172,804,734
1972	26,925,094	91,658,121	9,664,973	128,248,189	69,344,598	7,279,267	76,623,866	204,872,054
1973	29,419,904	105,964,237	10,137,173	145,521,314	77,135,236	7,909,126	85,044,361	230,565,676
1974	33,143,373	140,657,325	10,677,412	184,478,109	116,646,542	11,677,487	128,324,029	312,802,138
1975	51,616,577	134,818,844	11,680,843	198,116,264	124,454,641	12,158,576	136,613,217	334,729,481
1976	58,510,331	150,958,457	12,625,191	222,093,979	116,360,517	11,088,023	127,448,540	349,542,519
1977	58,244,103	170,977,368	11,705,346	240,926,818	128,790,048	11,964,103	140,754,151	381,680,968
1978	65,073,661	199,557,283	13,882,399	278,513,343	155,476,143	14,072,541	169,548,684	448,062,027
1979	93,744,064	231,892,497	18,647,077	344,283,637	202,074,808	5,021,236	207,096,045	551,379,682
1980	109,129,780	248,704,091	22,477,451	380,311,322	216,657,571	5,501,796	222,159,367	602,470,689
1981	132,708,790	246,808,554	22,851,060	402,368,404	208,014,302	4,934,169	212,948,472	615,316,875
1982	140,690,053	253,961,251	25,281,169	419,932,473	207,466,721	4,127,498	211,594,219	631,526,691
1983	142,848,509	246,649,872	21,707,958	411,206,338	175,675,642	3,686,952	179,362,595	590,568,933
1984	158,208,643	256,874,970	22,612,172	437,695,786	224,745,687	2,855,485	227,601,172	665,296,958
1985	172,359,744	267,797,268	23,579,636	463,736,647	253,174,102	3,808,516	256,982,618	720,719,266
1986	179,401,996	252,441,705	23,357,030	455,200,731	246,328,470	3,406,819	249,735,289	704,936,020
1987	188,599,521	257,938,922	23,082,755	469,621,197	252,276,482	2,330,230	254,606,712	724,227,910
1988	198,227,790	282,031,690	23,454,725	503,714,205	292,113,346	2,053,329	294,166,675	797,880,880

Source: DoS (1969) Table 31; 33; DoS (1970; 1971; 1972) Table 33; 35 Department of Statistics (1973; 1974; 1975; 1976; 1977; 1978) Table 44; 45; DoS (1979; 1980; 1981); DoS (1979) Table 45 DoS (1982; 1983); Table 42; DoS (1982) Table 43; DoS (1984; 1985; 1986; 1987; 1988) Table 10.2; DoS (1988) Table 10.1; and WDI (2014)

3.2 Materials Mature area up-keep costs

The approach to estimate the material costs for mature area up-keep costs was relatively straightforward. Data for mature area up-keep were only available for the period 1981-1987. However, data on fertilizer cost was available for the period 1967-88. Fertilizer is the biggest expenditure of materials for mature area up-keep costs, and the approach is then to estimate the cost through a mark-up on fertilizer costs through equation A3.1:

$$Mature\ Upkeep\ Costs_t = (1 + \mu) Fertilizer\ Costs_t \tag{A3.1}$$

For the period the 1980-86, fertilizer costs are approximately 75.7 % of total mature upkeep costs using a weighted average. There were no large yearly fluctuations. The mark-up is $\mu \approx 1.32$. Using this mark-up, I estimate the total costs for materials mature upkeep costs for 1969-79.

3.3 Materials Immature area up-keep costs

It is not possible to take the same approach as for materials for mature area up-keep costs and use fertilizer data, since these constitute a far lesser share of the overall costs of materials immature area up-keep costs and are more volatile in terms of their share. Data does exist for total costs for immature area up-keep 1969-1988, but the problem is that it includes wage costs. For the years 1981-87, however, both material costs and total costs are given. Using table 11.2 from DoS (1985-1987), one can calculate the share of materials cost of immature area as a share of total costs of immature area through equation A3.2:

$$Share\ Material\ Costs\ Immature\ Area_t = \frac{Material\ Costs\ Immature\ Area_t}{Total\ Costs\ Immature\ Area_t} \tag{A3.2}$$

For 1981-1987, the weighted share was 45.5 %, and the share was relatively constant for each individual year. As the share does not vary for the observable years, I assume this share is constant, and I estimate material costs for immature area by using equation A3.3:

$$Material\ Costs\ Immature\ Area_t = Share\ Material\ Costs\ Immature\ Area_t * Total\ Costs\ Immature\ Area_t \tag{A3.3}$$

3.4 Other Costs

Rather than take the five other cost categories individually, I take them as a whole. These other costs have a weighted share of total production costs 1981-1987 of 21.6 %. This share is relatively constant over time. I will therefore assume that this goes for the 1969-1988 period as a whole, and estimate other costs to be 21.6 % of total production costs.

3.5 Total and Unit Costs

Table appendix 3.3 shows total real costs and the various cost categories. For unit costs, I used the production data presented in table appendix 2.2 to estimate the unit costs presented in table appendix 3.4. Finally, table appendix 3.5 presents the real production costs for United Plantations for individual years.

Table Appendix 3.3: Total Costs (2005 Ringgit) Plantations Peninsular Malaysia 1969-1988

Year	(1) Wages	(2) Materials Mature Area Keep-Up	(3) Materials Immature Area Keep-Up	(4) Other Cost	TOTAL = (1) + (2) + (3) + (4)
1969	143,022,675	45,208,851	142,460,224	91,271,922	421,963,673
1970	143,365,404	62,476,183	115,496,547	88,690,296	410,028,429
1971	157,481,726	93,244,807	123,974,700	103,418,673	478,119,906
1972	187,927,814	114,433,542	149,079,800	124,599,123	576,040,280
1973	212,519,377	121,646,248	144,686,776	132,164,710	611,017,110
1974	290,447,240	182,820,344	181,699,691	180,772,947	835,740,223
1975	310,890,062	214,699,728	181,688,896	195,211,055	902,489,740
1976	325,829,305	223,162,337	172,166,541	199,041,838	920,200,021
1977	358,011,519	211,010,283	122,296,814	190,806,027	882,124,643
1978	420,107,087	256,101,690	148,199,858	227,539,275	1,051,947,910
1979	527,711,369	321,741,733	147,409,587	275,137,115	1,271,999,804
1980	574,491,442	385,380,506	147,412,248	305,613,784	1,412,897,979
1981	587,531,646	402,356,918	214,104,935	332,305,844	1,536,299,343
1982	602,118,024	321,280,258	153,665,512	297,272,862	1,374,336,656
1983	565,174,023	300,374,209	156,035,087	281,960,083	1,303,543,402
1984	639,829,301	346,449,870	152,439,463	314,289,784	1,453,008,417
1985	693,331,114	401,535,302	196,760,655	356,492,975	1,648,120,046
1986	678,172,171	285,573,482	189,422,990	318,278,030	1,471,446,674
1987	698,814,925	296,284,089	181,153,273	324,649,186	1,500,901,472
1988	772,372,826	410,620,643	160,444,101	370,792,829	1,714,230,398

Source: DoS (1969) Table 27; 30; DoS (1970-1972) Table 31; 34; DoS (1973-1981) Table 39; 42; DoS (1982-1983) Table 36; 39; 41; DoS (1984-1988) Table 7.1; 11.1; DoS (1984) Table 11.4; DoS (1985-1986) Table 11.3; Table Appendix 3.1; and Table Appendix 3.2.

Table Appendix 3.4: Unit Costs (2005 Ringgit) Plantations Peninsular Malaysia 1969-1988

Year	(1) Wages/FFB	(2) Materials Mature Up-Keep/FFB	(3) Materials Immature Up-Keep/FFB	(4) Other Cost/FFB	TOTAL/FFB = (1) + (2) + (3) + (4)
1969	83	26	83	53	246
1970	85	37	68	52	243
1971	70	42	55	46	214
1972	73	45	58	49	225
1973	73	42	50	46	211
1974	82	51	51	51	235
1975	73	50	42	46	211
1976	72	50	38	44	204
1977	69	40	23	37	169
1978	57	35	20	31	143
1979	75	46	21	39	180
1980	73	49	19	39	180
1981	67	46	24	38	174
1982	56	30	14	27	127
1983	60	32	17	30	138
1984	53	29	13	26	120
1985	53	31	15	27	126
1986	49	21	14	23	106
1987	51	22	13	24	110
1988	50	27	10	24	111

Source: Appendix Table 2.2 and Appendix Table 3.3

Table Appendix 3.5: Real cost of production (2005 Ringgit)

Year	Crude Palm Oil	Palm Kernel
1966	910	199
1967	898	216
1968	822	203
1969	882	209
1970	868	210
1971	783	211
1972	803	226
1973	813	360
1974	714	292
1975	707	183
1976	912	178
1977	810	227
1978	806	217
1979	820	212
1980	783	201
1981	780	210
1982	699	206
1983	771	249
1984	743	231
1985	713	209
1986	630	214
1987	708	220
1988	684	224
1989	661	220
1990	627	182
1991	593	191
1992	564	174
1993	546	149
1994	590	159
1995	585	152
1996	572	142
1997	547	131
1998	643	186
1999	556	139
2000	573	133
2001	577	143
2002	551	143
2003	544	124
2004	550	118
2005	536	115
2006	488	106
2007	524	123
2008	515	109
2009	481	107

Source: United Plantations (1975-2009)

Essay 3: Resource-Led Growth Past and Present*

Abstract

The impact of natural resources on economic growth has clearly differed among countries. This paper asks whether this impact has also changed over time when comparing Finland and Sweden (1860-1910) to Indonesia and Malaysia (1960-2010). The results indicate that natural resources have a positive effect in all four countries. Better institutions, more supportive economic policy and a higher degree of human capital all affect a country's ability to manage its natural resources. However, natural resources have less of an impact on economic growth in the more recent period. The most plausible reason is the larger technological catch-up potential, which leads to a greater reliance on non-resource manufacturing exports in the latter period. In addition, the increasing share of manufacturing in world trade might also affect the result.

Introduction

Most economic historians agree that natural resources greatly enhanced economic growth in a number of early industrialisers. In the late 19th century, Finland, Germany, Norway, Sweden and the United States all benefited greatly from their natural resources. Economic historian Gavin Wright claims that natural resources not only benefited these early industrialisers, but also current resource-abundant countries.[102] However, these claims are contradictory to the majority of relatively recent literature dubbed the 'resource curse' literature.[103] Representative of these views is Richard Auty (2001a p.840) who claims: '*Since the 1960s, the resource-poor countries have outperformed the resource-rich countries compared by a considerable margin*'. The obvious question that arises is which of the two views is correct. Do natural resources have a different effect on economies in the late 19th compared to the late 20th century?[104]

Many scholars claim that natural resources do have a similar impact in both periods. Ferranti *et al.* (2002) claimed that industrialisation in the late 19th century was highly dependent on natural resources. They illustrate how Italy's failure to industrialise in this period might have been caused by a lack of necessary natural resources. Sweden, in contrast, is an example of successful 19th century resource-led growth. The country utilised its forests to upgrade its production from wood to wood manufacturing and, later, paper. The value-added content of production thereby increased over time, leading to increased economic growth. Wright and Czelusta (2006) argued that this same process was present for mineral products in Australia and Chile in the late 20th century, meaning that natural resources had the same impact in the late 19th as in the late 20th century. If true, current resource-abundant developing countries can learn important lessons from the late 19th century experience.

However, other researchers disagree and believe that the late 20th century is different from the late 19th century. Sachs and Warner (1995) claimed that the 1971-1990 period (their period of study) was different from the late 19th century period. The problem was that they provided few empirical or theoretical reasons for

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[102] See for instance Wright (1990); David and Wright (1997); and Wright and Czelusta (2006).

[103] The term resource curse describes the paradox that many resource rich countries since 1970 have failed to experience high economic growth.

[104] Comparing these two time-periods is natural. 1850-1914 called the first era of globalisation, with an increased integration of the world economy, just as the post-1950 period, analogously called the second era of globalisation. These periods contrast with the interwar period, between 1918 and 1939 when the world economy disintegrated.

why this should be the case. In one way, however, Sachs and Warner (1995) were right. The 1971-1990 period was unusual as commodity prices were highly volatile, there was much macroeconomic instability and economic growth declined in comparison to the 20 years that preceded it. The 1971-1990 period is unlikely to yield the true relationship between natural resources and economic growth. More recently, Ragnar Torvik (2009), commenting on the difference between the 19th and 20th century resource abundance, admitted it was still an underexplored topic.

The current paper aims to increase our understanding of resource-led growth in different periods by analysing four case studies. For this purpose, Finland and Sweden (1860-1910) are compared to Indonesia and Malaysia (1960-2010). An obvious weakness is the lack of generalizability of case studies. However, important lessons can be learned by analysing a limited number of countries, as one can analyse mechanisms more in depth compared to a broad cross-country study.

The paper is organised as follows. First, a brief literature review is presented, emphasising some relevant theoretical links between natural resources and economic growth. Second, the empirical approach of the paper is explained. In the following two sections, Finland/Sweden and Indonesia/Malaysia are analysed in turn. Finally, the results of the two preceding sections are compared to analyse whether there are differences between the two periods.

The results indicate that natural resources do have a positive effect on the economy in both periods. In addition, the reasons for this positive impact are broadly similar, since better institutions, a more supportive policy and increased human capital all seem to increase the success of the natural resource sectors. However, the impact of natural resources on economic growth was greater for the 1860-1910 case studies. The most likely reason is that the technological catch-up potential was far greater in the 1960-2010 period, which allowed for a more rapid economic growth through technological learning.

1. Literature overview

1.1 Dutch Disease and Rent Seeking

The traditional Dutch disease and rent seeking models have a number of common features. First, they are deterministic and pessimistic with regard to economic growth: An increase in natural resources will set in motion some mechanism X, which in turn reduces economic growth. Second, they assume no idle production factors, meaning that capital and labour are fully utilised. This means that an increase in natural resources distorts the resource allocation in the economy. Finally, there is no theory of the resource sector as natural resources are often modelled as a currency gift. In other words, these models take a ‘black box’ approach of the natural resource sectors and do not consider processes that occur at the sector level.

The traditional Dutch disease argument suggests that the discovery of natural resources leads to an appreciation of the exchange rate and affects the allocation of labour and capital. Sachs and Warner (1995) use a Dutch disease model with three sectors: a tradable natural resource sector, a tradable (non-resource) sector, and a non-traded sector. An assumption is that the tradable (non-resource) sector generates learning-by-doing and thereby technological progress, while the other sectors do not. The larger the natural resource sector, the less labour and capital would be diverted to the tradable (non-resource) sector. Hence, an increase in natural resources reduces technological progress and thereby long-term economic growth.

In an extension of the Dutch disease argument, Gylfason (2001) argued that the increased resource abundance would lead to a decrease in education. The argument was similar to the one for the Dutch disease models. As manufacturing experiences learning-by-doing; the sector has a higher demand for human capital than the natural resource sectors. If the natural resource sectors expand, it would lower demand for human capital. A lower degree of human capital is then equated with a decrease in economic growth.

Similarly, the resource curse has also been associated with excessive rents. Entrepreneurs can potentially engage in productive activities or attempt to capture rents in natural resource sectors, so-called windfall profits. A resource boom increases the number of entrepreneurs investing in natural resource sectors to capture this windfall profit (as it is privately optimal), and thereby reduces activities that are more productive, thereby lowering economic growth. Many studies have linked rent-seeking behaviour to lower economic growth (Torvik, 2002, Robinson *et al.*, 2006, Sandbu, 2006).[105]

These explanations have a number of problems. The first is the assumption that natural resource sectors have fewer linkages than the growth sector. The argument is that an expansion in the natural resource sector will have less impact on the economy because of its enclave structure; thereby, an economy would experience a lower growth rate compared to a situation with a similar expansion in manufacturing (Hirschman, 1958; Seers, 1964; Baldwin, 1966). However, the growth experience of 19th century resource-abundant countries contradicts this view, since natural resource sectors increased their linkages to manufacturing sectors.[106] In addition, many studies argue that processing their natural resources is a feasible and desired way forward for many developing countries (Roemer, 1970, Lewis Jr, 1989, Cramer, 1999, Jaffee and Gordon, 1993). The problem is that little evidence exists on the development of linkages from natural resources over time.

In addition, the 'fewer linkages' argument implicitly relies on the assumption that manufacturing automatically generates linkages. However, manufacturing sectors in developing countries can be highly inefficient and have little connection with the rest of the economy. This is related to the 'low level equilibrium trap' caused by coordination failure proposed by Rosenstein-Rodan (1943). In an attempt to promote industrialisation, governments in several developing countries have invested in state-owned manufacturing companies with no clear incentives for increasing production. This 'White Elephants' problem leads to manufacturing sectors with low capacity utilisation, low productivity and few linkages to the rest of the economy (Auty, 2001a; Baland and Francois, 2000; Sala-i-Martin and Subramanian, 2003; Robinson and Torvik, 2005).[107] It is safe to say that manufacturing production alone is not sufficient for linkages to develop.

A second problem is the assumption of learning-by-doing as a sole property of the growth sector. This assumption implies that productivity growth in manufacturing is higher than in agriculture. However, Martin and Mitra (2001) concluded that total factor productivity growth had been higher for agriculture than for manufacturing for the period 1967 to 1992, which is consistent with the results from other studies (Lewis *et al.*, 1988; Martin and Warr, 1993; Bernard and Jones, 1996a). This means that there is little evidence to support the assumption that manufacturing is 'superior' with regard to productivity. However, these studies only compared agriculture and manufacturing, not mining and fuel sectors, for which, to my knowledge, no studies have compared productivity performances with manufacturing. Still, little compelling evidence has thus far been presented to justify the assumption of a 'superior' productivity performance of manufacturing over the natural resource sectors.

A third problem is that neither Dutch disease nor the rent seeking effects seem sufficiently strong to lower economic growth (Leite and Weidmann, 2002; Sala-i-Martin and Subramanian, 2003; Bulte *et al.*, 2005). Oil economies are found to have higher wages, but its effect on economic growth is not severe. In addition, these explanations fail to account for the cases in which resource-abundant countries have achieved economic growth

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[105] A related mechanism is the classic commons problem, in which the discovery of new natural resource deposits leads to an inefficient exploitation of the public good (Lane and Tornell, 1996). While the commons problem is associated with inefficient resource utilisation, rent seeking is associated with inefficient production. Both can potentially reduce long-term economic growth.

[106] One obvious question is how applicable Dutch disease and rent seeking models are for 19th century economies, since these models assume full usage of the factors of production. The Lewis-Ranis-Fei model assumes that countries in an early stage of development have underutilised labour (so-called 'surplus labour'), which can be transferred to modern sectors without affecting wages. The evidence of the applicability of the Lewis-Ranis-Fei model is weak, however; since economic growth in the 19th century was correlated with increased wages, see for instance Blomqvist (1990) for the case of Finland.

[107] Related to this argument is the effect of foreign direct investments, which has been criticised for the lack of technology transfer to the local economy. On the debate on the impact of foreign direct investments, see for instance Lipsey and Sjöholm (2005).

(Auty, 2001b). This goes especially for 19th century resource-led growth in which increased production in the natural resource sectors was correlated increased economic growth and industrialisation (Wright, 1990).[108] Most economists do acknowledge that Dutch disease effects are present, but claim they do not affect long-term economic growth.

1.2 Institutions

The institutional explanation comes in two different variants.[109] The first of these, dubbed endogenous institutions, emphasises that natural resources affect institutional quality and institutions in turn affect economic growth. The second, dubbed exogenous institutions, instead claims that countries that had good quality institutions benefit from their natural resources. Both explanations, like the Dutch disease, employ a 'black box' approach towards the natural resource sector itself.

The endogenous institutions view is similar to the Dutch disease and rent-seeking arguments, with institutions becoming mechanism X. The argument is that natural resources do not have a direct impact on economic growth, but rather, an indirect effect by reducing the quality of institutions (Leite and Weidmann, 2002). A number of studies have linked resource abundance with a decline of the quality of institutions (Auty, 2001a; Auty, 2001b; Ross, 2001; Atkinson and Hamilton, 2003). Sala-i-Martin and Subramanian (2003) and Isham *et al.* (2005) suggested that institutions were only affected by geographically concentrated natural resources (so called 'point sources' which were defined as minerals and plantation crops). Thereby, only certain natural resources affect the economy adversely.

However, similar problems are associated with the endogenous institutional explanation as with the Dutch disease. Endogenous institutions fail to explain resource-led growth in economies with point sources. Resource-led growth in 19th century US was based mainly on minerals and fuels, the same resources claimed to reduce institutional quality (David and Wright, 1997). In addition, it fails to explain resource-led growth in the late 20th century. Since 1970, oil exporting Norway has experienced high economic growth, and it is hard to claim that Norwegian institutions have deteriorated in the process.[110]

The exogenous institutions explanation differs as resources do not affect institutions, but institutions instead determine how natural resources affect the economy (Mehlum *et al.*, 2006a; Mehlum *et al.*, 2006b). On the one hand, countries that had good institutions prior to a resource discovery, will benefit from their natural resources. On the other hand, countries with bad institutions may experience a resource curse. Mehlum *et al.* (2006b pp.2-3) made the following distinction on institutional quality:

> '*The distinction we make is between producer friendly institutions, where rent-seeking and production are complementary activities, and grabber friendly institutions, where rent-seeking and production are competing activities. With grabber friendly institutions, there are gains from specialisation in unproductive influence activities, for instance due to a weak rule of law, malfunctioning bureaucracy, and corruption. Grabber friendly institutions can be particularly bad for growth when resource abundance attracts scarce entrepreneurial resources out of production and into unproductive activities.*

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[108] In an interesting extension of the Dutch disease explanation, Torvik (2001) constructed a model in which natural resources had a more ambiguous effect on economic growth. The difference in this model, compared to the ones above, was that learning-by-doing occurred in all sectors, and the growth effect of natural resources depended on the extent of learning-by-doing in the various sectors and the spillover effect between sectors. The Torvik (2001) model is different from other Dutch disease models as its outcome is less deterministic. It is more promising as it incorporates many of the problems mentioned with the more standard explanations of Dutch disease and rent seeking.

[109] The recent resurgence of institutions in economics is attributed to North (1990) who popularised the study of institutions as a cause for long-term growth. Subsequent research has strongly indicated that there is a link between the two, see for instance Hall and Jones (1999), Acemoglu *et al.*(2001), Acemoglu *et al.* (2005), Easterly and Levine (2003) and Rodrik *et al.* (2004).

[110] Another problem is the quality of the evidence presented in Isham *et al.* (2005), who claimed that point source reduced institutional quality. Point sources were defined as minerals and plantation crops, and a country was judged to be dominated by point sources if these were the two main primary export products. In the case of Malaysia, the two main exports were oil (a mineral) and palm oil (a plantation crop). However, Malaysia was judged not to have point sources, despite the definition in the paper.

> *With producer friendly institutions, however, rich resources attract entrepreneurs into production, implying higher growth.'*

Even though the exogenous institutions explanations are intuitive and appealing as they can explain both resource-led growth and the resource curse, they do have some issues. First, if a country has 'bad' institutions prior to a discovery, natural resources might hurt the economy, implying that a country should increase its institutional quality prior to natural resource production. However, little is explained on how to acquire 'good' institutions (Stevens and Dietsche, 2008). In addition, it is unlikely an economy is willing to postpone natural resource production until these 'good' quality institutions are acquired. Second, because these explanations treat natural resource sectors as a 'black box', little is explained on how institutions affect the resource sectors themselves.

1.3 Economic Policy

Economic policies offer a non-deterministic explanation of how natural resources affect economic growth. The explanation assumes that governments in resource-abundant countries can pursue either growth enhancing or growth retarding economic policies. These explanations have some common features. First, the outcome is open and policy explanations have therefore more potential to explain why some countries experience resource-led growth, while others experience a resource curse. Second, the policy explanations in general highlight fiscal policy as the resource sectors generate large revenues. Finally, as above, the natural resource sectors are generally treated using a 'black box' approach.

In theory, governments can use large resource revenues to stimulate a big-push industrialisation, which overcomes coordination failures. Economic policy can also be concentrated in specific areas such as human capital. Evidence found by Stijns (2006) suggests that resource abundance increased human capital. Atkinson and Hamilton (2003), also highlights that the curse may be caused by the government's inability to manage large revenues. They present examples of cases in which a combination of natural resources, macroeconomic instability and public expenditure have caused a low rate of genuine savings. As a number of researchers emphasise, this is not a 'resource curse' per se, but rather a 'fiscal income' curse, which could as easily occur by other means such as foreign aid (Harford and Klein, 2005, Morrison, 2012).

Related to the management of revenues is the high volatility of commodity prices, which continues to receive much attention as an important cause of the resource curse (Davis, 2001, Davis *et al.*, 2003, Atkinson and Hamilton, 2003, Bleaney and Halland, 2009, Van der Ploeg, 2011). This explanation becomes more powerful when combined with foreign debt, as many oil-rich countries increased long-term borrowing in the 1970s following the oil price increase, using future oil income as collateral. When oil prices subsequently declined, the foreign debt became unsustainable, leading to a debt crisis in a number of oil-rich countries during the 1980s (Manzano and Rigobon, 2006). A potential solution to the fiscal policy challenges is the establishment of a stabilisation fund for non-renewable resources, as has been done in Norway. Uncertainty would decrease as price shocks have less of an impact on government spending and would therefore improve fiscal responsibility (Davis, 2001).

The economic policy explanations are attractive, but do have some issues. Often, the only economic policy considered is revenue management. While important, it is far from the only policy that influences resource sectors. US resource-led growth in the 19th century involved a broader economic policy that promoted search activity, research and innovation in the natural resource sectors (David and Wright, 1997).

1.4 Technology

Economic historians use a different approach when analysing resource-abundant countries. First, natural resources are seen as endogenous. In other words, there is no 'black box' approach toward the natural resource sector. Second, the interrelationship between institutions and economic policy is analysed. Third, the research relies on case studies, which allow for a more in-depth analysis.

Case studies on the US are particularly interesting. The US emerged as the world's largest economy towards the end of the 19th century with much of its growth being related to the country's resource abundance (Habakkuk, 1962). David and Wright (1997) claimed that the resource abundance in the 19th century US was endogenous to the government's policies. No other country invested as much in the exploration and development of new technologies to produce and apply minerals.

US resource abundance and 19th century industrialisation are closely linked. In fact, the US became the world leading manufacturing producer in the same period as the country became the world leading producer of numerous mineral and fuels. Wright (1990) proved that these two processes were linked as the mineral factor content of US manufacturing exports increased from 1870 until the onset of the Great Depression in 1929. According to David and Wright (1997), the US experience highlighted the importance of (i) Strong institutions, especially an accommodating legal framework; (ii) Infrastructure and public knowledge; and (iii) Human capital, especially in the education in mining, minerals and metallurgy.[111]

The problem is that not much can be generalised from analysing only one country, especially as the US has a number of unique characteristics. Findlay and Lundahl (2004), however, compares various resource-abundant countries in the 1870-1914 period. Their findings indicated that Australia, Canada, New Zealand and the US used their natural resources as a catalyst, with linkages spreading to other sectors, which was used to industrialise. Argentina and Brazil managed to promote some linkages between the primary sector and manufacturing, allowing for the development of early industrialisation. Other primary exporting countries such as Costa Rica and Siam (Thailand) failed to establish strong linkages between the primary sector and manufacturing. The findings indicate that the difference between 'successful' and 'not successful' 19th century resource-led growth lay in the country's ability to upgrade the level of technology and develop linkages to other sectors in the economy.

Some researchers believe that these differences also apply to late 20th century resource-abundant countries (Ferranti *et al.*, 2002). Wright and Czelusta (2006) analysed mineral-abundant Australia and Chile in the late 20th century, and concluded that the growth process is similar to the one in the mineral-abundant US in the late 19th century. In addition, Bravo-Ortega and De Gregorio (2006) found that countries with a higher level of human capital benifited more from their natural resources, indicating that the level of technology is important for resource-led growth. If these arguments are true, the countries that experience a 'resource curse' are more likely suffering from a 'low level of technology curse'.

There are, however, two main issues with the technology explanation of resource-led growth. First, the case study methodology limits its generalizability. One notable exception is Bravo-Ortega and De Gregorio (2006) who apply a panel data set-up to analyse the effect of the level of technology. However, one quantitative study alone is not sufficient evidence. Second, the claims from Gavin Wright, that 20th century mineral economies have the same pattern of growth as late 19th century economies, is not clear. The claim was based solely on two mineral economies, Australia and Chile. In addition, only the domestic factors were considered, leaving out a number of potentially important mechanisms.

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[111] Mineral owners were not rent-seeking agents interested in windfall profit from a sector with backward technology as assumed in the Dutch disease and rent seeking models. Rather, the mining sector invested heavily in new technologies and created new linkages to manufacturing. These effects might have been long lasting, as a larger mining industry in 1880 is correlated with a better productivity performance among US states up until as late as 1980 (Bernard and Jones, 1996b, Mitchener and McLean, 1999, Mitchener and McLean, 2003).

2. Empirical approach

The research strategy is to use a two-stage analysis. In the first stage, I compare two countries within each period to analyse the reasons for differences in performance. In the second stage, I compare the two periods in order to analyse differences over time.

For 1860-1910, Finland and Sweden are analysed as examples of resource-led growth. The two countries both have large forest areas, have relatively similar cultures and are geographically located in the same region. Sweden was, however, more successful than Finland, in that industrialisation occurred earlier, economic development in the period of analysis was higher and the development of forestry-related industries was more rapid.

For 1960-2010, Indonesia and Malaysia are analysed. Indonesia and Malaysia are both large producers of oil and palm oil; they have similarities culturally and are located in the same region. However, Malaysia was the more successful of the two with more rapid industrialisation and higher economic growth. In other words, the Finland/Sweden comparison share many features of the Indonesia/Malaysia comparison.

The analysis will use some simple time-series econometrics to quantify some features of the growth process in the four countries mentioned above. In particular, three specifications are tested. The first will measure the absolute contribution of natural resource value-added to the rest of the economy to determine if natural resources have a positive correlation with non-resource production. The second will measure how the share of natural resource (% of GDP) is correlated with total production to measure if the process is consistent with resource-led growth. The final specification measures how the share of natural resource production (% of GDP) affects non-resource production. This specification attempts to measure some Dutch disease effects in order assess the potential relevance of these theories for the four resource-abundant countries.

Before proceeding to the country case studies, I will first explain the econometric approach in more detail and give an overview of the main determinants analysed.

2.1 Econometric specifications

The main practical problem was that all variables of interest were non-stationary. Ideally, analysing the driving factors behind economic growth would involve an analysis of the levels of natural resources and economic growth if these are co-integrated. However, when testing for co-integration using the Engle-Granger test, I failed to reject the null hypothesis of non-stationarity for the dependent variables and the natural resource indicators.[112] To correct for non-stationarity, I use two techniques; (i) The first difference; and (ii) De-trending. More advanced techniques lie beyond the scope of this paper, as the research problem is adequately addressed using the above-mentioned techniques.

2.1.1 First-difference

The first-difference technique has a number of advantages. First, one obtains stationary variables if the series follow an I (1) process. In the case of the present study, all variables become stationary with first differencing.[113] Second, first differencing removes any linear time trend, simplifying the interpretation of the coefficients.

However, first differencing has a number of drawbacks. Probably the most serious is that first differences should only be used to determine levels in the short-run. The reason is that the first differences

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[112] I ran four specifications for each country, sixteen specifications in all. The test statistic is a modified Dickey-Fuller test developed by MacKinnon (1990, 2010). In all but one specification, the null hypothesis of no co-integration was accepted, and the one specification in which the null hypothesis was rejected was only at the 10 % level of significance.

[113] Using a Dickey-Fuller test, the null hypothesis of a random walk was rejected at the 99 % degree of confidence for all variables used.

method assumes away all long-run information on the relationship between the two variables. Another drawback is that one loses the first observation because one always need the lagged value. Dropping the first observation means that first differences are less efficient than other estimation techniques. To counter some of these drawbacks, I will also use de-trended figures to conduct the same analysis as a robustness check.

The first difference estimation is used to test three equations. The main problem in measuring the extent of resource abundance are the few indicators available for both time-periods. It is possible to use natural resource exports as a share of GDP, but this indicator has many problems (see essay 4 in this PhD thesis). To be able to compare the impact of natural resources over time, I chose to use natural resource value-added (in effect agriculture and mining). The first reason is because it shows the absolute value-added of the natural resource sectors. Second, it allows testing for both the 1860-1910 and the 1970-2005 periods (data limitation on Malaysia prevented the series going back to 1960). The definition of what constitutes the different sectors is relatively similar across sources allowing for a great degree of comparison.

The first equation tests the impact of the natural resource sectors on non-resource GDP:

$$\Delta \ln(GDP - NR)_t = \beta_0 + \beta_1 \Delta \ln NR_t + \beta_2 \Delta \ln GOV_t + \beta_3 \Delta \ln TRADE_t + \beta_4 \Delta \ln INV_t + \varepsilon_t \qquad (1)$$

Where GDP is gross domestic product and NR is natural resource value-added.[114] The choice of control variables is limited by data availability, as some of the controls preferred are not available for both periods.[115] For a full list of sources and descriptive statistics, see appendix 1.

The first control variable is investments, which has the notation INV. This control variable measures the effect of investments on GDP. More investments increases the productive capacity of the economy, which leads to improved long-term economic growth.

The second control variable is the sum of exports and imports, which has the notation TRADE. The control measures the degree of openness, which is often assumed to be positively correlated with higher GDP as sectors engaging in international trade are more productive than sectors producing for the domestic market.

The third control variable is government consumption with the notation GOV. Government consumption measures the degree of government expenditures on non-investment activities, which according to Barro (1991) is negatively correlated with economic growth. It is argued that government consumption (as opposed to government investment) does not contribute to long-term economic growth, and is a proxy for government wastefulness.

Equation (1) shows that the growth in non-resource GDP is dependent on the growth of the natural resource sectors and the growth of the control variables. The coefficient β_1 in equation (1) is the % change in the growth rate of non-resource GDP associated with a 1 % increase in the growth rate of the value-added of the natural resource sectors. The equation captures the impact the resource sectors have on the rest of the economy, to see if there is any difference between the four countries. I expect the coefficient $\beta_1 > 0$, as an increase in the value-added of agriculture and the mining sector is expected to benefit the rest of the economy.

The second equation is the effect of natural resource share on GDP per capita:

$$\Delta ln(GDP\ per\ capita)_t = \beta_0 + \beta_1 \Delta \left(\frac{NR}{GDP}\right)_t + \beta_2 \Delta \left(\frac{GOV}{GDP}\right)_t + \beta_3 \Delta \left(\frac{TRADE}{GDP}\right)_t + \beta_4 \Delta \left(\frac{INV}{GDP}\right)_t + \varepsilon_t \qquad (2)$$

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[114] All variables are measured as total economy sizes as dividing each variable by the population size would yield identical results.

[115] There are three controls which would have been preferable to have included had these been available; (i) Age dependency ratio to control for the demographic burden; (ii) Institutions to control for institutional quality; and (iii) Domestic credit to the private sector to control for the quality of the financial system.

The resource indicator chosen is the value-added of natural resource sectors as a share of GDP, which can be interpreted as a measure of resource dependence. The resource curse literature often uses a measure of resource dependence as the indicator for resource abundance, with the natural resource exports as a share of GDP the most common.[116] Equation (2) shows that economic growth in GDP per capita is dependent on the change in resource dependence and the change in the control variables.

As equation (2) is a log-level specification, the coefficient 100*β_1 in equation (2) shows the % change in the growth rate of GDP per capita associated with a one percentage point increase in the change in resource dependence.[117] The sign of β_1 is interesting, as it is undetermined. The first possibility is that the coefficient $\beta_1 > 0$, which could be interpreted as evidence for resource-led growth. The second possibility is that the same coefficient $\beta_1 < 0$, which in the literature is interpreted as a resource curse, since a larger degree of resource dependence slows economic growth. The final possibility is that it is not statistically significant, which could mean that natural resources are not correlated with economic growth.

The final equation I test is how resource dependence affects non-resource GDP per capita:

$$\Delta ln([GDP - NR]\ per\ capita)_t = \beta_0 + \beta_1 \Delta \left(\frac{NR}{GDP}\right)_t + \beta_2 \Delta \left(\frac{GOV}{GDP}\right)_t + \beta_3 \Delta \left(\frac{TRADE}{GDP}\right)_t + \beta_4 \Delta \left(\frac{INV}{GDP}\right)_t + \varepsilon_t \qquad (3)$$

Equation (3) shows that economic growth in non-resource GDP per capita is dependent on the change in resource dependence and the change in the control variables. Similarly as above, the coefficient 100*β_1 in equation (3) is the % change in the growth rate of non-resource GDP per capita associated with a one percentage point increase in the change in resource dependence. Equation (3) measures the impact of the relative size of the resource sector on non-resource GDP per capita. For equation (3), I therefore expect the coefficient $\beta_1 < 0$, as a relative increase of the natural resource sector implies that the non-resource sector has grown less than the resource sector. The reason for including this equation is to test whether Dutch disease effects are present.

2.1.2 De-trending

De-trending is a highly effective way of dealing with non-stationarity if the data is trend stationary. It also allows the use of levels rather than the differences, which removes some of the potential problems associated with first-differencing, such as its usage for short time periods.

One problem associated with de-trending is that the 'true' time trend is unknown. Therefore, the analysis with de-trended data was done twice; once for a linear trend and once for a stochastic trend.

The linear time trend presented a number of problems. First, the de-trended variables were not stationary.[118] Second and probably caused by the first, there was a high degree of autocorrelation in the regressions using linear detrended variables. To correct for this I used feasible generalised least squares (GLS) to correct for autocorrelation. I used the Prais-Winsten approach as it includes the first observation, and therefore is potentially more efficient.[119] Given the problems with the linear trend, I also decided to de-trend with a stochastic trend.

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[116] Resource exports as a share of GDP was first used by Sachs and Warner (1995) and quickly became the standard measure of the resource curse literature. However, in recent times, it has increasingly become more popular to measure resource abundance as resource income per capita, see for instance Ramsay (2011) and Bjorvatn *et al.* (2012).

[117] A coefficient β_1 of 0.05 implies that the growth rate increases by 5 %. If the change in resource dependence increases from 0 % to 1 %, the growth rate of 2 % in GDP per capita would then increase by 5 % to 2.1 %.

[118] The Dickey-Fuller test was used to test for stationarity.

[119] The Prais-Winsten approach assumes that the autocorrelation is generated by an AR(1) process. I used the estimated error terms to perform a t-test for the presence for AR(1) and AR(2) autocorrelation for each regression, and for most specifications I found evidence of an AR(1) process, but not an AR(2) process.

To estimate a stochastic trend, I used the Hodrick-Prescott (HP) filter with a λ = 6.25 which is standard for yearly observations. One beneficial property of the de-trended data using an HP filter was that all variables were stationary.[120] The HP trend analysis had a low degree of autocorrelation; I could therefore run standard ordinary least squares (OLS) on all but two specifications.

There are, however, a number of pitfalls in using the HP filter. First, there is no way of knowing the true smoothing parameter λ. I followed the standard in the literature and set λ = 6.25 as I used yearly data. However, there are no theoretically objective ways of setting this parameter, so the HP filter will always have some arbitrary judgement relating to it. Second, I had to drop the first and last observations in my sample, since the HP filter needs one lag and one forward observation to be calculated. This makes the HP estimation less efficient than other estimations in which more observations can be included.

I use de-trended variables to test three similar specifications as for the first difference as a robustness check. All equations are estimated with both linear and HP de-trended data. The de-trended equivalent of equation (1) is:

$$\ln(GDP - NR)_t^{DT} = \beta_0 + \beta_1 \ln NR_t^{DT} + \beta_2 \ln GOV_t^{DT} + \beta_3 \ln TRADE_t^{DT} + \beta_4 \ln INV_t^{DT} + \varepsilon_t \quad (4)$$

The notation 'DT' stands for de-trended. The interpretation of β_1 is slightly different from equation (1), as it represents the % increase in non-resource GDP from a 1 % increase in natural resource value-added.

The de-trended equivalent of equation (2) is:

$$\ln(GDP\ per\ capita)_t^{DT} = \beta_0 + \beta_1 \left(\frac{NR}{GDP}\right)_t^{DT} + \beta_2 \left(\frac{GOV}{GDP}\right)_t^{DT} + +\beta_3 \left(\frac{TRADE}{GDP}\right)_t^{DT} + \beta_4 \left(\frac{INV}{GDP}\right)_t^{DT} + \varepsilon_t \quad (5)$$

For equation (5), the coefficient 100*β_1 shows the % increase in GDP per capita from a one percentage point increase in resource dependence.

The final equation is the de-trend equivalent of equation (3):

$$\ln([GDP - NR]\ per\ capita)_t^{DT} = \beta_0 + \beta_1 \left(\frac{NR}{GDP}\right)_t^{DT} + \beta_2 \left(\frac{GOV}{GDP}\right)_t^{DT} + \beta_3 \left(\frac{TRADE}{GDP}\right)_t^{DT} + \beta_4 \left(\frac{INV}{GDP}\right)_t^{DT} + \varepsilon_t \quad (6)$$

For equation (6), the coefficient 100*β_1 in equation (6) is interpreted as the % increase in non-resource GDP per capita with a one percentage point increase in resource dependence.

2.2 Determinants for growth

In addition to the time-series econometrics, this essay analyses the underlying causes of resource-led growth, using the three determinants illustrated in figure 1:

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[120] Using a Dickey-Fuller test, the null hypothesis of a random walk was rejected at the 99 % degree of confidence for all variables used.

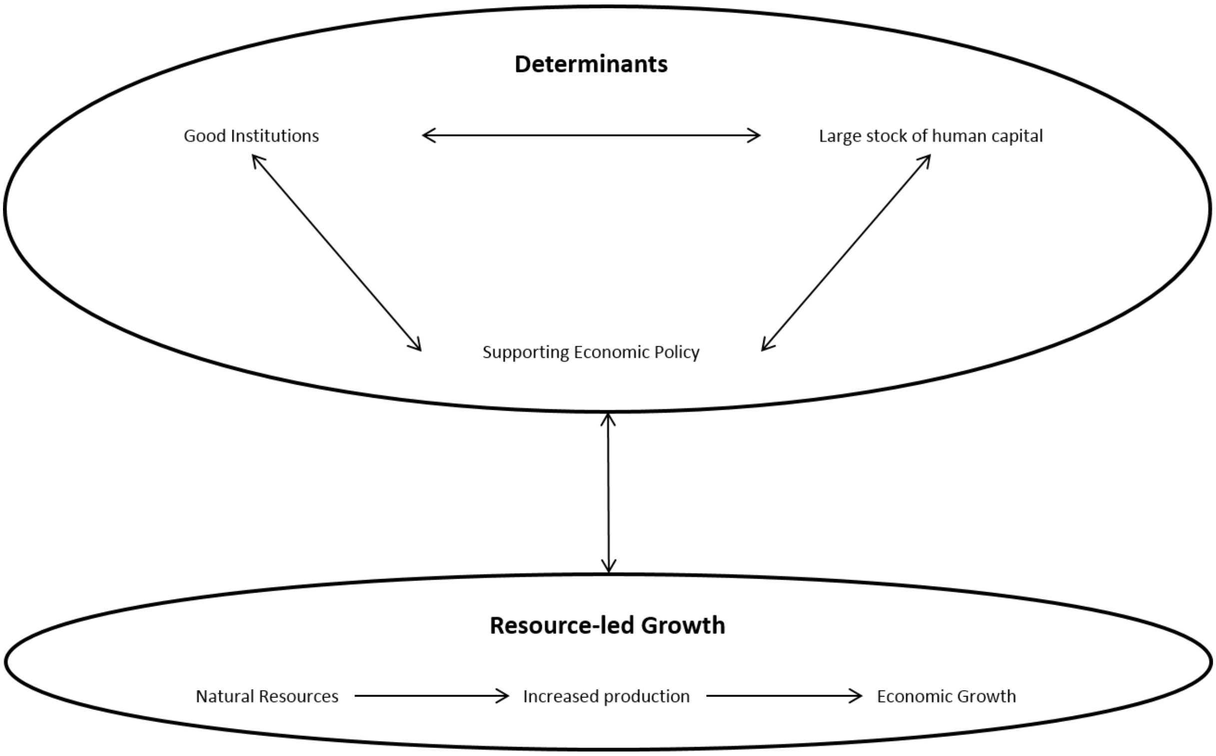

Figure 1: Analytical Framework

Each of the three determinants in figure 1 has been mentioned in the literature overview, so I will only briefly touch upon them. The first determinant for growth in resource-abundant countries are good institutions, with 'good' meaning the ability to promote long-term sustained economic growth by generating incentives for the accumulation of physical and human capital, and for increased technological development. In figure 1, institutions can change in two ways. The first is through economic policies, as emphasised by Rodrik (2000). Policies that initiate large institutional reforms have often occurred in a period immediately prior to a country's growth take-off, such as in a number of East Asian countries. The second is through the degree of human capital, as emphasised by Glaeser *et al.* (2004). The argument is that a more highly educated civic society does not accept 'bad' institutions, thereby ensuring that institutions evolve into stronger ones as education levels increase.[121]

The second determining factor in figure 1 is a large stock of human capital.[122] Human capital accumulation is clearly linked to both institutions and economic policy. First, institutions provide incentives for economic agents, and can therefore influence the returns and the cost of education. Second, economic policy increases human capital through for instance government spending on education or through selective industrial policy that promote sectors intensive in their usage of human capital.

The final determining factor in figure 1 is a supporting economic policy. Economic policies are highly dependent on a strong state, which again is dependent on institutions and on human capital. First, strong institutions such as a competent bureaucracy and a strong rule-of-law increase the effectiveness of economic policy, and therefore increase state power. Second, a higher education level means that the state can employ more skilled workers, and the policies that promote growth can be implemented more effectively.

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[121] For this mechanism to work the preferences of low educated people has to be different than for highly educated people. This process might have occurred in South Korea and Taiwan during the 1980s, in which both countries evolved into democracies following two decades of high economic growth.

[122] The evidence for a link between education levels and economic growth is strong, see for instance Barro (2001); and Hanushek and Woessman (2008; 2012).

3. Finland and Sweden 1860-1910

3.1 Resource-Led Growth in Finland and Sweden

Finnish and Swedish economic growth improved considerably in the second half of the 19th century compared to the first. Economic growth, measured as annual growth rate of GDP per capita (1990 Int. GK$), increased from 0.6 % in Sweden for 1820-1850, to 1.1 % for 1850-1890, and increased further to 2.2 % for 1890-1910. Finland's growth increased from 0.5 % for 1820-1850, to 1.0 % for 1850-1890, to 1.6 % for 1890-1910 (all figures from Bolt and van Zanden, 2013). As living standards in Sweden were higher than in Finland in 1820, and the subsequent growth rate higher in Sweden, there was no convergence. Instead, GDP per capita in Sweden was 1.3 times the level of Finland's in 1910.

Whether Finland experienced resource-led growth is somewhat unclear given the first specification. Result (1-1) in table 1 for Finland shows that a 1 % increase in the growth rate of natural resource value-added reduces the growth rate of non-resource GDP by 0.747 %. This is an odd result, as one would expect that the feedback mechanisms were strong between the natural resource sectors and the rest of the economy. Separating the natural resource sectors into forestry and the natural resource sectors apart from forestry, the forestry coefficient in result ($1\text{-}1^+$) shows that a 1 % increase in the growth rate of forestry value-added increases the growth rate of non-resource GDP by 0.349 %. The reason for the differences between the two results might be that Finnish agriculture was characterised by non-modern production methods, and therefore 'backward' with little interaction with the rest of the economy. The Finnish results are consistent with forestry-led economic growth.

In the case of Sweden, resource-led growth is far clearer. Result (2-1) from table 2 shows that a 1 % increase in the growth rate of the value-added of the resource sectors increases the growth rate of non-resource GDP by 0.245 %. This result is statistically significant, indicating a strong correlation between the natural resource sectors and non-resource GDP in Sweden.[123]

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[123] The reason for not testing forestry explicitly for Sweden is that the Schön figures do not differentiate between agriculture and forestry.

Table 1: First-Difference Results for Finland 1860-1910

	(1-1) Δ ln(GDP-NR)	(1-1^{+}) Δ ln(GDP-NR)	(1-2) Δ ln(GDP per capita)	(1-3) Δ ln([GDP–NR] per capita)
Δ ln(NR)	-0.747*** (-8.93)			
Δ ln(Forestry)		0.349*** (3.66)		
Δ ln(NR-Forestry)		-0.604*** (-10.32)		
Δ (NR/GDP)			0.00771*** (5.37)	-0.0248*** (-14.02)
Δ ln(Gov.consum)	-0.118 (-0.80)	-0.106 (-1.36)		
Δ ln(Trade)	0.415*** (6.83)	0.250*** (4.37)		
Δ ln(Investments)	0.152** (2.06)	0.147** (2.50)		
Δ (Gov.consum /GDP)			-0.0414*** (-3.51)	-0.0467*** (-4.56)
Δ (Trade/GDP)			0.000453 (0.31)	0.00164 (0.98)
Δ (Investments/GDP)			0.00208 (0.54)	-0.00112 (-0.30)
Observations	50	50	50	50
R^2	0.743	0.838	0.665	0.898
Adjusted R^2	0.720	0.819	0.635	0.889
Durbin Watson test statistic	1.849	2.259	1.875	2.086

Note: t statistics in parentheses based on heteroskedasticity-robust standard errors with * Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels indicating no autocorrelation.

Table 2: First-Difference Results for Sweden 1860-1910

	(2-1) Δ ln(GDP-NR)	(2-2) Δ ln(GDP per capita)	(2-3) Δ ln([GDP–NR] per capita)
Δ ln(NR)	0.245*** (3.69)		
Δ (NR/GDP)		0.0110** (2.30)	-0.00445 (-0.94)
Δ ln(Gov.consum)	-0.0903 (-0.86)		
Δ ln(Trade)	0.150** (2.20)		
Δ ln(Investments)	0.167*** (5.40)		
Δ (Gov.consum /GDP)		-0.0560*** (-5.51)	-0.0558*** (-5.53)
Δ (Trade/GDP)		-0.00295** (-2.09)	-0.00314** (-2.25)
Δ (Investments/GDP)		0.0122** (2.66)	0.0120** (2.67)
Observations	50	50	50
R^2	0.586	0.569	0.583
Adjusted R^2	0.549	0.531	0.546
Durbin Watson test statistic	1.976	1.705	1.707

Note: t statistics in parentheses based on heteroskedasticity-robust standard errors with * Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels indicating no autocorrelation.

More evidence of the importance of natural resources comes from results (1-2) and (2-2). For both countries, the change in resource dependence is positively correlated with GDP per capita. Result (1-2) shows that a one percentage point increase in the change in resource dependence increases the growth rate of GDP per capita by

0.771 % in Finland. Result (2-2) shows that the similar figure in Sweden is 1.1 %. In both Finland and Sweden, a positive statistically significant correlation strongly indicates that economic growth was resource-led.

The importance of the forestry sector and its relationship with other sectors is also highlighted in figure 2, which shows the export structure in both Finland and Sweden. Forestry and those manufacturing sectors that used wood as an important input in production (including furniture and paper) increased in both countries toward the turn of the century.

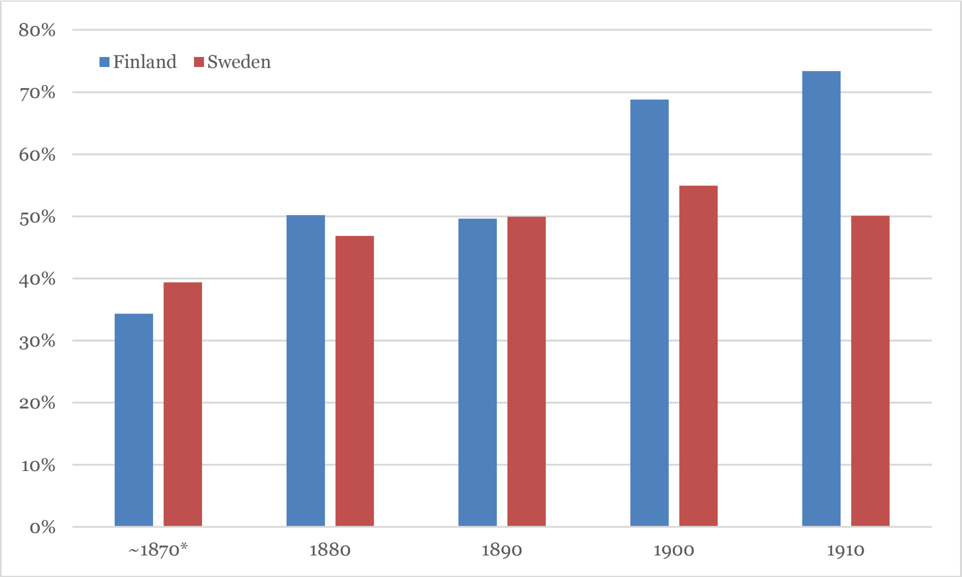

Figure 2: Forestry and Wood Manufacturing as Shares of Total Exports 1870-1910 (%)
Source: Calculations based on Hjerppe (1996) and Statistics Sweden (1972)
* For Finland the 1869 share and for Sweden the 1871 share is reported

Dutch disease effects might have been present in both countries. Result (1-3) shows that a one percentage point increase in the change in resource dependence decreased the growth rate of non-resource GDP per capita in Finland by 2.48 %. The Finnish result is statistically significant. Result (2-3) for Sweden also shows a decrease, but this coefficient is not statistically significant. These results indicate that an increase in the relative share of natural resource value-added has a negative correlation on the rest of the economy. The difference between results (1-1)/(2-1) and (1-3)/(2-3) is that the former measure the absolute impact of the natural resource sector while the latter measure the relative impact.

The robustness check, running all specifications mentioned above with de-trended data, yield similar results. Results for the linear and HP de-trended figures are reported in appendices 2 and 3. Natural resource value-added is positively and statistically significantly correlated with both non-resource GDP (as with first-differences, it holds only for forestry for Finland). In addition, resource dependence is positively and statistically significant correlated with GDP per capita, and negatively correlated with non-resource GDP per capita. As mentioned, the first-differences have some weaknesses as a method. However, obtaining similar results using two different de-trended analyses increases the robustness of the first-difference findings.

The paper has already mentioned that Sweden is more ‘successful’ than Finland within the 1860-1910 period, since economic growth and living standards at the end of the period were higher in Sweden. There are three areas that are important in the context of this paper.

First, the growth take-off occurred earlier in Sweden and is usually set in the 1850s, following a large expansion in forestry exports.[124] The Finnish growth take-off did not occur before the 1890s, and was interrupted by World War I and the following Finnish Civil War. While considerable progress was made in Finland in the interwar years, the true take-off of the Finnish economy occurred first in the post-1945 era in which Finland converged with Sweden. Rostow (1959) argued that an economy goes through five growth phases from a traditional to a mature economy. With the take-off occurring at different times, it indicates that the preconditions in the two countries were different, something I will return to when discussing the determinants.

Second, the productivity was higher for Swedish sawmills. Even though comparable figures are hard to come by, there is sufficient indirect evidence. For instance, for the period from 1859 to 1869, when wood price quotations decreased by 25 %, Swedish wood production increased, while Finnish wood production decreased. Profit margins in Sweden must have decreased in periods with decreasing prices (Söderlund, 1953). However, the increase in production is a strong indication that profit margins were still sufficient to allow for a further expansion of production, indicating that Swedish exports remained more cost efficient than their Finnish counterparts.

Finally, the linkages from the forestry sector to other sectors of the economy were more extensive in Sweden. This difference is illustrated in figures 3 and 4, as the manufacturing sectors (that used wood as an important input) increased more in Sweden than in Finland. Following a crisis in the 1870s, the Swedish forestry industry evolved from a market structure with many small producers in the 1860s to a market with a few large producers in the 1880s. Companies increasingly owned the entire value chain, leading to increased economies-of-scale and more efficient production of the higher value-added products. In Finland, wood manufacturing and paper production did emerge prior to 1910, with many of these being directed towards the Russian market. However, these were often protected from foreign competition and productivity was low.

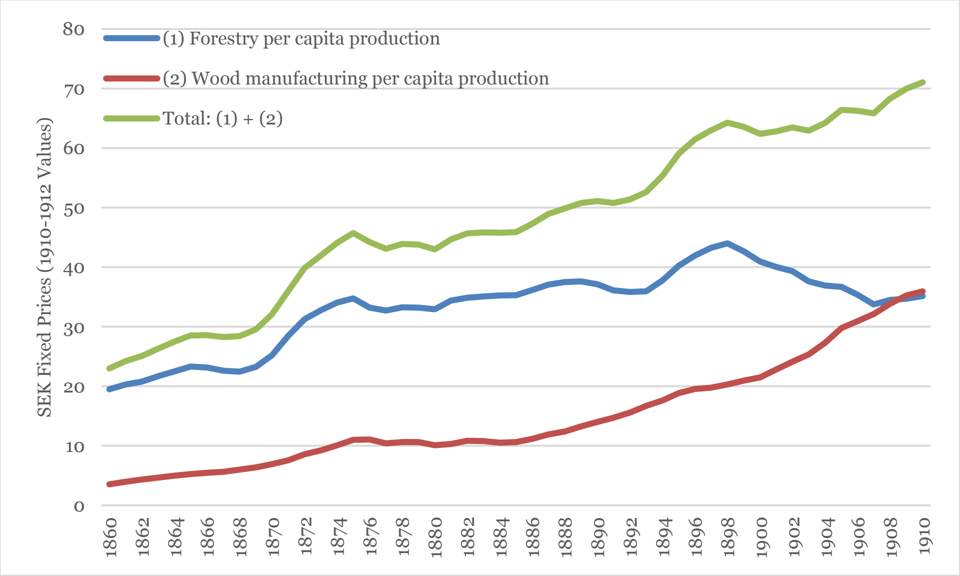

Figure 3: Sweden Forestry and Wood Manufacturing Value-Added per Capita (SEK 1910-1912) 1860-1910 (Five-Year Moving Average)
Source: Own calculations based on Edvinsson (2005) and Smits *et al.* (2009)

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[124] Söderlund (1953) mentions that the key reasons for this expansion were (i) The increase in wood prices as British demand increased; (ii) Decreasing British trade barriers; (iii) Supply problems in the Norwegian forestry sector; and (iv) Increased domestic support for the Swedish forestry sector.

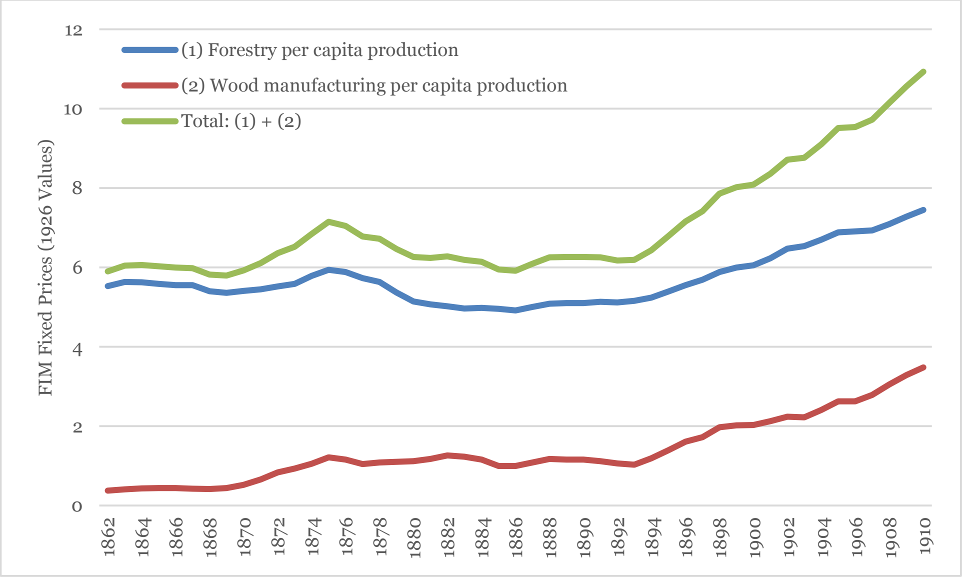

Figure 4: Finland Forestry and Wood Manufacturing Value-Added per Capita (1926 FIM prices) 1862-1910 (Five-Year Moving Average)
Source: Own calculations based on Hjerppe (1996) and Smits *et al.* (2009)

3.2 Determinants of Resource-Led Growth

3.2.1 Institutions in Finland and Sweden

In the mid-19th century, institutions in Sweden were better suited for an expansion in the forestry sector than they were in Finland. One example is in the area of property rights, as Sweden had strengthened the property rights to forests by transferring these to farmers during the 1820s (Söderlund, 1951). With clear property rights, Swedish forest owners had strong incentives to invest in sawmills. Gradually, sawmills grew more productive and invested in new technologies and forest owners attempting to expand into higher value-added production.

In contrast, Finnish property rights were still weak in 1850. The consequence was that Finnish forests in practice were open access forests, which led to typical commons problems of a lack of incentive to promote the long-term economic value of forests. The lack of property rights was especially prevalent in Eastern, Western and Northern Finland (Michelsen, 1995; Palo and Uusivuoriu, 1999). By 1900, the demarcation of property rights was mostly completed (Palo and Uusivuoriu, 1999). Once clear private and state property rights had been established, new incentives were created which emphasised the forests' long-term economic value, which led to increased investments and eventually increased production and exports.

Another notable institutional difference is the restriction on forestry production. In Sweden, restrictions on forestry had existed since the 18th century to protect the mining industry. However, the invention of the Bessemer process led to the abolishment of the restrictions on the usage of forests as access to forests was no longer important for the mining industry.[125] In 1841, the export tax on sawn timber was abolished, and in 1842, the start-up privileges of sawmills was also abolished (Söderlund, 1951, Schön, 2007). These abolitions gave way to a near unrestricted exploitation of the forests for the sawmill industry. This development, coupled with an increase in wood prices in the 1850s, led to a large increase in production and exports in the Swedish sawmill industry.

In Finland, the Swedish restrictions had stayed in place following the Finnish annexation into the Russian empire in 1809. The Russian emperor allowed the Finnish a semi-autonomous rule, and the Swedish laws simply remained in effect during a transition period into the Russian empire that lasted until the mid-19th century. As

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[125] Prior to the Bessemer process, the access to wood was vital as an input for the production of steel. The Bessemer process allowed the production of steel without the usage of wood, meaning that the forests were no longer of strategic importance to the Swedish mining industry.

Finland had few mines, these restrictions were largely redundant. However, attempts to get rid of these restrictions proved difficult. The Forestry Act of 1851 continued to put restrictions on sawmills, including yearly production quotas and a ban on steam-powered sawmills (Michelsen, 1995). The rationale behind continued restrictions was a scepticism of the sawmill industry and a fear of deforestation. These restriction were only gradually lifted in the late 1850s and early 1860s; for instance, the ban on steam-power sawmills was lifted in 1858. However, the establishment of sawmills still required an application to the Senate for official permission (Michelsen, 1995). The first large steam-powered sawmills were not constructed before early 1870s (Hjerppe, 1989). Finnish restrictions stayed in place longer than in Sweden, making a similar export expansion unlikely (Söderlund, 1951, Kaukiaien, 2006).

The key difference between Finland and Sweden were the institutional reforms in the first half of the 19th century, and was most likely a key factor in determining the differences in resource-led growth. While Swedish institutions increasingly became more market-oriented, Finland retained many mercantile institutions up until the mid-19th century. One example is the development of the financial system, which came earlier in Sweden, and played an important role in financing the forestry and related industries following 1870. [126] An underlying cause was that the Finnish Diet did not meet in the first half of the 19th century, and first started to assemble from the 1860s and onwards (Ojala and Karonen, 2006 p.103). The lack of an active political body meant that reforms were not enacted before this time.

3.2.2 Economic Policy in Finland and Sweden

While Finland and Sweden in general were supportive in terms of the provision of public goods, the big difference lay in their support for forestry and related industries. I have already mentioned the abolishing of restrictions on the exploitation in Sweden that was crucial for their initial expansion. Following this initial expansion of the 1850s, Swedish state support for the forestry sector was high. One example is how the Swedish state pursued an active industrial policy to promote the pulp and paper industry, which started to emerge in the 1850s in Southern Sweden. These ventures generally proved unprofitable even as late as the 1890s and therefore needed state support (Glete, 1989). One method to promote higher value-added production was the imposition of high tariffs on the import of high-value added products in which wood was a major input (Bohlin, 2005). This protection led to higher profits, which led to increased investment and an expansion of production in wood manufacturing and the paper industry in Sweden.

In contrast, Finnish state support was mixed. In the 1850s and 1860s, there was much hostility towards the sawmill sector, which undoubtedly halted the sector's development. For instance, Johan Vilhelm Snellman, an influential journalist and later professor, senator and prime minister, strongly opposed the education of foresters and a professional state forest administration (Michelsen, 1995). According to Brems (1971), a part of this resistance was caused by a linguistic and social conflict between the Finnish-speaking majority and the Swedish-speaking minority. This minority, often more wealthy, constituted a Swedish-speaking business elite. The Finnish resistance towards forestry was eventually eased, and there was an increasing amount of support towards the end of the 19th century. This included the establishment of the Finnish Forestry Association in 1877 to promote forest research (Palo, 2004).[127]

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[126] For the emergence of the Swedish banking sector, see for instance Sandberg (1978) and Adams *et al.* (2005); and for the emergence of the Finnish banking sector, see for instance Palo (2004).

[127] Following independence in 1917, several forest scientists and foresters became leading politicians, marking a new degree of support for the forest industries in Finland. Several politicians with a strong forestry background eventually served as prime minister or in other leading functions. The same year as Finnish independence, the Forest Research Institute was established. The Forest Research Institute would play a leading role in the development of forest policies following independence.

3.2.3 Human capital in Finland and Sweden

Human capital played an important role for the establishment of the sawmill industry in both Finland and Sweden as it constituted a major source of technology transfer. Norway had been the major exporter of wood to Great Britain up until the 1840s. However, the increased British demand in the 1850s led to Norwegian supply problems as primal forests declined. This decline led many Norwegian businesses to relocate to Sweden, taking with them superior sawmill technology and business knowhow. The inflow of Norwegian human capital thereby created a more productive Swedish sawmill sector (Söderlund, 1951). For Finland, there was an increase in the influx of Norwegian and Swedish businesses in the 1870s as Finnish regulation on sawmills were increasingly relaxed. This led to a technological transfer for Finland, in similar fashion as it had been for Sweden two decades earlier (Palo, 2004). This pattern of technological upgrading has some similarities to the Flying Geese Pattern of development in which maturing, industries relocate in accordance to shifting comparative advantages.

In Sweden, there was a strong connection between the forestry sector and research institutions. Industrialised forestry, which had as its aim to keep a sustainable high yield, was a priority for leading members within the industry. A forestry college was established as early as 1830, while a modern state forestry administration was in place in 1838 (Palo, 2004). Ahlström (1992; 1993) argues that the successful innovators and entrepreneurs illustrate that there already existed a network among the technical institutions, industry and the government by the middle of the 19th century, and this contributed significantly to the success of Swedish industrialisation. The networks were of central importance for the development of industry, especially after the 1880s, when products became more differentiated and higher value-added products became increasingly more important (Blomström and Kokko, 2006).

In Finland, research institutions developed later than in Sweden. Michelsen (1995) has written at length about the problems facing not only the sawmill sector but also state institutions that attempted to support the forestry industry. The State Forestry Board was concerned with establishing a professional set of foresters to oversee and administer the forests, but was for the most part on the receiving end of critics opposing a professional forest administration (Palo, 2004). The Evo Forestry Institute was established in 1858 to be a source of forestry education and research, but because of a lack of funding and lack of political support, it was not able to fill any effective role before the 1880s.[128]

4. Indonesia and Malaysia 1960-2010

4.1 Resource-Led Growth in Indonesia and Malaysia

Indonesia and Malaysia both increased their economic growth rates starting in 1970, which is widely regarded as the take-off for both countries. Malaysian economic growth (growth rate of GDP per capita 1990 Int. GK$), increased from 1.4 % for 1950-1970, to 4.6 % for 1970-1990, and decreasing slightly to 3.4 % for 1990-2010. Indonesia’s growth increased from 2.1 % for 1950-1970, to 3.6 % for 1970-1990, and to 3.2 % for 1990-2010 (all figures from Bolt and van Zanden, 2013). As in the Finland/Sweden case, living standards in Malaysia were higher than in Indonesia in 1970, and the subsequent growth rate was higher in Malaysia, meaning that there was a divergence in living standards. GDP per capita in Malaysia was 2.1 times the level of Indonesia’s in 2010.

In both countries, natural resources have contributed to economic growth. This is consistent with results (3-1) and (4-1). Result (3-1), for Indonesia, shows that a 1 % increase in the growth rate of value-added of the

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[128] Following independence, Finland was quick to increase the support for forestry. In 1917, the Forest Research Institute and the Society of Forest Sciences were established (Palo and Uusivuoriu, 1999, Palo, 2004). By 1922, Finland had five state schools teaching elementary forestry, which in the early 1920s educated 70-80 forestry foremen a year (Heikinheimo and Saari, 1922). In 1921, the Finnish Sawmills Industries Schools, with a mixture of state and private funding, began teaching. In 1908, higher education in forestry was transferred from the Evo Forestry Institute to the University of Helsinki. A higher education in forestry would take 3-4 years, which included theoretical studies and practice in the forests (Heikinheimo and Saari, 1922).

resource sectors increased the growth rate of non-resource GDP by 0.643 %. Result (4-1) shows that the similar figure for Malaysia was 0.208 %. However, the Malaysia results are only significant at the 10 % level of significance. The results do indicate that the natural resource sectors contributed to GDP in excess of their own value-added. These results are broadly similar to the ones for Finland and Sweden.

Table 3: First-Difference Results for Indonesia 1970-2005

	(3-1) Δ ln(GDP-NR)	(3-2) Δ ln(GDP per capita)	(3-3) Δ ln([GDP–NR] per capita)
Δ ln(NR)	0.643**		
	(2.48)		
Δ (NR/GDP)		-0.00902	-0.0291***
		(-1.20)	(-4.13)
Δ ln(Gov.consum)	-0.0671		
	(-0.82)		
Δ ln(Trade)	-0.145*		
	(-1.90)		
Δ ln(Investments)	0.368***		
	(3.72)		
Δ (Gov.consum /GDP)		-0.00765	-0.00649
		(-0.88)	(-0.81)
Δ (Trade/GDP)		-0.00162	-0.00128
		(-1.28)	(-1.13)
Δ (Investments/GDP)		0.00738*	0.00627
		(1.80)	(1.63)
Observations	35	35	35
R^2	0.615	0.399	0.694
Adjusted R^2	0.564	0.319	0.653
Durbin Watson test statistic	1.751	1.632	1.581

Note: t statistics in parentheses based on heteroskedasticity-robust standard errors with * Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels indicating no autocorrelation.

Table 4: First-Difference Results for Malaysia 1970-2005

	(4-1) Δ ln(GDP-NR)	(4-2) Δ ln(GDP per capita)	(4-3) Δ ln([GDP–NR] per capita)
Δ ln(NR)	0.208*		
	(1.89)		
Δ (NR/GDP)		-0.00205	-0.0171***
		(-0.37)	(-3.15)
Δ ln(Gov.consum)	0.00817		
	(0.14)		
Δ ln(Trade)	0.179***		
	(2.94)		
Δ ln(Investments)	0.197***		
	(5.04)		
Δ (Gov.consum /GDP)		-0.0129***	-0.0127***
		(-3.35)	(-3.25)
Δ (Trade/GDP)		-0.000117	-0.000139
		(-0.23)	(-0.29)
Δ (Investments/GDP)		0.00617***	0.00610***
		(3.44)	(3.58)
Observations	35	35	35
R^2	0.780	0.611	0.751
Adjusted R^2	0.751	0.559	0.718
Durbin Watson test statistic	1.965	2.466	2.436

Note: t statistics in parentheses based on heteroskedasticity-robust standard errors with * Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels indicating no autocorrelation.

One notable difference between Finland/Sweden and Indonesia/Malaysia has been the nature of economic growth. Most economists believe that Indonesia and Malaysia are two resource-abundant countries that have experienced high growth, rather than having experienced resource-led growth, at least since 1985 (Jomo *et al*. 1999, Hill, 2000). These views are consistent with results (3-2) and (4-2) which show that the coefficient of the change in resource dependence is not statistically significant (and negative), indicating that natural resources might have played a lesser role in Indonesia/Malaysia compared to Finland/Sweden. These views are also consistent with figure 5 showing a declining share of natural resource exports as a share of exports over time. The major difference between Finland/Sweden and Indonesia/Malaysia is the composition of exports. In Finland/Sweden, resource-based manufacturing exports took over when natural resource exports declined. However, in Indonesia/Malaysia the increase in exports and economic growth from 1985 was led by manufacturing exports that were not resource-based, such as textiles and electronics (Hill, 2000, Felker *et al*., 2002).

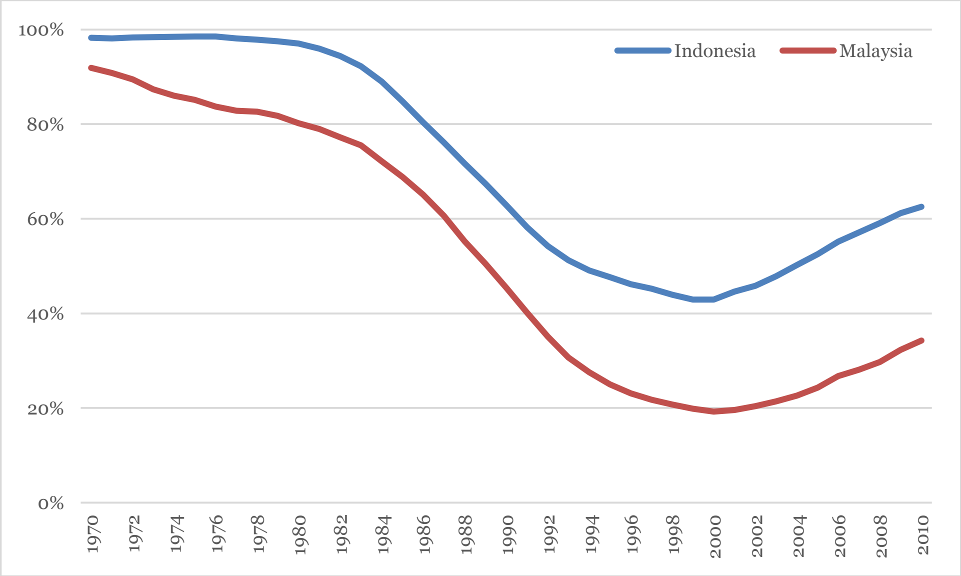

Figure 5: Natural Resource Exports as a Share of Merchandise Exports 1970-2010 (Five-Year Moving Average)
Source: Calculated using figures from WDI (2014). Natural resource exports are comprised of (i) Agricultural raw materials (SITC section 2 crude materials except fuels excluding divisions 22, 27; crude fertilizers and minerals excluding coal, petroleum, and precious stones, and 28 metalliferous ores and scrap); (ii) Food (SITC sections 0 food and live animals, 1 beverages and tobacco, and 4 animal and vegetable oils and fats and SITC division 22 oil seeds, oil nuts, and oil kernels) (iii) Fuels (SITC section 3 mineral fuels); and (iv) ores and metals (SITC section 27 crude fertilizers and crude minerals; 28 metalliferous ores, scrap; and 68 non-ferrous metals).

Still, results (3-1) and (4-1) indicated that in absolute terms, natural resource value-added still contributed to GDP. The natural resource sectors did in fact remain more important than the export statistics would lead one to believe for four reasons. First, the high degree of local ownership played a role. Much of the export expansion in labour-intensive manufacturing exports came through foreign direct investments, with relatively little technological spillover to the Malaysian economy. Ownership in the natural resource sectors is primarily domestic; implying that these sectors have a larger effect on the domestic economy than competing businesses owned by foreigners. Second, an expansion in labour-intensive exports would have been more difficult without the initial growth surge in the natural resource sectors. The increased economic growth allowed for more investments in infrastructure and human capital, which benefited the later increase in labour-intensive exports. Third, since the East Asian financial and economic crises in 1997/1998, there has been an increase in the share of exports of natural resource products or manufacturing products intensive in natural resources following increased demand from China. Finally, the natural resource sectors constitute an important backbone for both economies through the entire period, lifting rural people out of poverty and providing the export income that finances the imports that are important for technological progress. Increased technological progress has in turn been vital for economic growth.

In the case of Indonesia and Malaysia, the paper specifically focuses on two natural resources: oil and palm oil. The first reason is that these two natural resources are highly important for both countries, see figure 6.[129] The second reason is to allow for a better comparison between the two countries and give an indication of how similar resources affect different economies. In addition, both oil and palm oil are well-established products that are affected by international prices. Finally, palm oil is representative of how other natural resource sectors (such as cocoa, forestry and natural rubber) were promoted in both countries.

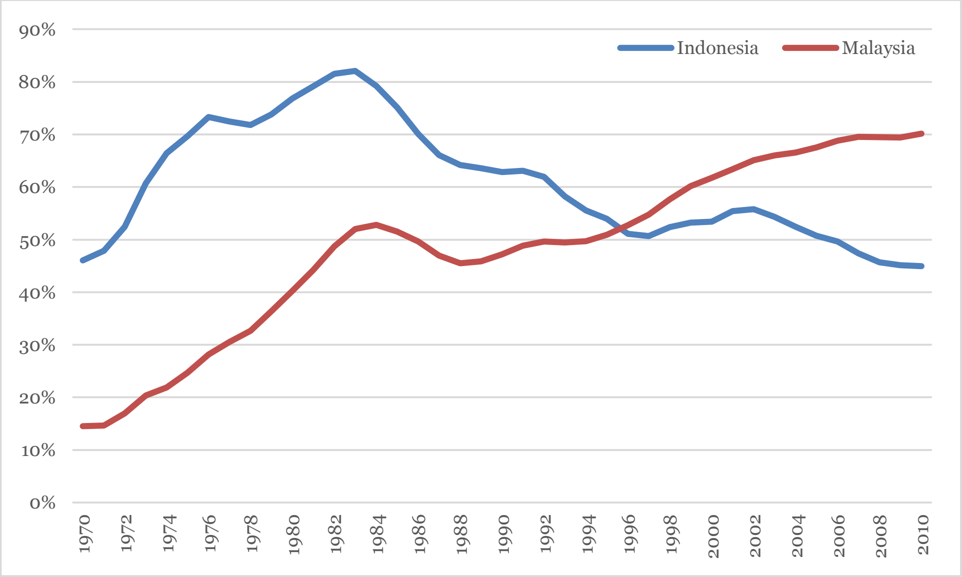

Figure 6: Oil and Palm Oil as a Share of Total Natural Resource Exports 1970-2010 (Five-Year Moving Average)
Source: COMTRADE (2013)

Some degree of Dutch disease effects might be present, as indicated by results (3-3) and (4-3). Result (3-3) shows that for Indonesia, a one percentage point increase in the change in resource dependence decreased the growth rate of non-resource GDP per capita by 2.91 %. The similar figure for Malaysia in results (4-3) was a decrease of 1.71 %. Both coefficients were statistically significant. The interpretation is the same as for the Finland/Sweden case.

The robustness checks for all three specifications yielded similar results as when using first differences. Results with the de-trended variables are shown in appendices 2 and 3. Natural resource value-added is positively and statistically significantly correlated with non-resource GDP. The results that natural resource dependence is not correlated with GDP per capita still holds for the de-trended analysis. Finally, natural resource dependence is negatively correlated with non-resource GDP per capita. As the evidence when using de-trended data is similar as for first-differences, the results are more robust.

As mentioned, Malaysia is more ‘successful’ than Indonesia for similar reasons as to why Sweden outperformed Finland. GDP per capita in Indonesia and Malaysia has been diverging, and this in part is explained by two differences in the resource sectors.

First, Malaysia is a more efficient resource-producing country. The contrast between the Malaysian state-owned company Petronas and its Indonesian counterpart Pertamina exemplifies this difference. Since its establishment in 1974, Petronas has expanded into upstream activities as well as some downstream projects.

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[129] For Malaysia, palm oil and oil constituted more than 50 % of total natural resource exports in 18 of 41 years and more than 40 % in 29 of 41 years in the period 1970-2010. For Indonesia, palm oil and oil constituted more than 50 % of total natural resource exports in 33 of 41 years.

From the 1990s and onwards, the company became an important international oil company with overseas operations in 35 countries. They also invested in shipping and became the world's largest single owner-operator of LNG vessels (Von der Mehden and Troner, 2007). Petronas' growing market share and ability to enter new markets give the company a reputation of being a relatively efficient oil company.

In contrast, Pertamina, established through a merger in 1968, has experienced little technological learning from foreign companies, resulting in high exploration costs for oil. Following the transition to democracy in 1998, Pertamina lost its monopoly power in upstream activities in the domestic Indonesian market. Since the company lacked a competitive environment prior to 1998, it was unable to compete with foreign competitors coming into the Indonesian market, among them Petronas. The low efficiency and, thus, lack of competiveness has resulted in decreasing market shares and political influence (Hertzmark, 2007). Pertamina is an example of how excessive protection and a lack of incentives for technological upgrading can hurt a company long-term when the economic environment changes.

Second, Malaysia was able to generate more extensive linkages from the natural resource sectors to manufacturing sectors. In effect, Malaysia managed to achieve a larger extent of resource-based industrialisation than Indonesia. This difference is most adequately illustrated in the palm oil sector. Malaysia established a refinery sector in the 1970s, and developed linkages to other industries in the 1980s (Rasiah and Shahrin, 2006). Figure 7 illustrates the expansion of Malaysian exports and the share of exports that are of the processed palm oil variety. Industrial policies were used to increase value-added and expand linkages to other sectors in the economy. There is a near consensus that these linkages would not have been developed by the market mechanism alone (Gopal, 2001).

The Indonesian palm oil sector lagged behind the Malaysian until recent years in terms of both production and exports. The reason lies in the orientation of the palm oil sector. While Malaysia promoted an export-oriented strategy, the Indonesian palm oil sector pursued an import substitution strategy until the early 1990s. In 1994, the Indonesian palm oil sector started to pursue a similar export-oriented strategy as Malaysia and exports has since expanded greatly as illustrated in figure 7. However, the share of palm oil exported that is processed is far lower than in Malaysia, and the linkages of the Indonesian palm oil sector is weaker than in Malaysia. The reason, as explained below, is probably the less efficient industrial policy in Indonesia.

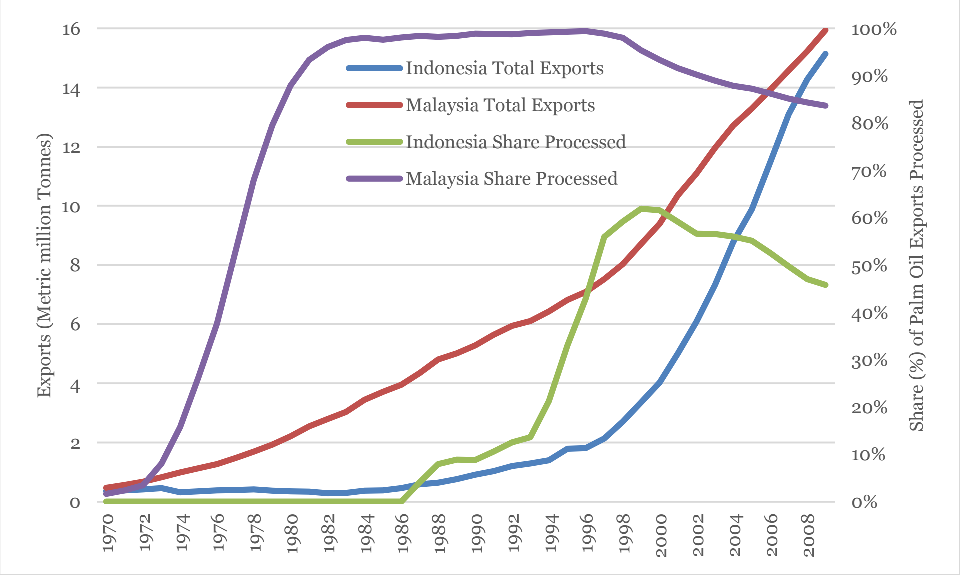

Figure 7: Malaysia and Indonesia Palm Oil Exports 1970-2009 (Five-Year Moving Average)
Source: Gopal (2001); MPOB (2011); and COMTRADE (2013)

4.2 Determinants of Resource-Led Growth

4.2.1 Institutions in Indonesia and Malaysia

Compared to Indonesia, Malaysian institutions are more suited for an expansion in the natural resource sectors. The difference in property rights and ownership structure in the palm oil sector illustrates this difference. In Malaysia, private ownership was strongly encouraged. This included investment incentives and replanting grants that provided incentives for private investments in palm oil plantations. Most of the expansion in the palm oil sector subsequently came through increased production from these private plantations. Investments both opened up new land and led to existing rubber plantations shifting to palm oil cultivation.

The government was highly supportive in providing public goods, and supporting the sector through industrial policies (Pletcher, 1990). The government either owned or supported a number of institutions. To increase the quality of palm oil produced, the government established the Palm Oil Regulation and Licencing Agency (PORLA) in 1975. To promote palm oil research and development, the government established the Palm Oil Research Institute of Malaysia (PORIM) in 1979. In 1998, PORLA and PORIM merged to form the Malaysian Palm Oil Board (MPOB). Another example is the Malaysian Palm Oil Council (MPOC), which has the task of promoting the general interests of the palm oil sector abroad, including its image. In addition, the state also produced palm oil through so-called government schemes. These schemes gave landless people access to land and organised many small land plots as a collective to exploit economies-of-scale. Individual farmers were allowed to keep the profit from their sales, with the collective being responsible for tasks involving economies-of-scale. The government in Malaysia was therefore supportive and complemented the private sector.

In contrast, the Indonesia government intervention hindered the palm oil sector prior to 1988. Private ownership was limited until the government came to regard the palm oil sector as a strategic sector. From 1968 to 1988, the growth in the palm oil sector was led by direct government investments through the so-called Perseroan Terbatas Perkebunan (PTP). The government, in an effort to control inflation, controlled palm oil prices and restricted exports.[130] From 1988 and onwards, there was a gradual shift in policies. Trade restrictions on palm oil were removed in 1991 and 1992 was the first year that private estates produced more than the state-owned plantations. From 1994 onwards, the government increasingly played a supporting role in a similar capacity as in Malaysia, with growth in the palm oil sector primarily coming through private plantations.

Another difference is the stronger rule of law in Malaysia, which is related to the independence of business. The best example is for the Malaysian state-owned oil company, Petronas. The company was relatively independent of the government and focused mainly on its core business activities. This included professional management, which focused on expanding the company into new business areas as Malaysian oil reserves were declining. Despite some exceptions, such as the Petronas Twin Towers and a 'new capital' in Putra Jaya, government involvement was generally low (Von der Mehden and Troner, 2007). Some of these government ventures were in fact profitable for Petronas and the company did not always do the governments' bidding. Petronas for instance refused to bail out the failing Malaysian airline MAS.

However, the Indonesian state-owned company Pertamina experienced a long-term decline since the 1980s following massive government intervention. The company came under increasing control of President Suharto, his bureaucrats and his family members (Hertzmark, 2007). With a weak legal system, there was little to stop the president from using the company as a source of finance for various projects. While the Malaysian counterpart was protected by laws, and was able to develop professional management, Pertamina increasingly

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[130] Controlling inflation through controlling the prices of agricultural products is common in Indonesia and many other developing countries. The Indonesian government successfully managed to control inflation by keeping rice prices low, as rice constitutes 68 % of food (Hill, 2000). However, cooking oil only constituted 0.4 % of household expenses (4 % for the poor), so the arguments for controlling palm oil prices based on inflation were weak (Larson, 1996). The regulations were complex, and by the end of the 1980s, there were four separate prices administered. According to Tomich and Mawardi (1995) these regulations harmed both consumers and producers.

became prone to corruption, which led to many problems in the post-1998 era. These problems included a lack of competiveness due to high costs and a declining market share in the Indonesian market following liberalisation.

The difference in institutional quality between Indonesia and Malaysia is more general. Malaysia has relatively well-developed institutions, with well-defined property rights, a clear legal framework, rule-of-law and a functioning bureaucracy (Kanapathy, 2001). In comparison, Indonesia's institutions were not as well developed, property rights were not as strong, rule-of-law and the legal framework were weak because the judiciary was marginalised, and the bureaucracy was weak as there was a shortage of skilled personnel (Hofman *et al.*, 2004). Institutions are difficult to measure, but there is a near consensus that Malaysia's institutions have been more conducive to economic growth.[131]

4.2.2 Economic Policy in Indonesia and Malaysia

While Indonesian and Malaysian economic policy in general was supportive in the provision of public goods, state support for the resource sectors differed. This difference is best illustrated in the palm oil refinery sector, in which Malaysia pursued an active industrial policy. The industrial policy was conducted through investment tax credits, export allowances and export duties on crude palm oil and duty exemptions on processed palm oil (Rasiah and Shahrin, 2006). The export allowance in 1973 put an export tax on crude palm oil, but the duty was exempted for processed palm oil, thereby increasing the incentives to process crude palm oil locally. These measures allowed for increased investments in the Malaysian palm oil plantations and refineries. There is a near consensus that the palm oil refineries would not have been established without the strong degree of state support (Gopal, 2001, Rasiah and Shahrin, 2006).

Also in terms of ownership, Malaysia pursued a rather active policy. In 1970, most of the palm oil plantations were foreign-owned, and these protested against the government policies to move into the higher value-added processed palm oil, as the foreign-owned plantations preferred to have their palm oil processed in Europe. The Malaysian government responded with an aggressive buy-out of foreign plantations through stock market operations on the London Stock Exchange and selling them to domestic owners willing to support the government's plans.

Indonesian support for the higher value-added palm oil segment of the palm oil sector was lacking prior to 1988. Following 1988, and partly caused by the spectacular success of Malaysia, Indonesian policies shifted. In 1994, the government attempted to promote the refinery sector through an export tax. However, Rasiah and Shahrin (2006) claim that these efforts did not succeed in the same manner as in Malaysia as the Indonesian export tax was inconsistent and did not provide the same incentives as it had done in Malaysia. In Malaysia, incentives for investments and an export on crude palm oil (CPO) meant that profits for investments in palm oil refineries was potentially high. In Indonesia, no similar investment incentives followed the export tax and the export tax targeted not only CPO but also processed palm oil. In addition, there was uncertainty regarding the willingness of the Indonesian government to support the industry as policy changes have been numerous, meaning that potential profits of investing in palm oil refineries was uncertain. This meant that while investments in the refinery sector increased in Malaysia, Indonesia did not see a similar surge.

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[131] Quantitative assessments of institutions are difficult at best as these by definition are not measurable. However, some indicators might tell something about the outcome. According to the Corruption Perception Index Indonesia scores a 32 out of a 100 points which means is the Indonesia 118th 'cleanest' out of 176 countries; while Malaysia compares more favourably with a score of 49, which means it is the 54th 'cleanest' country (Transparancy International, 2014). Indonesia also ranks poorly in the World Bank's 'Doing Business' indicators as it ranks as the 128th best country (out of 185) in the world to do business WDI (2014). Malaysia ranks as the 12th best country in the world to do business in. The two main contributing factors were the easiness to get credit, and the high protection for investors. The general perception is that Malaysia has better institutions to support economic growth than does Indonesia.

4.2.3 Human capital in Indonesia and Malaysia

Malaysia has a more human capital-intensive resource sector and conducts more research than Indonesia. One example is the case of Petronas. The company was intent on learning to produce oil themselves, rather than being reliant on foreign technology and knowledge. However, there was a severe shortage of engineers during the 1970s. Petronas launched several scholarships to increase the number of students of Malay origin in engineering and related fields (Von der Mehden and Troner, 2007). In 1997, Petronas established its own engineering university, Universiti Teknologi Petronas. The focus on educating engineers meant that learning and productivity increased in the long run. In the Indonesian oil sector, no such process took place for Pertamina. As mentioned before, the lack of a competitive environment and a lack of focus on technological learning in the oil sector made Pertamina a less efficient oil company compared to Petronas.

Another example is in the palm oil sector. The Malaysian Palm Oil Board conducts applied research on problems facing the palm oil industry. In addition, the Malaysian Agricultural Research and Development Institute educates an increasing number of students within agricultural studies. The focus of Malaysian agricultural policies was to promote increased productivity and allow the most profitable sectors such as the palm oil sector to export their products. Consequently, the level of full-time employees conducting agricultural research per 1000 person active in agriculture has been steadily increasing from 1985 until 2005 as seen in table 5.

The Indonesian palm oil sector has not attained the same level of human capital and research. Following the Malaysian model, Indonesia established the Indonesian Oil Palm Research Institute (IOPRI). However, the quality of the support and the research conducted was far lower than in Malaysia, as private estates in Indonesia view the research conducted by the IOPRI to be more directed towards government schemes and smallholders (Rasiah and Shahrin, 2006). One of the main obstacles for the IOPRI is the lack of qualified post-graduate personnel. Table 5 shows that the level of personnel conducting agricultural research in Indonesia is far from the Malaysian level, and has virtually been stagnant from 1985 to 2005.

Table 5: Agricultural research employment per 1000 persons active in agriculture (five-year moving average)

	1985	1995	2005*
Indonesia	0.08	0.11	0.10
Malaysia	0.44	0.55	0.80

Source: ASTI (2013) for agriculture research data; FAO (2014) for active population in agriculture

Agricultural research is measured as the total number of full-time equivalent (FTE) agricultural research staff in the government, higher education and non-profit sector combined

*For Indonesia the 2005 figure is only for 2003

5. Comparison

5.1 Similarities

There are numerous similarities between the two late 19th and the two late 20th century case studies. First, important natural resource sectors are correlated with non-resource production. This implies that the natural resource sectors were important for economic growth. Table 6 summarises the results for the first difference analysis, which are similar to the de-trended results presented in appendix 2 and 3. Finland is the exception, but this correlation is positive for the forestry sector. The absolute effects of the natural resources might therefore have been similar for all four countries.

Sweden increased its productivity, expanded its linkages and was able to generate major innovations. The value-added of forestry and the related industries increased over time, and is still an important part of both the Finnish and the Swedish economy. In fact, many of the most successful companies started in the forestry sector, and have since expanded into other areas.

In Malaysia, the palm oil industry also increased its productivity, expanded its linkages and had to become a main innovator within palm oil. The success of the Malaysian palm oil sector is to a large extent caused by supportive government policies which provided incentives not only for expanding production but also to increase research and the value-added content of palm oil. Many of the applications that palm oil is used for today were first developed by Malaysian companies that managed to expand the potential usages of palm oil.

Table 6: Summary of the main correlations from the first-difference specifications (tables 1, 2, 3 and 4)

Time period	Country	Natural resource sectors value-added on growth in non-resource GDP	Share of natural resource sectors (of GDP) on growth in GDP per capita	Share of natural resource sectors (of GDP) on growth in non-resource GDP per capita
1860-1910	Finland	Negative (Positive for forestry)	Positive	Negative
	Sweden	Positive	Positive	Not significant (Negative)
1970-2005	Indonesia	Positive	Not significant (Negative)	Negative
	Malaysia	Positive	Not significant (Negative)	Negative

A second similarity is that the share of natural resource value-added is negatively correlated with non-resource GDP. The results are summarized in table 6 for first differences, and are similar as for the de-trended results in appendices 2 and 3. This could be a potential Dutch disease effect, as the relative share of production factors affects the rest of the economy adversely. This effect is logical as a slower expansion in the non-resource sectors (than in the resource sectors) will automatically allow the relative share of the resource sector to increase.

A third similarity is the role of the determinants in both centuries. Sweden and Malaysia were more successful, and their institutions, economic policy and human capital were all more conducive to growth than in Finland and Indonesia.

The obvious question is how generalizable these results are to other resource-abundant developing countries. Indonesia and Malaysia are unusually blessed with natural resources, thereby casting doubts on which policy implications can be taken from studying these countries. There are especially three arguments for why Indonesia and Malaysia are not representative case studies: (i) The presence of oil cannot be ‘created’ as it is given by nature; (ii) Both countries are blessed with a near optimal climate for palm oil; and (iii) The variety of natural resources, especially for Malaysia, was large.

However, none of these make the Indonesia and Malaysia case study less relevant. First, oil production has in fact been in decline in both countries since the mid-1980s, and Indonesia became the first country ever to withdraw from OPEC in 2008. Oil, though important, has not been as abundant as in many other countries.[132]

Second, the potential for palm oil production is probably higher in Southeast Asia than most other regions in the world. However, there are other high-value crops for which there is a high demand, and for which linkages can be developed. As mentioned, Malaysia had to develop many of the linkages that are important to the industry today. The potential for other countries to have a similar strategy is plausible. Cramer (1999), for instance, discusses these possibilities against the backdrop of the Mozambican cashew nut industry.

Finally, the variety of natural resources has probably benefited Malaysia, as price shocks became less of an issue. Lederman and Maloney (2006) indicated that a more diverse export structure was beneficial. However, a number of successful resource-abundant countries have managed to cope with a highly concentrated export structure such as Botswana (diamonds), Chile (copper) and Norway (oil).

5.2 Differences

The differences are also numerous. First, resource dependence is positively correlated with GDP per capita in the late 19th century, but not in the late 20th century. The summary of the first-difference results is shown in

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[132] In fact, in per capita terms neither Indonesia nor Malaysia are that resource-abundant in oil. Using figures from Haber and Menaldo (2011) on the value oil of income per capita in 2006, Malaysia ranked 22nd out of 136; while Indonesia ranked 41st. Both countries lagged Canada, Denmark, Ecuador, Mexico and the United Kingdom when oil is measured per capita.

table 6, with the de-trended results in appendices 2 and 3 showing similar results. It means that natural resources might have been more important for economic growth for Finland and Sweden than they were for Indonesia and Malaysia.

One potential cause might be that the driver of economic growth, technological progress, is different in the two centuries. For countries far from the technological frontier, the primary driver behind technological progress is learning of already existing technologies from advanced economies. For a country close to or even at the technological frontier, new technologies have to be invented and applied, meaning that invention and innovation become the primary drivers behind technological progress.[133] In 1860, the technological leader was Great Britain, with Finland having 34 % of Great Britain's GDP per capita, while Sweden had 43 % (all figures are based on Bolt and van Zanden, 2013). In 1960, the technological leader was the US, with Indonesia having 9 % of US's GDP per capita while Malaysia had 14 %. As Finland/Sweden were closer to the frontier than Indonesia/Malaysia, innovation likely became an important source of technological progress. In contrast, Indonesia/Malaysia can rely longer on learning existing technologies as the gap is larger.

In Indonesia and Malaysia, foreign direct investments (FDI) was one of the main mechanisms for technological learning. There is little doubt that much of the economic growth in Indonesia/Malaysia has been driven by an increase from export-processing zones from mainly foreign-owned companies. It is therefore plausible that natural resources played a lesser relative role in generating economic growth in resource-abundant developing countries.

A second difference, emphasised by De Long and Williamson (1994), are transportation costs. As transport costs were higher in the 19th century, having natural resources close to markets or close to where they were to be processed was more important. However, transport costs are still sufficiently high to affect trade. In addition, trade barriers can increase transaction costs a lot more than transportation can. This is exemplified by the disintegration of world trade in the interwar period (1918-1939), which had less to do with transportation costs and more with trade barriers.

A third, and potentially more important difference, is the existence of entry barriers for resource-based manufacturing industries in the late 20th century. Sweden established itself in the international sawmill industry mostly without industrial policy. As mentioned, the paper industry in contrast was dependent on industrial policy for its establishment (Glete, 1989, Bohlin, 2005).

However, the Malaysian industrial policy was far more extensive than that of Sweden. The establishment of the palm oil refinery sector involved investment incentives, export taxes and reducing foreign ownership of palm oil plantations. The cause for the need for more industrial policy are the higher entry barriers in the international market in the late 20th century compared to the late 19th century.

There are numerous reasons for these higher barriers. First, food-processing companies, especially from advanced economies, were already present in 1960. Competition was therefore fiercer from the outset. Second, the technology lag was huge. Already present food processing companies had superior technology and had already achieved considerable economies-of-scale prior to Malaysia's entry. Finally, many companies received state support in various ways. In fact, the Malaysian government had to use an active industrial policy themselves for Malaysian refineries to be willing to establish themselves. Cramer (1999) and Gopal (2001) have made good overviews regarding the challenges developing countries face in establishing themselves in the food processing market.

A fourth difference is the composition of world trade as trade in primary goods is lower in the late 20th century compared to the late 19th century. In 1910, primary products accounted for around 62.5 % of world

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[133] The theoretical underpinning for the relationship of learning and innovation can be found in relationship to a country's 'absorptive capacity'. See for instance Gerschenkron (1962), Nelson and Phelps (1966), Ambramovitz (1986) and Benhabib and Spiegel (1994).

merchandise trade in value terms (Kenwood and Lougheed, 2002). In 2010, the comparable figure was around 35 % (WTO, 2014). This emphasises the increasing role of manufacturing in the 20th century. These figures do not include services, which also have grown considerably in the latter period. In relative terms, the value of the trade in natural resources is less than a century ago, especially in their unprocessed form.[134]

Another emerging trend is the splitting of the production process across countries, meaning that the trade in intermediate goods is increasing. Whereas this pattern makes international trade qualitatively different, it is less clear how these patterns affect the potential of resource-abundant countries.

Conclusion

The present paper sets out to answer the question of whether natural resources affect the economy in the same way today as in the past. This paper is limited as it only assesses two case studies from each period. Still, there were some interesting similarities and differences between these countries. Finland/Sweden in the 19th century and Indonesia/Malaysia in the 20th century did in general behave as Wright and Czelusta (2006) predicted. This meant that successful natural resource sectors were dependent on: (i) Institutions; (ii) State support; and (iii) Human capital. In addition, the countries that succeeded the most in promoting their natural resource sectors, Malaysia and Sweden, managed to improve productivity and the linkages between the natural resource sectors to other sectors in the economy.

Still, natural resources played a lesser role in the economic growth process for Indonesia/Malaysia than they did for Finland/Sweden. I believe this effect is largely explained by the catch-up potential to the technological leader. Manufacturing exports financed by foreign direct investment was highly important for both Indonesia and Malaysia, and clearly more so than for Finland and Sweden. In addition, the world market has changed, as primary commodities constitute a lesser share of world trade compared to manufacturing, which might limit the possibility for resource-led growth for some countries.

This study only focused on four countries, and its conclusions might therefore not be generalizable. Potential future research can explore the differences between periods even more extensively, using more advanced time-series techniques and increase the coverage of countries to test the nature of resource-led growth in the two periods.

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[134] There is a danger of thinking of manufacturing exports as panacea for high growth. However, Norway, ranked as number 1 on the Human Development Index, is a primary exporting country with manufacturing products constituting only 18.2 % of total merchandise exports (UNDP, 2013, WDI, 2014).

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Appendix 1: Sources and descriptive statistics

Table A1.1: Sources for the regressions analysis

Variable	Finland	Sweden	Indonesia	Malaysia
GDP per capita	Hjerppe (1989)	Schön and Krantz (2012)	WDI (2014)	WDI (2014)
Natural resource value-added	Smits *et al.* (2009)	Smits *et al.* (2009)	Timmer and de Vries (2009)	Timmer and de Vries (2009)
Investments	Hjerppe (1989)	Schön and Krantz (2012)	UNSD (2014)	UNSD (2014)
Imports and exports	Hjerppe (1989)	Schön and Krantz (2012)	UNSD (2014)	UNSD (2014)
Government consumption	Hjerppe (1989)	Schön and Krantz (2012)	UNSD (2014)	UNSD (2014)

Table A1.2: Descriptive statistics Finland 1860-1910

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Δ ln(GDP-NR)	50	.0335326	.076735	-.1570829	.230495
Δ ln(GDP)	50	.0137337	.0386899	-.0790038	.1483648
Δ ln(NR)	50	.0030199	.0749202	-.1860676	.2198043
Δ ln(Forestry)	50	.0063122	.0494946	-.1396259	.1187102
Δ ln(NR-Forestry)	50	.0017858	.1001792	-.2474234	.2895837
Δ (NR/GDP)	50	-.0066611	.0292354	-.0768266	.0496344
Δ(Government Consumption/GDP)	50	.0003418	.0041926	-.0107005	.0113832
Δ ((Exports + Imports)/GDP)	50	.0059631	.0300757	-.0689646	.0763379
Δ (Investments/GDP)	50	.0000232	.0084099	-.0170905	.0231342

Table A1.3: Descriptive statistics Sweden 1860-1910

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Δ ln(GDP-NR)	50	.0180797	.0387493	-.0779381	.1036654
Δ ln(GDP)	50	.0147196	.0382944	-.0940337	.1200318
Δ ln(NR)	50	.0071303	.0610437	-.1197047	.1439342
Δ (NR/GDP)	50	-.0023167	.0130605	-.0283516	.0313216
Δ(Government Consumption/GDP)	50	-.0004057	.0044638	-.0103076	.0084618
Δ ((Exports + Imports)/GDP)	50	.0050672	.0202967	-.0472478	.0531251
Δ (Investments/GDP)	50	.0005169	.0107275	-.0204619	.0290598

Table A1.4: Descriptive statistics Indonesia 1970-2005

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Δ ln(GDP-NR)	35	.0559848	.0515748	-.1985755	.1171036
Δ ln(GDP)	35	.0383673	.0389388	-.1553111	.0685744
Δ ln(NR)	35	.0126921	.0281979	-.0623341	.0905967
Δ (NR/GDP)	35	-.0099917	.0111086	-.0305661	.0315186
Δ(Government Consumption/GDP)	35	-.0000361	.0085324	-.0250181	.0187911
Δ ((Exports + Imports)/GDP)	35	.0104264	.094384	-.3003248	.3769682
Δ (Investments/GDP)	35	.0031003	.0160118	-.0443933	.0324149

Table A1.5: Descriptive statistics Malaysia 1970-2005

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Δ ln(GDP-NR)	35	.0539778	.0464916	-.1102352	.119112
Δ ln(GDP)	35	.0397158	.0376803	-.1013174	.086484
Δ ln(NR)	35	.004994	.0356957	-.0605021	.104465
Δ (NR/GDP)	35	-.0096314	.0102041	-.0328989	.010083
Δ(Government Consumption/GDP)	35	-.000993	.0129424	-.0325649	.0234509
Δ ((Exports + Imports)/GDP)	35	.0378062	.0863878	-.1637959	.2205348
Δ (Investments/GDP)	35	.0014349	.0421918	-.1752145	.0532511

Appendix 2: De-trending using a linear trend and regressing with fGLS

Table A2.1: Finland linear de-trended GLS

	(A2.1.1a) ln non-resource GDP (detrended)	(A2.1.1b) ln non-resource GDP (detrended)	(A2.1.2) ln GDP per capita (detrended)	(A2.1.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	-0.757***			
	(-8.69)			
ln (Forestry) (detrended)		0.411***		
		(5.12)		
ln (NR - Forestry) (detrended)		-0.607***		
		(-11.05)		
NR/GDP (detrended)			0.00758***	-0.0255***
			(5.26)	(-16.87)
ln (Gov.consum.) (detrended)	0.0110	-0.0243		
	(0.30)	(-0.98)		
ln (Trade) (detrended)	0.422***	0.231***		
	(7.12)	(4.80)		
ln (Investments) (detrended)	0.0381**	0.0412***		
	(2.46)	(3.67)		
Gov.consum./GDP (detrended)			-0.0411***	-0.0464***
			(-3.47)	(-5.00)
Trade/GDP (detrended)			0.000390	0.000925
			(0.26)	(0.61)
Investments/GDP (detrended)			0.00190	0.000216
			(0.48)	(0.05)
Observations	51	51	51	51
R^2	0.729	0.857	0.656	0.902
Adjusted R^2	0.705	0.841	0.626	0.894
Durbin Watson test statistic	1.715541	1.997795	1.841730	1.837487

Note: All results were obtained using feasible GLS (Prais-Winsten regression). t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. None of the Durbin-Watson results are below the lower bound.

Table A2.2: Sweden linear de-trended GLS

	(A2.2.1) ln non-resource GDP (detrended)	(A2.2.2) ln GDP per capita (detrended)	(A2.2.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	0.220***		
	(3.10)		
NR/GDP (detrended)		0.00666*	-0.00875**
		(1.76)	(-2.45)
ln (Gov.consum.) (detrended)	0.000925		
	(0.33)		
ln (Trade) (detrended)	-0.0121		
	(-0.20)		
ln (Investments) (detrended)	0.00629***		
	(7.69)		
Gov.consum./GDP (detrended)		-0.0560***	-0.0561***
		(-5.31)	(-5.41)
Trade/GDP (detrended)		-0.00683***	-0.00713***
		(-5.79)	(-6.34)
Investments/GDP (detrended)		0.0123***	0.0124***
		(3.10)	(3.16)
Observations	51	51	51
R^2	0.582	0.565	0.672
Adjusted R^2	0.545	0.528	0.644
Durbin Watson test statistic	1.669759	1.671329	1.662570

Note: All results were obtained using feasible GLS (Prais-Winsten regression). t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. None of the Durbin-Watson results are below the lower bound.

Table A2.3: Indonesia linear de-trended GLS

	(A2.3.1) ln non-resource GDP (detrended)	(A2.3.2) ln GDP per capita (detrended)	(A2.3.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	0.519**		
	(2.34)		
NR/GDP (detrended)		-0.0126*	-0.0333***
		(-1.84)	(-5.03)
ln (Gov.consum.) (detrended)	-0.000450		
	(-0.37)		
ln (Trade) (detrended)	-0.112*		
	(-1.70)		
ln (Investments) (detrended)	0.00177***		
	(4.47)		
Gov.consum./GDP (detrended)		-0.00719	-0.00480
		(-0.82)	(-0.56)
Trade/GDP (detrended)		-0.00136	-0.000947
		(-1.28)	(-1.00)
Investments/GDP (detrended)		0.00757*	0.00643
		(1.93)	(1.67)
Observations	36	36	36
R^2	0.645	0.478	0.753
Adjusted R^2	0.599	0.411	0.721
Durbin Watson test statistic	1.484494	1.566505	1.543457

Note: All results were obtained using feasible GLS (Prais-Winsten regression). t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. None of the Durbin-Watson results are below the lower bound.

Table A2.4: Malaysia linear de-trended GLS

	(A2.4.1) ln non-resource GDP (detrended)	(A2.4.2) ln GDP per capita (detrended)	(A2.4.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	0.212*		
	(1.93)		
NR/GDP (detrended)		-0.00324	-0.0177***
		(-0.53)	(-2.97)
ln (Gov.consum.) (detrended)	0.0000268		
	(0.21)		
ln (Trade) (detrended)	0.244***		
	(4.54)		
ln (Investments) (detrended)	0.000145***		
	(6.82)		
Gov.consum./GDP (detrended)		-0.0120***	-0.0119***
		(-3.30)	(-3.28)
Trade/GDP (detrended)		-0.0000408	-0.000162
		(-0.08)	(-0.33)
Investments/GDP (detrended)		0.00564***	0.00590***
		(3.41)	(3.79)
Observations	36	36	36
R^2	0.810	0.635	0.789
Adjusted R^2	0.785	0.588	0.761
Durbin Watson test statistic	1.559146	2.142171	2.040850

Note: All results were obtained using feasible GLS (Prais-Winsten regression). t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. None of the Durbin-Watson results are below the lower bound.

Appendix 3: De-trending using the Hodrick-Prescott filter and regressing with OLS

Table A3.1: Finland de-trending using a Hodrick-Prescott filter (λ = 6.25)

	(A3.1.1) ln non-resource GDP (detrended)	(A3.1.1a) ln non-resource GDP (detrended)	(A3.1.2) ln GDP per capita (detrended)	(A3.1.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	-0.755*** (-9.09)			
ln (Forestry) (detrended)		0.367*** (3.49)		
ln (NR - Forestry) (detrended)		-0.629*** (-11.35)		
NR/GDP (detrended)			0.00766*** (6.60)	-0.0244*** (-16.76)
ln (Gov.consum.) (detrended)	-0.209 (-1.35)	-0.147 (-1.46)		
ln (Trade) (detrended)	0.380*** (5.94)	0.237*** (3.45)		
ln (Investments) (detrended)	0.175** (2.66)	0.174*** (3.17)		
Gov.consum./GDP (detrended)			-0.0493*** (-6.03)	-0.0505*** (-6.70)
Trade/GDP (detrended)			0.000490 (0.44)	0.00210 (1.66)
Investments/GDP (detrended)			0.00223 (0.64)	-0.00137 (-0.33)
Observations	49	49	49	49
R^2	0.741	0.842	0.726	0.905
Adjusted R^2	0.717	0.823	0.701	0.896
Durbin Watson test statistic	1.801	2.108	2.001	2.052

Note: All results were obtained using OLS. t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels, and repeated Breusch-Godfrey test with different lags indicate that there is no autocorrelation.

Table A3.2: Sweden de-trending using a Hodrick-Prescott filter (λ = 6.25)

	(A3.2.1) ln non-resource GDP (detrended)	(A3.2.2) ln GDP per capita (detrended)	*(A3.2.2^{+})* *ln GDP per capita (detrended)*	(A3.2.3) ln non-resource GDP per capita (detrended)	*(A3.2.3^{+})* *ln non-resource GDP per capita (detrended))*
ln (NR) (detrended)	0.233*** (4.32)				
NR/GDP (detrended)		0.0109* (1.74)	*0.0123*** *(2.24)*	-0.00467 (-0.75)	*-0.00314* *(-0.57)*
ln (Gov.consum.) (detrended)	-0.0434 (-0.59)				
ln (Trade) (detrended)	0.241*** (2.99)				
ln (Investments) (detrended)	0.152*** (5.70)				
Gov.consum./GDP (detrended)		-0.0520*** (-5.20)	*-0.0530**** *(-5.38)*	-0.0519*** (-5.14)	*-0.0528**** *(-5.33)*
Trade/GDP (detrended)		-0.00188 (-1.10)	*-0.00186* *(-1.26)*	-0.00223 (-1.31)	*-0.00211* *(-1.44)*
Investments/GDP (detrended)		0.00932 (1.27)	*0.0105** *(1.70)*	0.00910 (1.24)	*0.0103* *(1.68)*
Observations	49	49	*49*	49	*49*
R^2	0.650	0.449	*0.531*	0.499	*0.515*
Adjusted R^2	0.618	0.399	*0.489*	0.454	*0.471*
Durbin Watson test statistic	1.878514	1.466281	*1.727959*	1.460377	*1.722712*

Note: Results in (A3.2.1); (A3.2.2) and (A3.2.3) were obtained by OLS; (A3.2.2^{+}) and (A3.2.3^{+}) through feasible GLS (Prais-Winsten regression). For (A3.2.2) and (A3.2.3) the Durbin-Watson test statistic is in the region of indecision, and the Breusch-Godfrey test indicated that aurocorrelation is present. Therefore, I ran regressions (A3.2.2) and (A3.2.3) with feasible GLS (Prais-Winsten regression) to obtain the results in (A3.2.2^{+}) and (A3.2.3^{+}).

t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. The Durbin-Watson results of (A3.2.1), (A3.2.2^{+}) and (A3.2.3^{+}) are within the accepted levels.

Table A3.3: Indonesia de-trending using a Hodrick-Prescott filter ($\lambda = 6.25$)

	(A3.3.1) ln non-resource GDP (detrended)	(A3.3.2) ln GDP per capita (detrended)	(A3.3.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	0.644**		
	(2.61)		
NR/GDP (detrended)		-0.00992	-0.0297***
		(-1.12)	(-3.86)
ln (Gov.consum.) (detrended)	-0.0239		
	(-0.28)		
ln (Trade) (detrended)	-0.0942		
	(-1.54)		
ln (Investments) (detrended)	0.328***		
	(4.67)		
Gov.consum./GDP (detrended)		-0.00675	-0.00625
		(-0.68)	(-0.71)
Trade/GDP (detrended)		-0.00178*	-0.00151
		(-1.83)	(-1.70)
Investments/GDP (detrended)		0.00527	0.00407
		(1.29)	(1.10)
Observations	34	34	34
R^2	0.623	0.408	0.691
Adjusted R^2	0.571	0.327	0.648
Durbin Watson test statistic	2.071597	1.718711	1.734105

Note: All results were obtained using OLS. t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels, and repeated Breusch-Godfrey test with different lags indicate that there is no autocorrelation.

Table A3.4: Malaysia de-trending using a Hodrick-Prescott filter ($\lambda = 6.25$)

	(A3.4.1) ln non-resource GDP (detrended)	(A3.4.2) ln GDP per capita (detrended)	(A3.4.3) ln non-resource GDP per capita (detrended)
ln (NR) (detrended)	0.289***		
	(2.83)		
NR/GDP (detrended)		0.000362	-0.0150**
		(0.06)	(-2.58)
ln (Gov.consum.) (detrended)	-0.0293		
	(-0.51)		
ln (Trade) (detrended)	0.124**		
	(2.50)		
ln (Investments) (detrended)	0.211***		
	(5.66)		
Gov.consum./GDP (detrended)		-0.0141***	-0.0140***
		(-4.22)	(-4.27)
Trade/GDP (detrended)		-0.000212	-0.000185
		(-0.66)	(-0.58)
Investments/GDP (detrended)		0.00652***	0.00634***
		(4.17)	(4.12)
Observations	34	34	34
R^2	0.799	0.663	0.775
Adjusted R^2	0.771	0.616	0.744
Durbin Watson test statistic	2.011903	2.369814	2.361163

Note: All results were obtained using OLS. t statistics in parentheses based on heteroskedasticity-robust standard errors, with * significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. Constant term is not shown. All of the Durbin-Watson results are within the accepted levels, and repeated Breusch-Godfrey test with different lags indicate that there is no autocorrelation.

Essay 4: Natural Resources, Technology and Production*

Abstract

This paper explores the link between natural resources, technology and GDP per capita. The difference between resource abundance and resource dependence is analysed in order to understand the different impacts natural resources have when a country is rich in them, or just simply dependent on them. The paper finds no evidence of the resource curse, but rather a positive effect of natural resources on GDP per capita. However, this effect is lower for higher levels of technology. No such relationship exists for resource dependence. In addition, the contribution of the level of technology to GDP per capita lowers with higher levels of resource abundance.

Introduction

The fate of resource-abundant countries varies. The past 50 years has seen a number of success stories. Botswana, rich in diamonds, has been one of the fastest growing economies in the world. Malaysia, with a multitude of natural resources, has managed to achieve high growth rates. Oil-rich Norway has used its considerable resource wealth to become one of the richest countries in the world and regularly ranks 1st on the Human Development Index. Other countries have not been as fortunate. Diamonds in Ivory Coast have been the source of ethnic and political conflict crippling its economy. Oil-rich Nigeria has seen multiple political coups, several failed attempts at industrialisation and a decrease in living standards over the past 30 years. Ragnar Torvik (2009) has summarised these contrasting experiences with the question: 'Why do some resource-abundant countries succeed while others do not?'

One potential mechanism is technology, which is the topic of the current paper. My research question is: 'How does the level of technology affect production in a country abundant in natural resources?' Other studies have also explored the link between technology and natural resources. One of them is Sachs and Warner (1995). They argue that the larger the natural resource sector, the less labour and capital would be diverted to the tradable (non-resource) sector. As the traded sector generated learning-by-doing, while the non-traded did not, a larger natural resource sector would reduce technological progress, and thereby reduce economic growth.

An alternative perspective is provided by Torvik (2001) who uses a Dutch disease model in which learning occurs in both the traded and the non-traded sectors. The result of the model is that economic growth is dependent on the productivity in both sectors and the spill-over effects between the two. Building on this argument, Bravo-Ortega and De Gregorio (2006) construct a two-sector endogenous growth model with one of the sectors being a natural resource sector. They claimed that a high stock of human capital, which is an indicator of a high level of technology, could offset a resource curse. In addition, Bravo-Ortega and De Gregorio (2006) also provided some empirical support for their model using the Sachs and Warner (1995) indicator to measure resource abundance.

Economic historians suggested another link between natural resources and technology. Habakkuk (1962) argues that the high productivity in the US was linked to the country's resource abundance, as the US became the world's leading manufacturer at the same time as the country became the leading producer of coal, copper, petroleum, iron ore, zinc, phosphate, molybdenum, lead, and tungsten. Wright (1990) proves that these two

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processes were linked as the factor content of US manufacturing exports increased from 1870 until the onset of the Great Depression in 1929. David and Wright (1997) claimed that the increased productivity and linkages from the mineral sectors to the manufacturing sectors caused the successful resource-led growth in the US.

Findlay and Lundahl (2004), extending the analysis beyond the US, analysed the experience of fifteen resource-abundant countries in the 1870-1914 period. They found that Australia, Canada, New Zealand and the US used their natural resources as a catalyst to achieve resource-led industrialisation. For the other economies in the study, there was a large degree of heterogeneity. For instance, Argentina and Brazil managed to promote some linkages between the primary sector and manufacturing, allowing for the development of early industrialisation, while other primary exporting countries such as Costa Rica and Siam (Thailand) failed to establish strong linkages between the primary and manufacturing sectors.[135] The central message of the study on 19th century resource-abundant countries is that the link between natural resources and technology is vital.

The literature on resource-based industrialisation claims that current developing countries can process their own natural resources in the same manner as current developed countries did in the 1870-1914 period (Roemer, 1970; Lewis Jr, 1989; Cramer, 1999). The feasibility of resource-based industrialisation is largely linked to the interrelationship between natural resources and technology.

However, the literature has thus far produced few stylized facts on this relationship. It is possible that there are negative synergies between the two, as a higher level of natural resources is linked with a lower level of technology (Sachs and Warner, 1995 and Gylfason, 2001). Such a negative link implies that resource abundance potentially might harm economic growth in the long run, and therefore a resource-based industrialisation might not be a desired strategy.

It is also plausible that there are positive synergies between natural resources and technology, as these reinforce each other. Natural resource abundance would then be linked with a higher level of technology, which might benefit long-term economic growth (Stijns, 2006; Bravo-Ortega and De Gregorio, 2006). If so, a resource-based industrialisation strategy might be a desirable strategy for current developing countries. Obviously, it is also possible that there is no link between natural resources and the level of technology. Alternatively, that the relationship between resource abundance and technological progress is not deterministic, but depends on policy choices (Atkinson and Hamilton, 2003).

This paper aims to find out more on the relationship between natural resources and technology. It does so through an explorative empirical study, by focusing on the contribution of natural resources and technology on GDP per capita. The period 1980-2009 is investigated, which is more relevant for current developing countries than the pre-1914 period, and more data is available for the latter years.[136] In addition, this study focuses solely on fuel and minerals, which are those resources most commonly associated with the resource curse.[137] First, the paper outlines some theoretical predictions on the link between natural resources and technology. Second, the data used in the study is outlined. Third, the empirical approach is explained. The final three sections of the paper conduct the empirical analysis.

1. Natural resources and technology

There is a consensus among economists that long-term economic growth is determined by technological improvements.[138] If natural resource abundance affects these improvements, it will therefore affect long-term

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[135] Findlay and Lundahl (2004) also found that initial income and the type of resource produced played a major part in determining its effect on the economy.

[136] It is common to compare the period 1850-1914, often referred to the first era of globalisation, and the period following 1945, the second era of globalisation. The reason for focusing on the period following 1980 is both data driven and to focus on the more recent period.

[137] Sala-i-Martin and Subramanian (2003) and Isham *et al.* (2005) indicated that geographically concentrated natural resources (so called 'point sources' which were defined as minerals and plantation crops) affect economic growth negatively.

[138] See for instance Acemoglu (2009).

economic growth. I am interested in two interrelated questions. First, is the impact of natural resources on GDP per capita affected by technology? Second, is the impact of technology on GDP per capita affected by natural resources? The potential correlations that correspond to these questions are illustrated in figures 1 and 2.

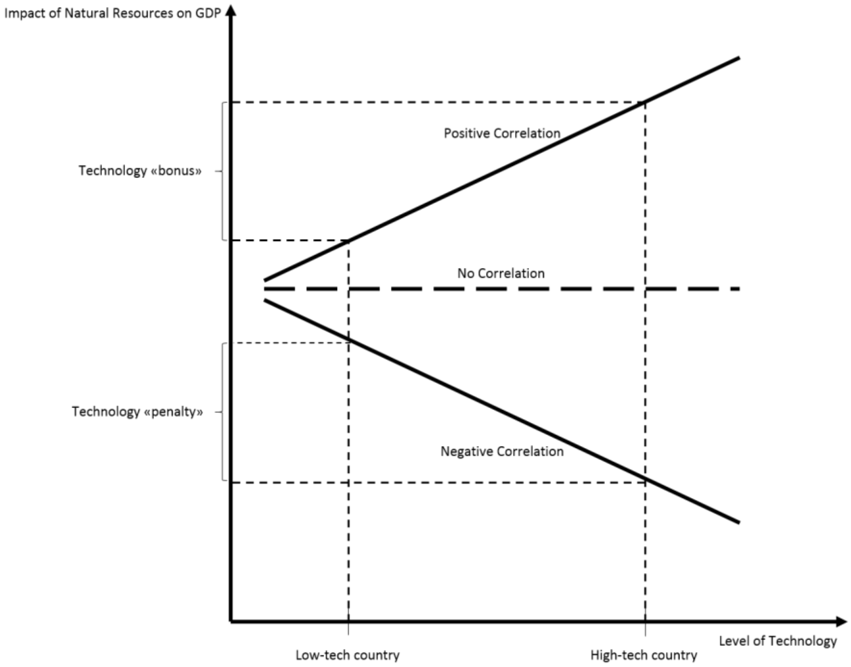

Figure 1: Impact of Natural Resources on GDP Dependent on Technology

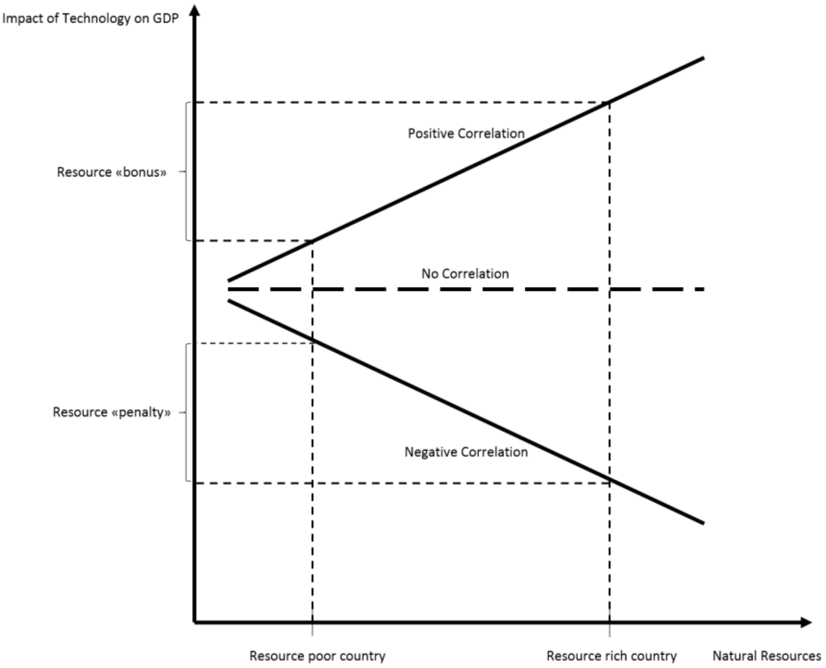

Figure 2: Impact of Technology on GDP Dependent on Natural Resources

The first possibility is for negative synergies between natural resource and technology, what I call a technology 'penalty' in figure 1 and a resource 'penalty' in figure 2. Such links imply that the level of technology contributes less to GDP in resource-abundant countries and vice versa. Sachs and Warner (1995) suggested such negative synergies. They divided the economy into two sectors, a 'growth' sector (which has technological progress) and a 'backward' sector (with little or no technological progress). Resource abundance in turn increases the production of the backward sector at the expense of the growth sector through, for instance, factor demand, thereby lowering the level of technology.

Another mechanism, proposed Gylfason (2001) is that increased resource abundance would lead to a decrease in education. The argument is similar to the one for the Dutch disease models. Manufacturing experiences learning-by-doing and the sector has a higher demand for human capital than the natural resource sectors. One reason could be that human capital investments are more necessary for resource-poor countries as they are more reliant on other non-resource exports for their export income. These non-resource exports can become more competitive with higher levels of human capital as productivity and learning increases. If the natural resource sectors expand, it would lower demand for human capital, and as increased human capital causes economic growth, it would mean that economic growth decreases.

Other mechanisms might also cause a negative correlation. One such mechanism is fiscal policy irresponsibility; revenues generated from natural resources can be misused through corruption or excessive social benefit schemes (Atkinson and Hamilton, 2003). Fiscal policy irresponsibility might also be caused by increased rent-seeking associated with resource booms which might reduce the institutional quality (Leite and Weidmann, 2002). This decrease might in turn cause increased corruption and decreased investments in growth-enhancing areas such as infrastructure and human capital.

The second possibility is that there are positive synergies between natural resources and technology, what I have chosen to call a technology 'bonus' in figure 1 and a resource 'bonus' in figure 2. This implies the opposite from above in that the contribution of technology on GDP is higher in resource-abundant countries and vice versa. One possibility is that natural resource sectors have a higher increase in productivity than manufacturing. In fact, Martin and Mitra (2001) concluded that total factor productivity growth had been higher for agriculture than for manufacturing for the period 1967 to 1992, which is consistent with the results from other studies. However, these studies focused on the difference between agriculture and manufacturing, not the fuel and mining sectors. To my knowledge, no cross-country research has explicitly compared productivity between manufacturing and mining.

Another possibility is that a high degree of human capital could prevent the resource curse as suggested by Bravo-Ortega and De Gregorio (2006). According to Glaeser *et al.* (2004), the accumulation of human capital predates an improvement in institutional quality, and an improved institutional quality can in turn positively affect economic growth.

Fiscal spending might also cause a positive synergy. Natural resource-abundant countries might receive additional revenues compared to resource-poor countries and these can be used to invest in human capital, research and development, or other areas that improve technological progress (Atkinson and Hamilton, 2003). Stijns (2006) found that the accumulation of human capital was higher in resource-abundant countries.[139]

One potential problem with the positive synergy argument can be the demand conditions for human capital in resource-abundant countries. Large natural resource sectors might crowd-out non-resource sectors that would benefit from increased human capital and technological progress at large. Therefore, it is possible that the positive synergies are not linear, but take the shape of an inverted U in which these effects are strongest for a medium level of resource abundance, or to borrow the phrase from Matsen and Torvik (2005), there might exist a level of 'optimal Dutch disease'.

The final possibility is that there is no correlation and that the production of natural resources has little bearing on technological improvements. The Torvik (2001) model claimed that the impact of natural resources on economic growth is not given, whether natural resources contribute to economic growth depends on (i) The

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[139] Stijns (2006) differed from the already mentioned Gylfason (2001) in that the former used more direct measures of resource abundance than the latter.

degree of learning by doing in both the traded and non-traded sectors; and (ii) The extent of spill-over effects between the sectors. If correct, it could imply that the mechanisms vary between countries, and resource-led growth could depend on a government's ability and/or willingness to promote technological progress in all sectors in the economy. Measurements of the link between resources and technology might turn up as statistically insignificant, despite being economically significant as countries differ in their ability to promote technological progress in the resource sector.

The direction of causality is unknown. As there are three variables to take into account, natural resources, technology and GDP, the direction of causality is potentially complex. Figure 3 illustrates six potential links. The first link is the direct impact of natural resources on GDP, as increased natural resource production increases value-added. The second link is the direct impact of technology on GDP as a higher level of education for instance can improve technological learning and labour productivity, which in turn increases GDP.

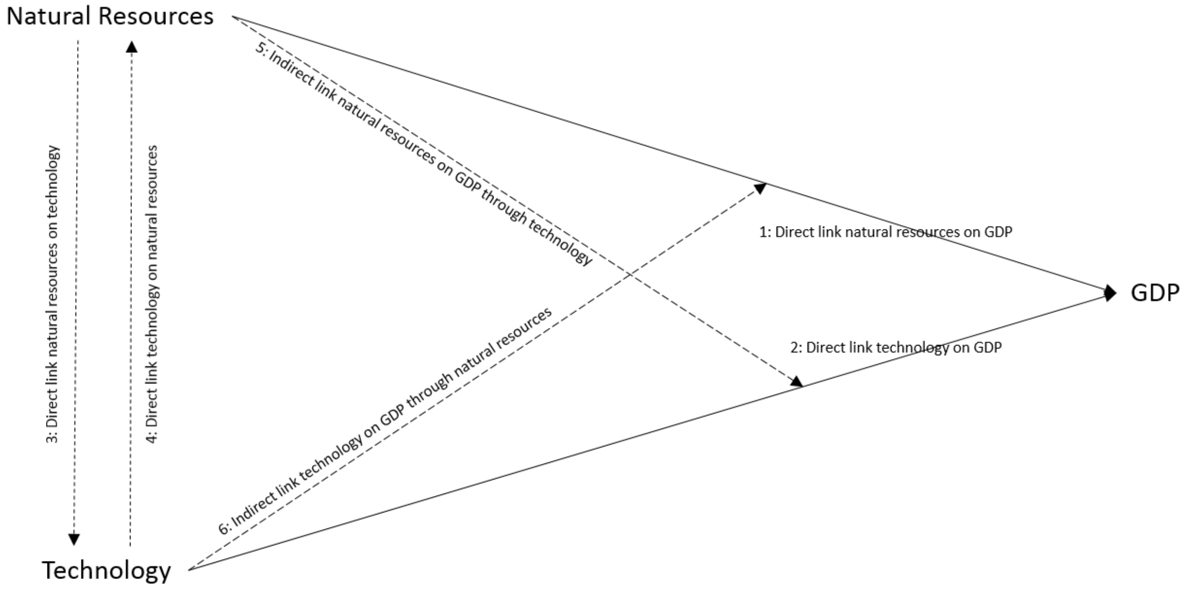

Figure 3: Links between natural resources, technology and GDP

Technology and natural resources can also affect each other. The third link in figure 3 is between natural resources and technology. Increased revenues from natural resources can increase investments in technology such as human capital and research and development. In addition, if natural resource sectors are technology-intensive they can generate spillover effects to other sectors in the economy. Increased production in the natural resource sectors would then increase the level of technology in other sectors, which would give a technology 'bonus'. The fourth link is between technology and natural resources. Natural resources can potentially increase its economic value when a country has a higher level of technology. Better technology improves exploration of resource deposits, extraction and transportation can become more efficient and cost effective and more forward linkages to resource-intensive manufacturing products can increase the usage of natural resources in other goods in the economy can increase the demand for natural resources. Most likely, there is a bi-directional relationship, since links three and four work simultaneously.

There are also two indirect effects, mainly predicted by the Dutch disease literature. The fifth link in figure 3 is the indirect effect of natural resources (through technology) on GDP. This is the classical Dutch disease argument from above. Increased resource abundance leads to a crowding-out effect of the growth sector. As the growth sector generates learning-by-doing (and the other sectors do not), the technological progress will decrease when natural resource abundance increases. The sixth and final link is an indirect effect of technology (through natural resources) on GDP. This effect could be the Dutch disease effect in reverse. Technological progress can be so large in the growth sector, that it dominates the contribution of natural resources. Alternatively, the technological progress in the natural resource sector is so large that it becomes the growth sector in the economy, which is a possibility in the Torvik (2001) model. This paper will only tentatively consider causality by analysing the links from figure 3 at the end of the analysis.[140]

2. Measuring Natural Resources and Technology

2.1 Natural Resource Indicators

No universally accepted indicator of resource abundance exists. I considered five indicators, each with their own strengths and weaknesses. The indicators considered are shown in table 1, and their sources are discussed when elaborating on each of the indicators.

Table 1: Different resource indicators considered

Primary resource exports	*Rents*	*Natural wealth*	*Natural resource income per capita*	*Stock*
Fuel and ores, and metals exports (often measured as a share of GDP)	The difference between the price of a commodity and the cost of producing it (including opportunity costs)	The sum of present value of rents from extraction of remaining reserves	Total natural resource income per capita	Resource stocks 1970 by adding past production data to current reserves
Source: WDI (2014)	Source: WDI (2014)	Source: WDI (2014)	Source: Haber and Menaldo (2011)	Source: Norman (2009)

The first measure considered, which has been the most common used indicator in the literature, is primary exports as a share of GDP. Sachs and Warner (1995) used this indicator as a proxy for natural resource abundance. The main advantages of this indicator are that it is easily observable for many countries, and it gives a good indication of the importance of unprocessed resource exports for a given economy.

However, there are many problems with this indicator. First, it is probably not a good proxy for resource abundance as it measures the degree of unprocessed exports. Natural resources that are processed and subsequently exported as manufacturing are not measured, leading to the false impression that resource-abundant countries that use natural resources as inputs in their manufacturing exports are resource-poor. Hence, it is a good estimation of resource dependence rather than resource abundance.

The second problem is that Sachs and Warner (1995) only used the 1971 observation to measure resource abundance for the entire period. In December 1969 Norway discovered oil, but production and exports were still limited in 1971. However, oil played a major part in the Norwegian economy for the entire 1970-1990 period and probably did have a major effect on economic growth.

The third problem is the reliance on the export figures themselves. Using data from WDI (2014), the degree of natural resource exports from Singapore in 1971 was 51.5 % as a share of GDP, while the same figure for Norway that year was 7.3 %. Taken literally, it would lead to the absurd conclusion that the city-state Singapore was more than seven times as resource-abundant as Norway. It is obvious that the problem is caused by the amount of re-export from Singapore. To counter this problem Sachs and Warner (1995) measured the net exports for Singapore. This creates a consistency problem, since a few observations are measured differently,

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[140] The descriptive statistics in appendix 2, as shown in figure A2.1, indicate that there might be a relationship between human capital and resource abundance. Figure A2.2 indicate the relationship appears to be weaker for resource dependence.

making inferences less reliable. One could, as suggested by Bravo-Ortega and De Gregorio (2006), use the average for a given period.

The second and third measures are rent and wealth data. As the wealth data are based on rents, I treat these together. Rents (a flow variable) is calculated as the resource income minus the estimated extraction costs (if actual are not available) and the alternative costs of resource production (which is the social discount rate taken to be 4 %). Natural wealth data is a stock variable calculated as the sum of the remaining rents available given the estimated resource stocks for extractive resources (if stock figures are not available, it is assumed that resources will be depleted in 20 years). The main advantage of the rent data is its availability for many years and coverage of numerous of countries for cross-country comparisons. The main advantage of the wealth data is that it is a stock variable and can measure the accumulated resource wealth.

There are, however, many problems associated with rent and wealth data. The first problem, for wealth data only, is that there are only three observations (1995, 2000 and 2005), which limit the coverage over time. The second problem, also only for wealth data, is the estimation used calculating resource stocks. For missing observations, the World Bank assumes that the resource is depleted within 20 years, regardless of country and type of resource (van der Ploeg and Poelhekke, 2010).[141]

The third problem, which goes for both rents and for wealth data, is the estimation of the cost of extraction. The costs of extraction for missing observations are assumed to be the same as for the Malaysian oil fields, whose cost figures are based on a study from Vincent (1997). It is likely that the costs of extraction are far higher for other developing countries, as Malaysia in relative terms is an efficient oil producer (Van der Ploeg and Poelhekke, 2010). The estimates would therefore overestimate resource rents in many developing countries.

A final problem is the social discount rate to measure opportunity costs. These are unknown and probably not uniform across time or for different countries. Van der Ploeg and Poelhekke (2010) claim that the social discount rates are too low for high growth economies and too low high for low growth countries. Given the number of assumptions that are used when calculating rents and wealth data, there is uncertainty about whether these figures actually show the extent of resource abundance.

The fourth indicator considered is natural resource income per capita, which is quickly becoming a new standard in the literature.[142] Natural resource income per capita has the advantage of being straightforward because few assumptions are made. The resource income is the production multiplied by the commodity price, with no deductions for costs. This paper uses the data from Haber and Menaldo (2011).

The Haber and Menaldo (2011) data gave primacy to internal consistency of the data; therefore they gathered their data from as few sources as possible. The data gathered was for 168 countries, and even though the time-series went back all the way until 1900, I am only interested in the period 1980-2006.

Natural resource income per capita consisted of four individual natural resources; (i) Oil; (ii) Natural Gas; (iii) Coal and (iv) Minerals (meaning antimony, bauxite, chromium, copper, gold, iron ore, lead, manganese, mercury molybdenum, nickel, silver, tin, tungsten, and zinc). To find per capita values, the population data for 1980-2006 was gathered from the World Development Indicators.

Production and price data on oil for 1980-2006 were gathered from three sources. Oil production data was collected from the '*The Oil and Gas Journal*', which has been petroleum industry's leading trade journal since 1902. For the few countries with missing observations the data was obtained from the other main leading journal of the petroleum industry '*World Oil*'. Nominal prices on oil were gathered from British Petroleum's, '*Statistical Review of World Energy, 2008*' and the same source was used to deflate nominal prices.

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[141] Different natural resources have widely different depletion rates. For instance, the median years until depletion (given current production) is 192 years for soft coal and 178 years for bauxite but only 16 years for copper and 17 years for zinc deposits.

[142] See for instance Dunning (2008), Aslaksen (2010), Ramsay (2011) and Bjorvatn *et al.* (2012).

For the other natural resources the production and nominal price data came from the same source. For natural gas, production and nominal price data were gathered from the U.S. Energy Information Administration, '*International Energy Annual*'. For coal, the production and nominal price data were gathered from U.S. Energy Information Administration, '*Energy Information Annual*'. For minerals, the production and nominal price data was gathered from the U.S. Geological Survey, '*Historical Statistics for Mineral and Material Commodities in the United States*'. All nominal prices were deflated the same way as for oil prices using British Petroleum's '*Statistical Review of World Energy, 2008*'.

The data gathered relied on relatively few sources for each natural resource, which means that production data across countries is comparable. Haber and Menaldo also cross-referenced their production data with other sources as a robustness check. They also published an online appendix which goes into detail on how the database was constructed which can be accessed online for more information.[143] The obvious disadvantage of this indicator is that by omitting extraction and other costs, natural resources are valued the same in different countries despite different profit margins. Natural resource income does not measure 'excess profits' or rents in the traditional economic sense.

The final indicator considered is the natural resource stock, meaning the value of the reserves available. Reserve data has some nice properties. First, reserves are exogenous to GDP, which none of the other indicators mentioned above are. However, reserves can only be partly exogenous, as reserves are a function of searching activity for resources, which again is a function of both income and technology. Thus, one would expect more exploration to have been conducted in developed countries (Cust and Harding, 2013). This might be problematic as it might overestimate the positive effects of resource abundance on technology because technologically more advanced countries have explored more oil, creating an upward biased estimate. However, reserves cannot be 'created'. In this respect, reserves are exogenous. Second, as a stock measure, it measures the absolute accumulated natural resource wealth, which gives a clearer picture than flow variables.

The Norman (2009) reserve data is estimated by summing-up current reserves and production data for oil, gas, coal and various minerals since 1970, and adding known reserves. Data on 35 different minerals were gathered with the production, reserve and price data taken from various publications of the US Geological Survey. For coal, reserve, production and price data was mainly gathered the International Energy Annual.[144] Gas and oil reserve, production and price data was gathered from the International Energy Annual, the Energy Information Agency and the US Geological Survey.

By constructing the estimated 1970 reserve data, it reflects the 'true stock' of natural resources, which in part was an unknown quantity at the time. The main weakness of the natural resource stock is that reserves in part are unknown to economic actors. If these actors are not aware of the resources present, it is difficult to act upon them and thereby have an effect on the economy.

The concept 'resource abundance' relates not only to the extent that a country is abundant in natural resources, but there is also the implicit assumption that the population of the country should benefit from abundance. If a country has a large resource base which is never discovered, the resources will never affect the economy. An indicator of resource abundance should therefore (i) give a good proxy of the extent of natural resources; (ii) be observable so it can be acted upon; and (iii) be exogenous to the dependent variable measured, in this case GDP. I compare how each of the five indicators of resource abundance mentioned above fare in table 2.

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[143] Available at https://iriss.stanford.edu/sshp/datasets.

[144] The exception is the production data 1971-77 which are gathered from US Department of the Interior, Bureau of Mines; and the 1978-1979 data which had to be estimated

Table 2: Resource indicators and the three criteria

	Primary resource exports	*Rents*	*Natural wealth*	*Natural resource income*	*Stock*
Good proxy of the extent of natural resources	Not fulfilled	Reasonably fulfilled	Reasonably fulfilled	Fulfilled	Fulfilled
Observable so it can be acted upon	Fulfilled	Reasonably fulfilled	Not fulfilled	Fulfilled	Not fulfilled
Exogenous to GDP per capita	Not fulfilled	Not fulfilled	Not fulfilled	Not fulfilled	Reasonably fulfilled

My preferred measurement of natural resource abundance is natural resource income per capita, as it relies on few assumptions, and because natural resources most likely affect the economy the most when used in production. The main disadvantage is that natural resource income is not exogenous to GDP. I do not use rent and wealth data, as these rely on too many assumptions, making inferences based on these more difficult. Natural resource exports are an inadequate indicator for measuring natural resource abundance, but give a good indication of natural resource dependence. As natural resource exports are a standard measure in the literature, I use this in some regressions for the sake of comparison. Stock measurement is the only measure that can, at least partially, be considered as exogenous to GDP per capita. However, as mentioned, unknown reserves cannot affect the decision making of economic agents, and will therefore not be used.

To differentiate between resource abundance and resource dependence, I use two versions of the resource income indicator. The first version is the natural resource income per capita (2005 USD) in order to measure the absolute level of resource abundance per person. The second version is the natural resource income as a share of GDP measuring the degree of resource dependence.

Table 3 compares these two measures for the 15 highest values for each indicator. In per capita terms, Qatar is the country with the largest resource income, but ranks only 14th in terms of resource dependence. Norway has the second largest income per capita, but ranks only 28th of most dependent countries. Kuwait, ranking third in resource abundance, ranks only 15th in terms of resource dependence. Iraq, the most resource-dependent country according to these figures, does not even feature among the top 15 resource-abundant countries. The point is that the type of measurement matters. Resource-dependent countries are more likely to be countries with a low GDP, as this would increase the relative share of natural resources. Most of the literature uses resource dependence rather than resource abundance as a measure of natural resources, thereby biasing the results in favour of a resource curse.

Table 3: Resource Abundance vs. Resource Dependence 2004-2006 (Three-Year Average)

Country	Resource abundance: Resource Income per capita (2005 USD)	Country	Resource Dependence: Resource Income Share (% share of GDP)
1. Qatar	24.525	1. Iraq	83
2. Norway	15.930	2. Equatorial Guinea	80
3. Kuwait	15.461	3. Gabon	77
4. United Arab Emirates	12.667	4. Congo, Rep.	71
5. Equatorial Guinea	9.908	5. Papua New Guinea	65
6. Oman	7.645	6. Libya	62
7. Saudi Arabia	7.171	7. Oman	62
8. Trinidad and Tobago	6.994	8. Trinidad and Tobago	55
9. Bahrain	6.460	9. Saudi Arabia	54
10. Libya	4.876	10. Angola	53
11. Gabon	4.784	11. Mongolia	51
12. Canada	2.872	12. Chad	48
13. Australia	2.832	13. Iran	47
14. Venezuela	2.042	14. Qatar	46
15. Chile	1.698	15. Kuwait	45

Source: Calculated from the Haber and Menaldo (2011) database converted to 2005 USD using BP (2008) historical oil price figures; GDP figures from WDI (2014).

2.2 Technology Indicators

By technological progress, I mean the process by which an economy learns or develops more advanced technologies that improve productivity, generate new products or increase the quality of the products already being produced. For developing countries far from the technological frontier, the primary driver behind technological progress is often the learning of already existing technologies from advanced economies. When a country is close to or even at the technological frontier, new technologies have to be invented and applied meaning that invention and innovation become the primary drivers behind technological progress.[145] The level of technology is the accumulated technological progress. In this paper, I chose to use three different indicators as they cover different aspects of technology.

The first indicator is the stock of human capital. Human capital, according to economic theory, increases labour productivity and learning. Using stock data also gives an indication of the level of technology rather than just educational inputs. The source chosen is from the latest version of the Barro and Lee database.[146] I have chosen this database for a number of reasons. First, the database is the most commonly used in the literature, making comparisons with other research easier. Second, the latest version of the database is improved as much of the criticism of the earlier versions of the Barro and Lee databases have been taken into account.[147] Finally, the data covers many countries, which increases the number of observations.

In the empirical literature, there is no uniform way of measuring human capital. The most common way is to measure the average years of education to measure the returns to education.[148] This approach works well with studies that explicitly want to measure the effect of an additional year of education. However, I use human capital as a proxy for the level of technology. Therefore, I construct the following measure of the stock of human capital:

$$Stock\ of\ Human\ Capital_t = Years\ of\ Secondary\ Schooling_t + Years\ of\ Tertiary\ Schooling_t \qquad (1)$$

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[145] The theoretical underpinning for the relationship of learning and innovation can be found in relationship to a country's 'absorptive capacity'. See for instance Gerschenkron (1962), Nelson and Phelps (1966), Ambramovitz (1986) and Benhabib and Spiegel (1994).

[146] See Barro and Lee (2013) for a detailed description of the data.

[147] For a criticism of previous versions of the Barro and Lee database see De La Fuente and Doménech (2006); and Cohen and Soto (2007). To see how this critique affected the human capital estimates see Barro and Lee (2013).

[148] Benhabid and Spiegel (1994) were the first to measure human capital as the average number of years of education, which still is a common measure in the literature.

This indicator captures the learning and productivity effects to a greater degree than total years of education. Secondary and tertiary education have higher returns, indicating that they have a greater effect than primary education.[149]

The second indicator I use is the number of patents per capita. Patents are highly useful for measuring technological progress, as they are an output variable (as opposed to input) that measures innovation more than learning. In addition, the data coverage is large as the information is freely available. However, there are many pitfalls in using patents as an indicator.[150] First, not all innovations are patented as the choice to apply for a patent depends on the industry, the cost of the application and the strength of the intellectual property rights. Second, countries that did not have patent systems such as the Netherlands and Switzerland in the 19th century did not experience a lower degree of innovation or economic growth. Nevertheless, I still choose to use patents as an indicator because the data coverage is large, and it does serve as an indicator for innovative activities. If one assumes that the ratio of patented innovations relative to non-patented innovations is constant in the time-period 1980-2006, patents still provide a good indicator for innovation.

The third indicator I use is research intensity, which is measured as expenditures on research and development (R&D) as a share of GDP. R&D captures both learning and innovation effects, as a considerable amount of R&D expenditures focuses on learning and improving already existing technologies in addition to being used to invent new technologies. Griffith *et al.* (2004) confirm that R&D is significant both for learning and innovation purposes. However, one disadvantage with R&D is that it is a flow variable, not a stock variable.[151] R&D therefore does not measure the level of technology, directly but gives an indication of the investments in research, which is assumed to be correlated with the level of technology. Another disadvantage is that R&D is an input measure, which says little of actual effects. R&D expenditure can be used efficiently as well as inefficiently depending on the quality of the research conducted. Still, the indicator captures investments which are aimed at increasing both learning and innovation.

Both the patent and the R&D data is taken from the Castellacci and Natera (2011) database. The database collected the patent data from the *United States Patent and Trademark Office*, while the R&D data were collected from three main sources.[152] One advantage of this dataset is that missing observations are estimated using a multiple imputation methodology giving more reliable estimates, which is also confirmed in a number of reliability tests (Castellacci and Natera, 2011). Another advantage is the dataset coverage, as the database has observations for 134 countries for the patent data and 94 countries for the R&D data during 1980-2006, including many developing countries, which are important for the current study.[153]

3. Empirical approach

To test the effect of natural resources and technology on a country's GDP per capita, I divide the analysis in two parts. In the first part, I employ a cross-sectional analysis for the time period as a whole. In the second part, I use a panel data analysis to analyse whether the conclusions change.

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[149] Barro and Lee (1996) discussed various measures of schooling and found no significant relationship between primary education and economic growth. Only secondary and tertiary education were found to be significant.

[150] For a discussion of the usage of patents as indicators of innovation, see Basberg (1987), Griliches (1990) and Moser (2013).

[151] One could potentially construct a R&D stock measure using an inventory method with assumptions regarding depreciation (or technology obsolescence). However, this is beyond the scope of the current paper.

[152] The three sources for R&D data were (i) OECD: Science, Technology and R&D Statistics; (ii) Red Iberoamericana de Indicadores de Ciencia y Tecnología (RICYT); and (iii) UNESCO online database. For more details see Castellacci and Natera (2011).

[153] For a more detailed description, reliability tests compared to other datasets and potential shortcomings see Castellacci and Natera (2011).

3.1 Cross-sectional data analysis

In the cross-country analysis, I will test the importance of natural resources and technology in 1980 for GDP per capita in 2009. I therefore use the following equation:

$$ln(GDP\ per\ capita)_{2009} = \beta_o + \beta_1 NR_{1980} + \beta_2 TECH_{1980} + \beta_3 (NR \cdot TECH)_{1980} + \beta_4 Z_{1980} + \varepsilon \qquad (2)$$

Countries are indexed by i (1, .., 110). GDP per capita figures are from the World Development Indicators (2014) and measured in constant 2005 dollars.[154] This paper uses the level of the logarithm of GDP per capita rather than the growth rate. This is a common approach in the literature and there are two reasons for why I have chosen levels in the present paper.[155] First, the impact of natural resources on economic growth is difficult to determine as the period of analysis is only 30 years, from 1980 to 2009. Most deposits of natural resources were discovered prior to 1950, and the impact of natural resources should be measured from discovery to commercial exploration and to depletion. It is possible that natural resources increase economic growth in the early stages of production, but slow growth when deposits mature (Alexeev and Conrad, 2009).[156] To able to capture the total effect of natural resources on the economy, levels are therefore more appropriate rather than growth rates. The second reason is that the level of GDP per capita captures more information about the accumulated growth process than does the growth rate (Brückner, 2010).

The variable NR stands for 'natural resources' indicators. The ones I use are resource income and resource exports. TECH stands for 'technology indicators'. The ones I will use are human capital, patents and research and development expenditure. All the natural resource and technology indicators have been explained in part 2.

Z denotes a set of control variables, the ones I have chosen are based on two criteria. The first criteria is their usage in the resource curse literature in general as well as their intuitive appeal. The second criteria is the data coverage. The control variables need to be available for many countries, preferably from the same source. In fact, for each individual control variable all observations came from the same source. This means that they are comparable across countries.

The control variables used cover important causes for economic growth mentioned in the literature. The first control variable is the age dependency ratio, which controls for the demographic burden of a country.[157] If a country has a relatively high share of people under 15 compared to the working population, this will be a fiscal burden on the working population which could decrease savings, and thereby investments.

The second control variable is government consumption as a share of GDP, measuring the degree of government expenditures on non-investment activities, which, according to Barro (1991), is negatively correlated with economic growth. It is argued that government consumption (as opposed to government investment) does not contribute to long-term economic growth, and is a proxy for government wastefulness.

The third control variable is trade as a share of GDP, measuring the degree of openness. The degree of openness is often assumed to be positively correlated with higher GDP as sectors engaging in international trade are more productive than sectors producing for the domestic market.

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[154] An alternative would be to use the Penn World Tables 7.1, which provides a measurement of GDP per capita in constant 2005 PPP, which in many ways is a preferred method for comparing living standards across countries. Differences in measurement of GDP from various sources might potentially lead to different results, as highlighted by Sørensen (2008). However, a number of the variables in the regression are measured not by PPP, but in 2005 USD and for the sake of consistency I use the same measure. I also estimate the same regressions as I did in the analysis (but did not report the results) using the Penn GDP per capita data, but the results were not noteworthy different.

[155] See for instance Hall and Jones (1999), Easterly and Levine (2003), Rodrik *et al.* (2004), Alexeev and Conrad (2009) and Bjorvatn *et al.* (2012).

[156] See also Boyce and Emery (2005) for a general equilibrium model in which such an exploitation pattern is optimal.

[157] The age dependency ratio is given by ((population aged 0-14 + population aged 65 and over)/population aged 15-64). It measures the share of the young and old population as a share of the population that is most likely of working-age.

The fourth control variable is investments as a share of GDP, which measures the effect of investments on GDP. Increased investments are thought to an enhancement the productive capacity of the economy which would lead to improved long-term economic growth.

The final control variable has to do with institutions. As a proxy of institutions, I have included the Transparency International Index, which ranges from 0 (high corruption) to 10 (low corruption). Recent research has stressed the importance of institutions for long-term economic growth.[158] For more information on the variables and their sources, see appendix 1.

A number of control variables were not included in this study, despite their potential relevance. Three of these deserve a special mention. The first control variable dropped was domestic credit to the private sector. This control is a proxy for the quality of the financial sector, which is an important determinant for economic growth. The reason for dropping the variable was mainly the lack of observations for a number of countries, which would have decreased the sample size considerably. However, the category of investments partly captures this effect.

The second control variable dropped is price fluctuation. Fluctuations in prices might have adverse effects for how natural resources affect the economy as fiscal policy becomes less predictable and countries might be tempted toward excessive borrowing during price booms (van der Ploeg and Poelhekke, 2010). The first reason for dropping this variable is a lack of observations. The second reason is the inappropriateness given the natural resource indicator chosen. As I have chosen resource income per capita, it means that not all natural resources are exported, since some natural resources are either consumed or processed domestically. Therefore, an international price index might not capture the effect natural resources have domestically other than a potential opportunity cost.

A final control variable dropped was public debt as a share of GDP. The reason for dropping this variable was mainly that I had already included government consumption, which is a proxy for government wastefulness. As the correlation between government consumption and debt is high, and because government consumption came from the same source as other control variables, while debt did not, I chose not to include public debt.

Equation (2) states that GDP per capita is affected by natural resources and technology directly, and through an interaction effect between the two. The marginal effect of natural resources on GDP per capita is therefore the partial derivate of equation (2) on natural resources:

$$\frac{\partial ln(GDP\ per\ capita)_{2009}}{\partial NR_{1980}} = \beta_1 + \beta_3 TECH_{1980} \tag{3}$$

Equation (3) states that the effect of natural resources in 1980 on GDP per capita in 2009 is dependent on $ß_1$ and the level of technology in 1980 times $ß_3$. The value of $ß_1$ can be negative, positive or not significant, as different empirical studies find different effects of natural resources on the level of GDP per capita. The coefficient $ß_3$ is the one of interest in the present study, as it shows whether the level of technology affects the effect of natural resources on GDP. As explained in part 1, little is known about the expected sign of this coefficient.

I also wish to explore the marginal effect of technology on GDP per capita, which is given by the partial derivative of equation (2) on technology:

$$\frac{\partial ln(GDP\ per\ capita)_{2009}}{\partial TECH_{1980}} = \beta_2 + \beta_3 NR_{1980} \tag{4}$$

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[158] See for instance Acemoglu *et al.* (2001; 2005), Rodrik *et al.* (2004) and Mehlum *et al.* (2006).

Equation (4) shows that the marginal effect of technology in 1980 on GDP per capita is β_2 plus natural resources in 1980 times β_3. The conditional effect of technology, β_2, is expected to be positive as a higher level of technology is assumed to be correlated with a higher level of GDP per capita. The coefficient β_3 is the same as the one in equation (3) and gets an additional interpretation in equation (4), as it measures how the level of natural resources affects the effect of technology on GDP. As mentioned above, little is known about the sign of this coefficient.

3.2 Panel data analysis

The panel data equation estimated is:

$$ln(GDP\ per\ capita)_{it} = \beta_o + \beta_1 NR_{it-1} + \beta_2 TECH_{it-1} + \beta_3 (NR \cdot TECH)_{it-1} + \beta_4 Z_{it-1} + \mu_i + \delta_t + \varepsilon_{it} \qquad (5)$$

As above, countries are indexed by i (1, .., 112). All the independent variables are the same as above. One difference in the panel data set-up is the time lag introduced to reduce endogeneity problems.[159] I have included country-fixed effects, denoted by μ to test for changes within countries over time. The time-fixed effects are given by δ and are used as a robustness check for whether time-specific events affect the result. The error term is clustered at the country level. In the empirical analysis, I use pooled OLS and fixed effects (to remove any unobserved cross-country heterogeneity).[160]

I categorise the years from 1980-2009 into six five-year time periods with t (1 = 1980-1984, ..., 6 = 2005-2009), and use five-year averages for each observation. As the independent variables are lagged by one period, there will be five time periods in the analysis. There are two main reasons for using five-year averages, one based on economic intuition and the other being more practical. First, it is intuitive that the variables included in the regression affect GDP per capita with a considerable time lag. An increase in the level of education from 1980 to 1981 is unlikely to have any real impact in the short-run. It is more likely that a higher average level of human capital from 1980-1984 has an effect on the average level of GDP per capita in 1985-1989. This also goes for the other independent variables included. Second, it is more practical to operate with five time-periods rather than twenty-six (which is the maximum number of time periods I have observations for). The simple reason being that a large number of countries and a long time-period gives rise to problems associated with nonstationary panels.[161]

As in the case of the cross-sectional analysis, I am interested in the marginal effects of natural resources and technology. In the panel data analysis, the marginal effect of natural resources on GDP per capita is the partial derivate of equation (5) on natural resources:

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial NR_{it-1}} = \beta_1 + \beta_3 TECH_{it-1} \qquad (6)$$

The interpretation of (6) is slightly different from the cross-sectional case. It states that the marginal effect of natural resources in period t affects GDP per capita in the period t+1 by β_1 and the level of technology in period t times β_3. As for the cross-sectional case, the expected signs of the coefficients β_1 and β_3 are unknown.

Finally, I also wish to explore the marginal effect of technology on GDP per capita, which is given by the partial derivative of equation (5) on technology:

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[159] See Mehran and Peristiani (2010); and Bjorvatn *et al.* (2012) for a similar approach.

[160] I do not use random effects as it assumes that the unobserved country characteristics are uncorrelated with the independent variables, which is implausible in the current study.

[161] For an introduction to potential problems with nonstatioanry panels and tests for detecting these, see Baltagi (2008 pp.273-308).

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial TECH_{it-1}} = \beta_2 + \beta_3 NR_{it-1} \qquad (7)$$

Again, the interpretation of the panel data marginal effect differs slightly from the cross-sectional analysis. Equation (7) measures the marginal effect of technology in period t on GDP per capita in period t + 1 which is dependent on β_2 plus natural resources times β_3. Equation (4) shows that the marginal effect of technology on GDP per capita is β_2 plus natural resources in period t times β_3. As in the cross-sectional case, the coefficient β_2 is assumed to be positive while the sign of the coefficient β_3 is unknown.

The main question in the context of the panel data analysis is whether to rely on the pooled OLS or the fixed effect estimations to evaluate the effects of resource abundance on the economy. Research has at times chosen the fixed effects estimation by default as it corrects for unobserved heterogeneity. In addition, there is little doubt that fixed country effects are present. However, the fixed effects estimation also assumes that the data generating process is similar in all economies once the unobserved heterogeneity is controlled for. In other words, fixed effects estimation assumes that oil affects the Norwegian economy in the same way as oil affects the Indonesian economy. This is a strong assumption. The oil sector in Norway is a human capital-intensive industry, has generated spill-over effects in terms of increased technological learning and Norway is managing its oil revenues conservatively through a resource income fund. The evidence from Indonesia indicates that its oil sector has been plagued with inefficient production, government intervention and a high degree of corruption (Hertzmark, 2007). It is safe to say that oil has had a different effect on the Indonesian economy than on the Norwegian one, which goes against the assumptions of fixed effects estimation.

The pooled OLS instead measures each observation without considering country effects. The disadvantage is that one has to assume that natural resources affect all observations in the same way. The potential advantage of pooled OLS is when there is reason to believe that each five-year period can be viewed as a single observation and not to consider the country-fixed effects. In the present case, the fixed effects are preferable, but pooled OLS estimates also provide important information as the number of observations increase and it allows us to treat each period as a single observation.

4. Empirical results cross-sectional analysis

4.1 Cross-sectional regression results

The results of the cross-sectional analysis for 1980-2009 are presented in tables 4 and 5. The reason for including the latter years, and potentially measuring a ‘financial crisis’ effect, is because I use the same period in the panel data analysis. I also ran the regression for 1980-2006, both with the WDI and the Penn estimates of GDP, and got similar results as for 1980-2009. The control variables in tables 4 and 5 do have signs that are mostly intuitive, but not all of these are statistically significant. Institutions and the age dependency ratio are clearly the two indicators that affect the level of income the most, as these are statistically significant at the 1 % level in all results. Government consumption and investments have a varying degree of significance level, and do have a positive sign when they are significant. Trade is only significant in result (5-3), albeit with a low negative coefficient.

Table 4: Dependent variable: Logarithm GDP per capita 2009 (2005 USD)

	(4-1) OLS	(4-2) OLS	(4-3) OLS	(4-4) OLS	(4-5) OLS	(4-6) OLS
Logarithm Resource Income per capita (RI)	0.198***		0.143***		0.136***	
	(5.27)		(4.42)		(2.88)	
Resource Income Share of GDP (RIS)		0.00237		0.00742**		0.00874**
		(0.42)		(2.55)		(2.46)
Sec and Tet Education (STE)	0.679***	0.348***				
	(4.98)	(3.11)				
Patents (P)			0.00713***	0.00217		
			(4.03)	(1.12)		
Research and Development (RD)					0.707***	0.400***
					(3.78)	(3.26)
RI*STE	-0.0632***					
	(-3.28)					
RIS*STE		0.00356				
		(0.98)				
RI*P			-0.000676**			
			(-2.21)			
RIS*P				0.000351		
				(0.69)		
RI*RD					-0.0877***	
					(-2.75)	
RIS*RD						-0.0238**
						(-2.52)
Institutions	0.137**	0.159***	0.171***	0.209***	0.181***	0.227***
	(2.45)	(2.79)	(3.55)	(4.28)	(3.05)	(4.09)
Age Dependency Ratio	-0.0366***	-0.0433***	-0.0490***	-0.0566***	-0.0408***	-0.0415***
	(-4.97)	(-5.48)	(-7.10)	(-7.95)	(-4.49)	(-4.60)
Government consumption	0.00938	0.00720	0.0212**	0.0171	0.0109	-0.0000678
	(0.94)	(0.57)	(1.99)	(1.45)	(0.72)	(-0.00)
Investment	0.0211*	0.0287**	0.0199*	0.0233*	0.0149	0.0227
	(1.81)	(2.39)	(1.66)	(1.85)	(1.01)	(1.57)
Trade	0.000841	0.000964	0.000612	0.000365	0.000650	0.000198
	(0.48)	(0.55)	(0.27)	(0.17)	(0.32)	(0.11)
Observations	103	103	110	110	75	75
R^2	0.839	0.803	0.799	0.769	0.805	0.790
Adjusted R^2	0.825	0.786	0.783	0.751	0.782	0.764

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Table 4 shows the results of the cross-section analysis using resource income. The first interesting result is that the coefficient for resource income per capita is positive and highly significant in results (4-1), (4-3) and (4-5). For instance, for (4-1) the conditional effect of a 1 % higher resource income per capita in 1980 would lead to a 0.198 % higher GDP per capita in 2009 (this effect would be unconditional if human capital = 0). This means that countries with a low level of technology have a strong positive correlation between natural resource abundance and GDP per capita. The positive correlation between natural resources and GDP per capita contradicts Sachs and Warner (1995), and is more in line with Alexeev and Conrad (2009). The most likely cause is that the dependent variable is in level terms, as in Alexeev and Conrad, and not in growth terms as in Sachs and Warner. I will return to its economic interpretation when I am discussing the marginal effects.

The conditional effect of resource dependence, measured in (4-2), (4-4) and (4-6) is less statistically significant compared to resource abundance. The interpretation of the coefficient of resource dependence is as a semi-elasticity as the specification is a semilog model (meaning that the coefficient is multiplied with 100 to show the % effect on GDP per capita). For instance, for (4-4), a one percentage point increase in natural resource income as a share of GDP in 1980 is correlated with a 0.742 % higher GDP per capita in 2009. As mentioned, the statistical robustness of the resource abundance results are stronger than for resource dependence. This is caused in part by a bias in the resource dependence indicator, as countries with a high resource dependence will have a relatively lower income level. The resource dependence coefficient is, however, still positive. As mentioned, for the true effect of natural resources, the marginal effect has to be considered which will be done below.

All technology coefficients, apart from patents in (4-4), are positive and significantly correlated with GDP per capita. The coefficients are semi-elasticities. For (4-1) this means that the conditional effect of a 1 year higher average years of secondary and tertiary education in 1980 is correlated with a 67.9 % higher GDP per capita in 2009 (for the effect to be unconditional the natural resource indicator needs to = 0). The size of the coefficient is remarkably high, and is probably a result of (i) the length of the time-period, from 1980 to 2009; and (ii) the skewedness of the educational data, with approximately 80 % of observations being for 3 years of education or less (see appendix 2 table A2.4). The results indicate that technology is positively correlated with GDP per capita, which is line with most economic theory and empirics.

The interaction term is negative and statistically significant in results (4-1), (4-3) and (4-5); indicating that resource abundance lowers the effect of the level of technology and vice versa. For instance, for (4-1) the interaction term is -0.063. This means that if people in a country have an average of 1 year of secondary and tertiary education (human capital = 1), the unconditional effect of a 1 % higher natural resource income per capita in 1980 leads to a (0.198 – 0.063 =) 0.135 % higher GDP per capita in 2009.

If true, a higher level of technology lowers natural resources correlation with GDP per capita. Numerous potential mechanisms could explain these results. The first potential mechanism is reduced demand for human capital as proposed by Gylfason (2001). He claimed that a larger resource abundance lowered the demand for human capital in countries with a large natural resource sector. One could also argue that the quality of education in resource-abundant countries lowers the competitive pressure to generate a labour force with good quality education.

A second potential explanation for a negative interaction might be adverse policies, which is a non-deterministic cause. It might reflect government misspending in resource-abundant countries as growth enhancing policies such as investing in human capital have not been pursued (Atkinson and Hamilton, 2003).

However, the converse might be true as well in that the results are caused by ‘policy successes’. Resource abundance has a conditionally positive coefficient indicating that resource-abundant economies have a higher GDP per capita. The negative coefficient of the interaction term can be caused by a ‘maturity’ effect. As an economy expands, the level of technology gets higher, and the economy increasingly diversifies. The diversification in turn causes the relative (but not necessarily the absolute) contribution of natural resources to decline. The economic policies that promote diversification might therefore potentially lower the effect of natural resources on GDP.

Resource exports as a share of GDP is the most common used indicator in the early literature on the resource curse. To test how resource exports fare, compared to resource income, I redid the same analysis as in table 4, but for resource exports, as shown in table 5. For instance, (5-1) shows that the conditional effect of a 1 % higher resource exports per capita in 1980 leads to a 0.294 % higher GDP per capita in 2009. The results obtained are different from Sachs and Warner (1995), for instance, in that the coefficients for resource exports (absolute values in (5-1), (5-3) and (5-5)) are positive and significant and the coefficients for resource exports as a share of GDP (relative values in (5-2), (5-4) and (5-6)) are mixed. In none of the specifications did I find a robust negative coefficient, meaning that I found no evidence of a resource curse.

Table 5: Dependent variable: Logarithm of GDP per capita 2009 (2005 USD)

	(5-1) OLS	(5-2) OLS	(5-3) OLS	(5-4) OLS	(5-5) OLS	(5-6) OLS
Logarithm Resource Exports per capita (RE)	0.294***		0.222***		0.235***	
	(5.72)		(6.65)		(4.53)	
Resource Exports Share (RIS)		-0.00372		0.0162***		0.0152*
		(-0.32)		(2.77)		(1.90)
Sec and Tet Education (STE)	0.584***	0.254**				
	(3.13)	(2.39)				
Patents (P)			-0.00184	0.00238		
			(-0.13)	(1.22)		
Research and Development (RD)					0.469	0.285**
					(1.61)	(2.47)
RE*STE	-0.0753**					
	(-2.42)					
RES*STE		0.0123**				
		(2.26)				
RE*P			0.000387			
			(0.17)			
RES*P				-0.000830		
				(-0.80)		
RE*RD					-0.0572	
					(-1.15)	
RES*RD						-0.0145
						(-0.65)
Institutions	0.144**	0.137**	0.174***	0.223***	0.127**	0.188***
	(2.50)	(2.32)	(3.67)	(4.45)	(2.21)	(3.15)
Age Dependency Ratio	-0.0467***	-0.0481***	-0.0516***	-0.0601***	-0.0455***	-0.0475***
	(-6.53)	(-5.89)	(-7.81)	(-8.01)	(-5.63)	(-4.96)
Government consumption	-0.00127	0.0204	0.00882	0.0222	0.00407	0.0112
	(-0.09)	(1.34)	(0.73)	(1.65)	(0.25)	(0.65)
Investment	0.00944	0.0331**	0.0122	0.0253*	0.00608	0.0181
	(0.71)	(2.53)	(1.02)	(1.86)	(0.41)	(1.16)
Trade	-0.00246	-0.00135	-0.00329**	-0.00303	-0.00154	-0.000780
	(-1.53)	(-0.76)	(-2.09)	(-1.44)	(-0.99)	(-0.35)
Observations	84	86	89	91	64	65
R^2	0.865	0.823	0.856	0.804	0.862	0.811
Adjusted R^2	0.850	0.805	0.842	0.785	0.842	0.784

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Again, this is probably caused by the choice of dependent variable. In addition, the Sachs and Warner findings were for the period 1970-1990, a period with much macroeconomic instability. My findings are for the 1980-2009 period, which for the most part was a more stable period. Finally, the difference might also be caused by the difference in specification. Sachs and Warner measured the unconditional effect of natural resource exports, whereas I only measure the conditional effect.

Possibly the most interesting finding is result (5-2), which shows an interaction term with a positive statistically significant coefficient. Taken literally, human capital in 1980 contributed more to GDP per capita in those countries with a higher share of natural resource exports (of GDP) in 1980. The study by Bravo-Ortega and De Gregorio (2006) claimed to find a positive link between natural resources and technological progress. As in result (5-2), their measure of resource abundance was natural resource exports as a share of GDP and their technology indicator was the level of human capital. The Bravo-Ortega and De Gregorio (2006) result might therefore have been caused by their choice in resource and technology indicator, rather than reflecting a true relationship.

Overall, to summarise, the cross-section analysis indicated three things. First, the conditional effect of natural resources was positively correlated with GDP per capita. Second, the conditional effect of technology was also positively correlated with GDP per capita. Finally, the coefficient of the interaction term was negatively correlated with GDP, indicating that natural resources lowers the effect of technology on GDP per capita and vice versa.

4.2 Cross-sectional marginal effects

4.2.1 Marginal effect of natural resources

Equation (3) showed the marginal effects of natural resources. I only consider the marginal effects of table 4, as I believe that natural resource income is a more reliable indicator than natural resource exports. For result (4-1) from table 4 the marginal effect of resource income per capita is:

$$\frac{\partial \ln(GDP\ per\ capita)_{2009}}{\partial \ln(Natural\ Resource\ Income\ per\ capita)_{1980}} = 0.198 - 0.0632 Human\ Capital_{1980} \tag{8}$$

The effect of the level of natural resource income on GDP lowers with the level of education. Figure 4 shows this effect with the corresponding 95 % levels of confidence. The marginal effect of natural resources remains positive for countries with a low level of human capital. For higher levels of human capital, natural resources are no longer statistically significant at the 95 % level. These results indicate that natural resource abundance is not significantly correlated with GDP per capita in 2009 for countries with high levels of human capital in 1980.

The confidence intervals in figure 4 can potentially be explained by the distribution of observations. As shown in table A2.4 in appendix 2, more than 80 % of the observations have less than two years of combined secondary and tertiary education. It also means that the marginal effects are statistically significant for the majority of countries.

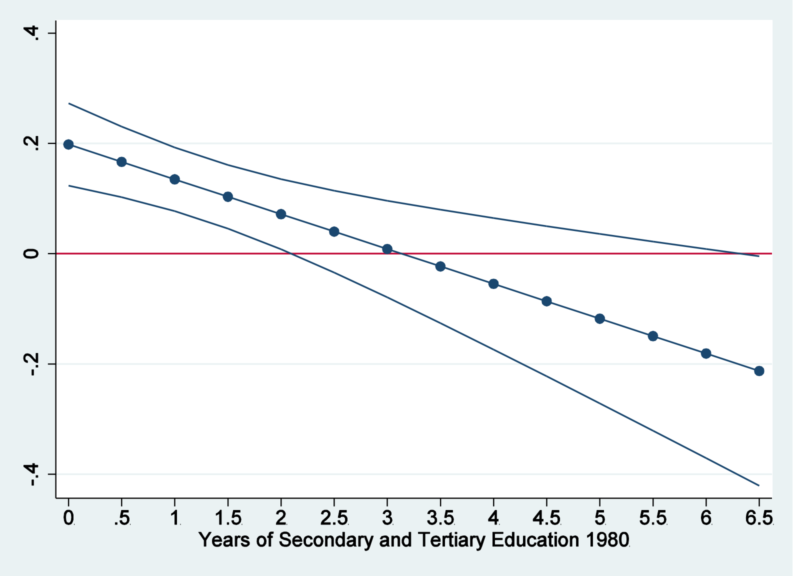

Figure 4: Marginal Effects of Resource Abundance using Equation (8)
Note: the middle line shows the marginal effects of a 1% higher natural resource income per capita on real GDP per capita at different levels of human capital. The upper and lower lines are 95 % confidence intervals

Equation 8 and figure 4 therefore indicate that natural resource abundance is positively correlated with the level of income. This can be explained through a number of potential mechanisms. The first potential mechanism is through government investments. Higher resource income can increase government income, which increases government savings and investments. These investments can improve infrastructure, schooling or other project that might benefit the economy in the long-run. Developing countries could potentially use these investments to finance a big-push industrialisation through a number of complementary investments.

The second potential mechanism is through reduced tax. If the government receives more resource revenues, it could reduce the tax rate for the rest of the economy. This could potentially increase private savings and in turn private investments, which again could increase economic growth.

A third potential mechanism could be through increased imports, especially if most of the natural resources are exported. If more foreign currency is generated, natural resources can increase the imports of more technologically advanced goods which could be used to upgrade the level of technology, which in turn can improve economic growth.

A final mechanism mentioned is that the natural resources themselves contribute through increased productivity and linkages (David and Wright, 1997). Increased productivity means that natural resources contribute to economic growth through direct production and through the release of labour and capital to other sectors. Resource sectors can also generate increased economic activity by increasing linkages to other sectors, thereby potentially increasing value-added.

If patents or R&D were used as the technology indicator, instead of human capital (in effect, results (4-3) and (4-5) from table 4), the results remain similar, see figure A3.1 and A3.5 in appendix 3. The distribution of both patents and R&D is also skewed, as can be seen in table A2.5 and A2.6 in appendix 2. For patents, 88 % of the countries had a score of 25 patents (as patents per capita are multiplied with 1,000,000 it means 0.000025 patents per capita); while 98 % of the countries had a score of less than 100 patents (meaning 0.0001 patents per capita). For R&D, 59 % of the countries had less than and R&D expenditure of 0.5 % of GDP; while 80 % of the countries had a R&D expenditure less than 1 % of GDP. In other words, the pattern is similar as for human capital, with the economic interpretation also being broadly similar.

For resource dependence, I analyse result (4-2) from table 4. The marginal effect with respect to resource dependence is:

$$\frac{\partial ln(GDP\ per\ capita)_{2009}}{\partial Resource\ Income\ Share_{1980}} = 0.00237 + 0.00356 Human\ Capital_{1980} \tag{9}$$

This equation is interesting as the resource income share is predicted to have a higher correlation with GDP the higher level of human capital. However, as figure 5 shows, the marginal effects associated with equation (9) are largely insignificant, apart from some intermediate values of human capital. The bulge in the confidence interval is likely to be a fluke because no evidence of a similar effect can be found when using the other technology indicators (see figures A3.2 and A3.6 in appendix 3). This means that resource dependence in 1980 is unlikely to be statistically significantly correlated with GDP per capita in 2009. The result therefore indicates that resource dependence is largely uncorrelated with levels of GDP, while resource abundance is positively correlated with higher levels of GDP.

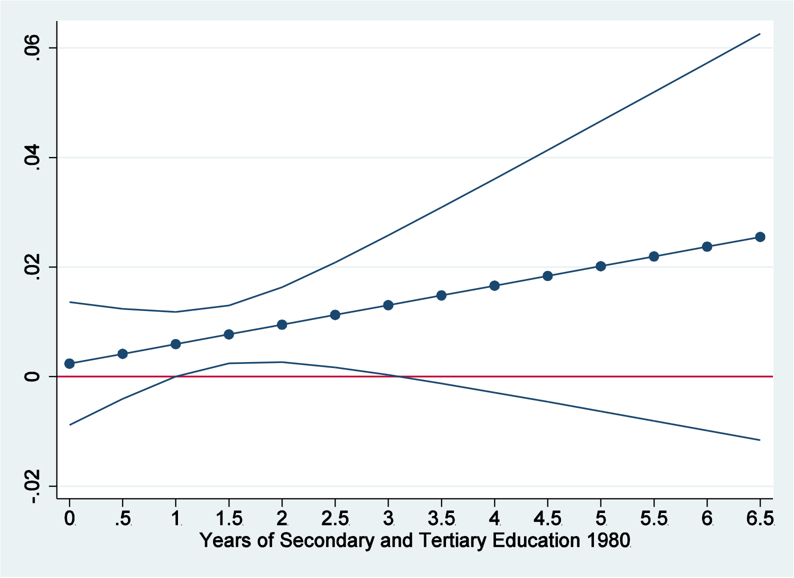

Figure 5: Marginal Effects of Resource Dependence using Equation (9)

Note: The middle line shows the marginal effects (needs to multiplied by 100) of a one percentage point higher natural resource income share of GDP on real GDP per capita at different levels of human capital. The upper and lower lines are 95 % confidence intervals

4.2.2 Marginal effect of technology

To consider the effect of technology, I only consider the marginal effects associated with (4-1) and (4-2) from table 4. For result (4-1) the marginal effect of resource abundance is:

$$\frac{\partial ln(GDP\ per\ capita)_{2009}}{\partial Human\ Capital_{1980}} = 0.679 - 0.0632\ln(Natural\ Resource\ Income\ per\ capita)_{1980} \qquad (10)$$

An increase in the number of years of education (secondary and tertiary) is thereby less correlated with GDP per capita the higher the resource abundance. Figure 6 indicates that there is a positive, but declining correlation. This correlation only becomes insignificant for a logarithm natural resource income of around 8. More than 90 % of the countries have a lower level of resource abundance than 8, see table A2.2. A feature of resource abundance is its relatively smooth distribution of data (compared to the technology indicators), see table A2.2. A smoother distribution, and thereby more natural variation in the data, might actually give a truer effect than some of the above equations.

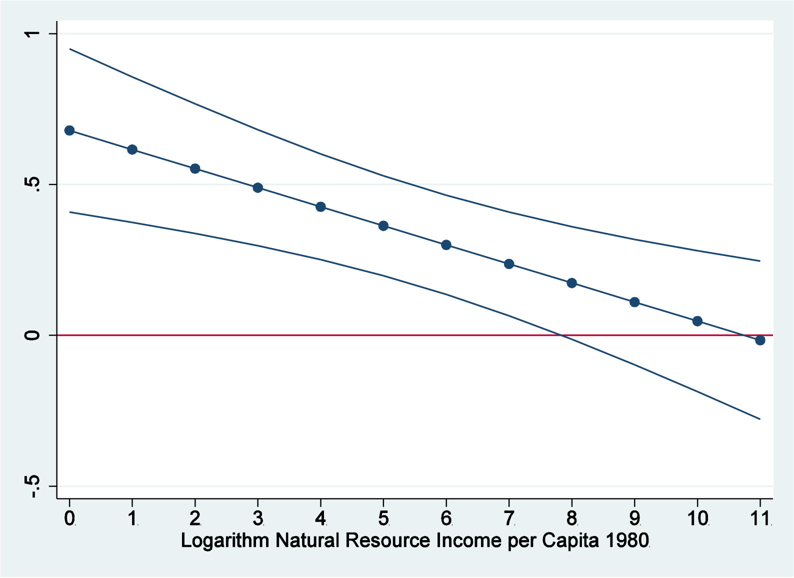

Figure 6: Marginal Effects of Human Capital using Equation (10)
Note: The middle line shows the marginal effects (needs to multiplied by 100) of a 1 year higher human capital on real GDP per capita at different levels of resource abundance. The upper and lower lines are 95 % confidence intervals

The results indicate a positive effect of human capital that is lower the higher resource abundance. The positive impact of human capital is expected, as increased education increases labour productivity and learning. The relationship exhibited in figure 6 could potentially be explained by the mechanisms I mentioned before: (i) Decreased demand for human capital; (ii) Policy failures; and (iii) Increased diversification with increasing maturity.

There might be an element of truth in all of these, since the direction of causality is therefore difficult to differentiate. However, one result does seem clear. There is no evidence that resource abundance and human capital have positive synergies, meaning that a higher level of technology does not increase the effect of natural resources on GDP and vice versa.

The evidence is not dependent on measuring technology as human capital. When patents and R&D are the technology indicators, the results are the same (see figure A3.3 and A3.7 in appendix 3). If anything, the evidence for patents and R&D shows an even greater 'penalty' of resource abundance, as the marginal effects of these two technology indicators becomes insignificant for lower levels of resource abundance than for human capital. However, this might also be caused by selection bias, the differences between developing and advanced is likely to be larger for patents and R&D then for human capital.

For equation (4-2), the marginal effect of human capital is:

$$\frac{\partial ln(GDP\ per\ capita)_{2009}}{\partial Human\ Capital_{1980}} = 0.348 + 0.00356 Resource\ Income\ Share_{1980} \tag{11}$$

An increase in the number of years of education (secondary and tertiary) is therefore positively correlated with GDP per capita, the higher the resource dependence (see figure 7). The results are statistically significant up until a resource dependence of a 100 %. In fact, 96 % of all countries (all but two countries) have a resource dependence in 1980 of less than a 100 %, see table A2.3 in appendix 2.

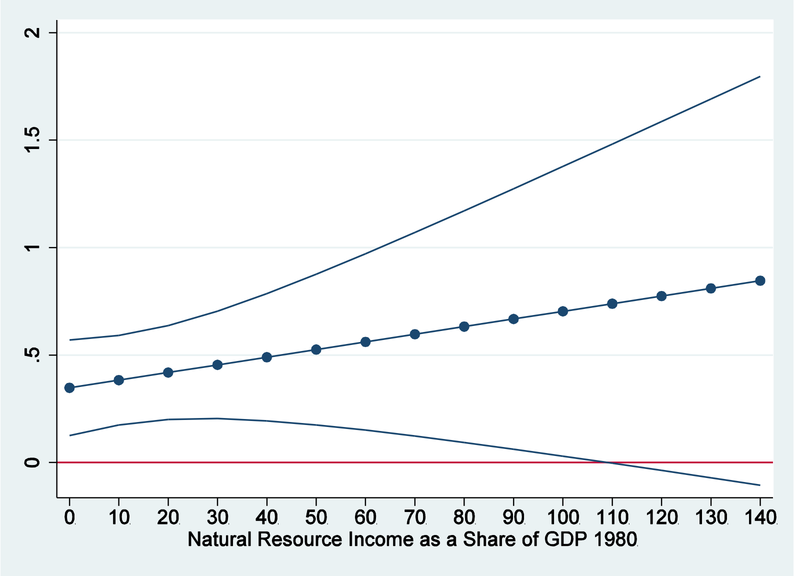

Figure 7: Marginal Effects of Human Capital using Equation (11)

Note: The middle line shows the marginal effects (needs to multiplied by 100) of a 1 year higher human capital on real GDP per capita at different levels of resource dependence. The upper and lower lines are 95 % confidence intervals

Figure 7 indicates a positive and statistically significant effect of human capital, which rises for higher levels of resource dependence. If true, it would be consistent with the findings of Bravo-Ortega and De Gregorio (2006), who predicted that a high level of human capital could offset the resource curse. It would also be in line with economic historians that claim that there are increasing returns to natural resources, and that the level of technology determines the impact resources have on the economy (Wright and Czelusta, 2006). It would also be in line with the research of Stijns (2006), who claimed that human capital increases with natural resources.

The problem with these findings is that they are not in line with the results when using patents and R&D as technology indicators instead (see figures A3.4 and A3.8 in appendix 3). I already mentioned that there might be a selection bias in patents and R&D, but it does indicate that the relationship between the effect of various technology indicators and resource dependence might differ. One regression result does not constitute sufficient evidence of a relationship. If true, one should be able to find corresponding evidence from the panel data specifications.

5. Empirical results panel data analysis

5.1 Panel data results

The panel data analysis analyses GDP per capita for two natural resource indicators (resource abundance and resource dependence) and three technology indicators. Table 6 provides an overview of where the different indicators are presented.

Table 6: Panel Data Analysis Overview Table

		Technology Indicators		
		Human Capital	Patents	Research and Development
Natural Resource Indicators	Resource Abundance: Natural Resource Income	Table 7	Table 9	Table 11
	Resource Dependence: Natural Resource Share	Table 8	Table 10	Table 12

All results (tables 7 through 12) have similar signs and significance for the coefficients of the control variables. Institutions, government consumption and the age dependency ratio are all highly significant when using pooled OLS, but the effect for institutions and government consumption disappears when using fixed effects as there is little variation over time in these variables. In contrast, investments and trade are not statistically significant when pooled OLS is used, but become statistically significant when fixed effects are used as the estimation allows for variation within the countries.

5.1.1 Resource Abundance and Human Capital

Table 7 presents the panel data results when resource income per capita is the resource indicator and human capital is the technology indicator. Pooled OLS results (7-1), (7-2), (7-3), give a strong positive coefficient for conditional effect of resource income. In (7-3) the conditional effect of a 1 % higher five-year average of resource income per capita is an 0.208 % higher five-year average GDP per capita the subsequent period (being unconditional if human capital = 0). Time trends and time dummies do not affect the pooled OLS results noteworthy. For the fixed effects, the interpretation of the resource income coefficients are the same in (7-4), (7-5) and (7-6), but the coefficients are less statistically significant.

These results are similar to those with cross-sectional data; the economic interpretation is also similar. This means that natural resources potentially have a positive effect on GDP per capita, which, as mentioned, could potentially be caused by (i) Government investments; (ii) Reduced tax; (iii) Increased imports; or (iv) Increased productivity and linkages in the resource sector. To examine the robustness of the finding, one needs to consider the marginal effects that will be done below.

The conditional effect of human capital is similarly positive and statistically significant for pooled OLS. As the coefficient in (7-3) is a semi-elasticity, a 1 year higher secondary and tertiary education (five-year average) is correlated with a 38.4 % higher GDP per capita in the subsequent five-year period (again, this effect is unconditional if resource income = 0). For fixed effects, human capital also has a positive and statistically significant conditional effect.

These results are the same as for the cross-sectional analysis, and indicate that human capital has a positive impact on GDP per capita as expected. The most likely explanation is that a higher level of human capital increases labour productivity and learning in the economy. Again, the marginal effects will assess whether these conditional effects are sufficiently strong to generate a net positive impact of human capital.

The interaction term is in each case negative and statistically significant, thereby lowering the effect of both natural abundance and human capital on GDP. For (7-3) (assuming that years of schooling = 1) the unconditional effect of a 1 % higher level of natural resource income will be a (0.208 % – 0.048 % =) 0.16 % higher GDP per capita the subsequent five-year period. Also for (7-3) (assuming that the logarithm of resource income per capita = 1), the unconditional effect of a 1 year higher level of secondary and tertiary education is correlated with a (38.4 % - 4.8 % =) 33.6 % higher GDP per capita in the subsequent five-year period. For fixed effects, the interaction term remains negative and statistically significant, but only at the 10 % level when controlling for time trend and time fixed effects. The potential economic interpretation of the pooled OLS is similar to the cross-sectional case.

Table 7: Dependent variable: Logarithm of GDP per capita

	(7-1) Pooled OLS	(7-2) Pooled OLS	(7-3) Pooled OLS	(7-4) FE	(7-5) FE	(7-6) FE
Logarithm Resource Income per capita (RI)	0.209***	0.207***	0.208***	0.0414*	0.0412*	0.0374
	(5.44)	(5.11)	(5.09)	(1.85)	(1.73)	(1.55)
Years of Schooling (YS)	0.383***	0.385***	0.384***	0.197***	0.0968**	0.0958**
	(4.38)	(4.27)	(4.26)	(5.59)	(2.39)	(2.34)
RI*YS	-0.0483***	-0.0476***	-0.0476***	-0.0116**	-0.00981*	-0.00968*
	(-3.68)	(-3.48)	(-3.47)	(-2.06)	(-1.70)	(-1.68)
Age Dependency Ratio	-0.0339***	-0.0341***	-0.0341***	-0.00876***	-0.00561**	-0.00549**
	(-5.73)	(-5.69)	(-5.66)	(-3.39)	(-2.41)	(-2.35)
Government consumption	0.0245***	0.0245***	0.0245***	0.00198	0.00318	0.00317
	(3.15)	(3.13)	(3.11)	(0.95)	(1.57)	(1.58)
Investment	-0.00212	-0.00242	-0.00248	0.00603***	0.00594***	0.00588***
	(-0.25)	(-0.28)	(-0.29)	(2.65)	(2.90)	(2.86)
Trade	0.000712	0.000781	0.000786	0.00337***	0.00283***	0.00268***
	(0.50)	(0.54)	(0.54)	(3.98)	(3.31)	(3.16)
Institutions	0.260***	0.257***	0.257***	0.00323	0.0264	0.0252
	(7.94)	(6.38)	(6.36)	(0.13)	(1.11)	(1.04)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	520 (104)	520 (104)	520 (104)	520 (104)	520 (104)	520 (104)
R^2	0.846	0.846	0.846	0.513	0.555	0.558
Adjusted R^2	0.843	0.843	0.842	0.506	0.547	0.548

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Table 8: Dependent variable: Logarithm of GDP per capita

	(8-1) Pooled OLS	(8-2) Pooled OLS	(8-3) Pooled OLS	(8-4) FE	(8-5) FE	(8-6) FE
Resource Income Share (RIS)	0.0189*	0.0175*	0.0177*	0.00462	0.00556	0.00527
	(1.92)	(1.70)	(1.68)	(1.27)	(1.48)	(1.38)
Years of Schooling (YS)	0.236***	0.252***	0.252***	0.153***	0.0544*	0.0565*
	(3.85)	(3.63)	(3.62)	(4.79)	(1.68)	(1.69)
RIS*YS	-0.00645	-0.00604	-0.00608	-0.00289*	-0.00264*	-0.00283*
	(-1.11)	(-1.02)	(-1.02)	(-1.86)	(-1.72)	(-1.85)
Age Dependency Ratio	-0.0419***	-0.0425***	-0.0425***	-0.00970***	-0.00664***	-0.00643***
	(-7.62)	(-7.70)	(-7.68)	(-3.90)	(-2.95)	(-2.83)
Government consumption	0.0264***	0.0264***	0.0263***	0.000210	0.00187	0.00166
	(2.76)	(2.77)	(2.75)	(0.10)	(0.91)	(0.81)
Investment	0.000374	-0.000764	-0.000757	0.00636***	0.00616***	0.00614***
	(0.04)	(-0.09)	(-0.09)	(2.77)	(3.00)	(3.00)
Trade	0.000246	0.000500	0.000508	0.00333***	0.00263***	0.00252***
	(0.17)	(0.33)	(0.33)	(4.04)	(3.35)	(3.17)
Institutions	0.261***	0.248***	0.248***	0.00265	0.0257	0.0246
	(7.38)	(5.90)	(5.88)	(0.10)	(1.00)	(0.94)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	520 (104)	520 (104)	520 (104)	520 (104)	520 (104)	520 (104)
R^2	0.819	0.820	0.820	0.515	0.561	0.564
Adjusted R^2	0.816	0.817	0.816	0.507	0.553	0.554

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Table 9: Dependent variable: Logarithm of GDP per capita

	(9-1) Pooled OLS	(9-2) Pooled OLS	(9-3) Pooled OLS	(9-4) FE	(9-5) FE	(9-6) FE
Logarithm Resource Income per capita (RI)	0.146***	0.146***	0.146***	0.0128	0.0285	0.0237
	(4.97)	(4.92)	(4.91)	(0.67)	(1.54)	(1.25)
Patents (P)	0.00953***	0.00957***	0.00960***	0.00336***	0.00209*	0.00191*
	(6.33)	(6.45)	(6.42)	(2.75)	(1.76)	(1.68)
RI*P	-0.000948***	-0.000943***	-0.000943***	0.0000145	-0.000151	-0.000148
	(-3.71)	(-3.64)	(-3.64)	(0.06)	(-0.76)	(-0.78)
Age Dependency Ratio	-0.0432***	-0.0434***	-0.0434***	-0.0155***	-0.00761***	-0.00725***
	(-9.71)	(-8.95)	(-8.91)	(-7.05)	(-3.36)	(-3.16)
Government consumption	0.0282***	0.0282***	0.0281***	0.000738	0.00292*	0.00297*
	(3.74)	(3.74)	(3.71)	(0.39)	(1.67)	(1.70)
Investment	-0.00501	-0.00526	-0.00533	0.00469**	0.00513***	0.00502***
	(-0.64)	(-0.66)	(-0.67)	(2.16)	(2.85)	(2.78)
Trade	0.00187	0.00192	0.00193	0.00365***	0.00231***	0.00213***
	(1.04)	(1.04)	(1.04)	(5.04)	(3.01)	(2.78)
Institutions	0.217***	0.215***	0.215***	0.00551	0.0300	0.0287
	(6.89)	(6.12)	(6.09)	(0.22)	(1.30)	(1.22)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	560 (112)	560 (112)	560 (112)	560 (112)	560 (112)	560 (112)
R^2	0.839	0.839	0.839	0.451	0.538	0.544
Adjusted R^2	0.837	0.836	0.836	0.443	0.531	0.534

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown.

5.1.2 Resource Dependence and Human Capital

Table 8 repeats the analysis of table 7, but uses resource dependence rather than resource abundance as its resource indicator. The results for human capital are similar for both pooled OLS ((8-1), (8-2) and (8-3)) and fixed effects ((8-4), (8-5) and (8-6)). However, the conditional effect of resource income share is only significant at the 10 % level of significance for pooled OLS and not significant for fixed effects. The coefficient associated with resource income share can be interpreted in a similar manner as resource income per capita could in table 7. The coefficient for resource dependence is a semi-elasticity. For (8-3), the conditional effect a 1 % higher level of resource income share of GDP (five-year average) is associated with a 1.77 % higher GDP per capita in the subsequent five-year period (unconditional if years of schooling = 0).

The results indicate that resource dependence is less important for GDP per capita compared to resource abundance. If true, simply being reliant on natural resources does not lower nor improve GDP per capita. This is intuitive, as countries with high resource dependence often have low growth rates and subsequently low levels of GDP per capita. This means that, in relative terms, the natural resource income has a larger share of GDP. Again, these findings need to be checked with the statistical significance of the marginal effects below.

The coefficients of the interaction terms are not significant for the pooled OLS and are significant at the 10 % level for fixed effects. These results are not in line with the findings in the cross-sectional case, as the positive coefficient between human capital and resource dependence (result (4-2) in table 4) is not statistically significant for most results (and negative for those that are significant). This means that the positive relationship found between resource dependence and human capital is probably false. However, it is difficult to give an exact interpretation without considering the marginal effects and its standard deviation, as will be done below.

5.1.3 Resource Abundance and Patents

Table 9 repeats the analysis of table 7, but replaces human capital with patents as the technology indicator. Results for the coefficients of resource abundance, associated with conditional effects, are relatively similar to those in table 7. The interpretation of the patents coefficient is again as a conditional effect. Result (9-3) implies that an increase in one patent (= patents per capita * 1,000,000) is correlated with a 0.96 % higher level of GDP per capita in the subsequent five-year period (again this effect is unconditional if RI = 0). The coefficients of the interaction term are negative and statistically significant for pooled OLS, but not for fixed effects. For (9-3), this implies that the unconditional effect of one patent (= patents per capita * 1,000,000) (given RI = 1) is a (0.96 % - 0.09 % =) 0.87 % higher level of GDP per capita in the subsequent five-year period. Again, a clearer interpretation of the statistical significance would need to consider the marginal effects.

The negative coefficient of the interaction term in the pooled OLS case might indicate less innovative activity in resource-abundant countries, as suggested by Matsen and Torvik (2005). This might be caused by increased rent-seeking as entrepreneurs seek profits in the natural resource sector, rather than enterprises which require more innovation. As mentioned, one should be cautious to interpret patent data as an indicator of technology, since it measures innovation more than the level of technology per se. As patents are more numerous in advanced economies and because the same economies are more diversified, resource abundance might therefore naturally have a relatively lower impact.

5.1.4 Resource Dependence and Patents

Table 10 repeats the same analysis as in table 9, but replaces resource abundance with resource dependence as the natural resource indicator. The coefficient associated with resource income share, measuring the conditional effect, becomes positive and significant for pooled OLS ((10-1), (10-2) and (10-3)), but not for fixed effects ((10-4), (10-5) and (10-6)). In addition, the coefficient associated with patents, its conditional effect, is significant for both pooled OLS and fixed effects. The interaction term is, however, no longer significant for any of the specifications in table 10.

5.1.5 Resource Abundance and Research and Development

Table 11 repeats the same analysis as in tables 7 and 9, but instead of human capital or patents, uses research and development as the technology indicator. The coefficients associated with research and development are positive and significant for pooled OLS ((11-1), (11-2) and (11-3)), but not for fixed effects when time trend and time fixed effects are controlled for in (11-5) and (11-6). These coefficients show the conditional effect of research and development on GDP per capita. For (11-3), a one percentage point increase in research and development (share of GDP, five-year average) is correlated with a 57.5 % higher GDP per capita, subsequent five-year average (this conditional effect is again unconditional if the logarithm of resource income per capita = 0). The size is large, which is probably a reflection of data skewness as close to 90 % of observations have R&D expenditures of 2 % or less in GDP (see appendix 2 table A2.12).

This result is not surprising as a higher spending on R&D is correlated with more learning and innovation, both of which are associated with a higher level of GDP. Countries that invest more in R&D therefore tend to have higher income levels.

The interaction terms are positive and significant for the pooled OLS specification, but not for fixed effects. For (11-3), it would imply that the unconditional effect of a 1 % higher level of research and development (given that the logarithm of resource income per capita = 1) is correlated with a (57.5 % - 6.5 % =) 51 % higher level of GDP per capita the subsequent five-year period. A higher degree of resource abundance seemingly lowers the effect of research and development on GDP per capita, and vice versa.

One needs to consider the unconditional effect to pass judgement on the truely statistically significant relationship. However, this negative coefficient in the interaction term is similar to the effect on human capital and patents. This effect can be a reflection of a lower R&D, and could reflect an increase in fiscal irresponsibility or the need to invest in R&D when resource abundance is higher. Alternatively, it can be a natural consequence in that countries with more natural resources, R&D contributes less relatively to GDP as natural resources relatively contribute more.

Table 10: Dependent variable: Logarithm of GDP per capita

	(10-1)	(10-2)	(10-3)	(10-4)	(10-5)	(10-6)
	Pooled OLS	Pooled OLS	Pooled OLS	FE	FE	FE
Resource Income Share (RIS)	0.0125***	0.0125***	0.0127***	0.000416	0.00258	0.00200
	(2.77)	(2.69)	(2.66)	(0.17)	(1.05)	(0.77)
Patents (P)	0.00451***	0.00453***	0.00456***	0.00328***	0.00128**	0.00117**
	(4.13)	(4.06)	(4.07)	(5.44)	(2.37)	(2.17)
RIS*P	-0.000355	-0.000352	-0.000348	0.0000486	-0.0000218	-0.0000608
	(-0.46)	(-0.45)	(-0.44)	(0.30)	(-0.23)	(-0.60)
Age Dependency Ratio	-0.0504***	-0.0505***	-0.0505***	-0.0155***	-0.00798***	-0.00754***
	(-12.05)	(-11.18)	(-11.16)	(-7.35)	(-3.53)	(-3.26)
Government consumption	0.0316***	0.0316***	0.0315***	0.000599	0.00309	0.00303
	(3.73)	(3.73)	(3.70)	(0.30)	(1.65)	(1.59)
Investment	-0.00364	-0.00373	-0.00376	0.00491**	0.00521***	0.00508***
	(-0.43)	(-0.44)	(-0.44)	(2.15)	(2.68)	(2.63)
Trade	0.000849	0.000868	0.000890	0.00364***	0.00219***	0.00208***
	(0.47)	(0.47)	(0.48)	(4.88)	(2.94)	(2.79)
Institutions	0.261***	0.260***	0.260***	0.00591	0.0285	0.0274
	(7.70)	(6.82)	(6.80)	(0.22)	(1.14)	(1.09)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	560 (112)	560 (112)	560 (112)	560 (112)	560 (112)	560 (112)
R^2	0.815	0.815	0.815	0.449	0.538	0.544
Adjusted R^2	0.813	0.812	0.811	0.441	0.531	0.534

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Table 11: Dependent variable: Logarithm of GDP per capita

	(11-1) Pooled OLS	(11-2) Pooled OLS	(11-3) Pooled OLS	(11-4) FE	(11-5) FE	(11-6) FE
Logarithm Resource Income per capita (RI)	0.137***	0.137***	0.137***	-0.00911	0.0140	0.00754
	(3.25)	(3.24)	(3.22)	(-0.32)	(0.60)	(0.32)
Research and Development (RD)	0.572***	0.575***	0.575***	0.244**	0.123	0.115
	(3.93)	(3.92)	(3.91)	(2.22)	(1.65)	(1.57)
RI*RD	-0.0647**	-0.0647**	-0.0646**	-0.00926	-0.00401	-0.00258
	(-2.38)	(-2.37)	(-2.36)	(-0.49)	(-0.31)	(-0.20)
Age Dependency Ratio	-0.0396***	-0.0397***	-0.0397***	-0.0149***	-0.00449**	-0.00439**
	(-7.19)	(-6.70)	(-6.67)	(-6.29)	(-2.12)	(-2.05)
Government consumption	0.0240**	0.0241**	0.0241**	0.00120	0.00234	0.00218
	(2.62)	(2.61)	(2.59)	(0.50)	(1.09)	(1.04)
Investment	-0.0163*	-0.0165*	-0.0167*	0.00702**	0.00743***	0.00760***
	(-1.80)	(-1.80)	(-1.81)	(2.44)	(2.97)	(3.03)
Trade	0.000858	0.000897	0.000915	0.00431***	0.00222***	0.00205***
	(0.51)	(0.52)	(0.53)	(5.35)	(3.17)	(2.74)
Institutions	0.232***	0.230***	0.230***	-0.0117	0.00108	0.0000179
	(5.44)	(4.75)	(4.71)	(-0.43)	(0.05)	(0.00)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	385 (77)	385 (77)	385 (77)	385 (77)	385 (77)	385 (77)
R^2	0.830	0.830	0.830	0.590	0.727	0.731
Adjusted R^2	0.827	0.826	0.825	0.582	0.720	0.722

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

Table 12: Dependent variable: Logarithm of GDP per capita

	(12-1) Pooled OLS	(12-2) Pooled OLS	(12-3) Pooled OLS	(12-4) FE	(12-5) FE	(12-6) FE
Resource Income Share (RIS)	0.00993	0.00988	0.00986	-0.00303	-0.00137	-0.00188
	(1.30)	(1.28)	(1.26)	(-1.18)	(-0.51)	(-0.65)
Research and Development (RD)	0.259***	0.261***	0.262***	0.228***	0.0924*	0.0936*
	(2.85)	(2.78)	(2.76)	(3.36)	(1.81)	(1.80)
RIS*RD	-0.0204	-0.0204	-0.0203	-0.00421	0.00637	0.00522
	(-1.01)	(-1.01)	(-0.99)	(-0.67)	(1.63)	(1.28)
Age Dependency Ratio	-0.0453***	-0.0454***	-0.0454***	-0.0136***	-0.00412**	-0.00391*
	(-8.35)	(-7.83)	(-7.80)	(-6.50)	(-2.06)	(-1.92)
Government consumption	0.0264***	0.0264***	0.0264***	0.000628	0.00219	0.00193
	(2.67)	(2.67)	(2.65)	(0.22)	(0.93)	(0.82)
Investment	-0.0123	-0.0124	-0.0126	0.00767**	0.00702***	0.00726***
	(-1.33)	(-1.35)	(-1.36)	(2.48)	(2.66)	(2.72)
Trade	-0.000449	-0.000418	-0.000411	0.00455***	0.00227***	0.00213***
	(-0.31)	(-0.29)	(-0.28)	(5.54)	(3.12)	(2.85)
Institutions	0.269***	0.267***	0.267***	-0.00554	0.00132	0.00109
	(6.62)	(5.73)	(5.70)	(-0.20)	(0.06)	(0.05)
Country fixed effects	No	No	No	Yes	Yes	Yes
Time trend	No	Yes	No	No	Yes	No
Time fixed effects	No	No	Yes	No	No	Yes
Observations (countries)	385 (77)	385 (77)	385 (77)	385 (77)	385 (77)	385 (77)
R^2	0.812	0.812	0.813	0.599	0.729	0.733
Adjusted R^2	0.808	0.808	0.807	0.590	0.722	0.725

Notes: t statistics in parentheses based on clustered standard errors proposed by Liang and Zeger (1986), see Angrist and Pischke (2008) pp.231-240.
* Significant at the 10 % level, ** Significant at the 5 % level, *** Significant at the 1 % level. Resource income measured in 2005 USD and the logarithm was used in the regression. Constant term is not shown

5.1.6 Resource Dependence and Research and Development

Table 12 repeats the analysis of table 11, but replaces resource abundance with resource dependence. The conditional effect of research and development is significant for both pooled OLS and fixed effects, but only at the 10 % level when time trend and time fixed effects are controlled for in (12-5) and (12-6). Both the resource income share and the interaction term are statistically insignificant for all specifications in table 12. R&D again contributes to GDP per capita, which again is potentially caused by increased learning and innovation through R&D investments.

5.2 Panel data marginal effects

5.2.1 Marginal effect of natural resources

It is not necessary to assess the marginal effects for all equations above; I only consider the pooled OLS and fixed effects specification that control for time fixed effects. I also only report a few results in this section, as the other results follow similar patterns. However, appendix 4 shows the marginal effects for all equations with time fixed effects not reported in this section.

First, I consider resource abundance conditional on human capital. Results (7-3) and (7-6) in table 7 showed the coefficients associated with pooled OLS and fixed effects respectively. The associated marginal effects of these two specifications are:

Pooled OLS Result (7-3):

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial \ln(NR\ per\ capita)_{it-1}} = 0.208 - 0.0476 Human\ Capital_{it-1} \tag{12}$$

Fixed Effects Result (7-6):

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial \ln(NR\ per\ capita)_{it-1}} = 0.0374 - 0.00968 Human\ Capital_{it-1} \tag{13}$$

Figure 8 shows the graph associated with equation (12), and shows the marginal effect of natural resource abundance (five-year average) on GDP per capita in the subsequent five-year period. The results for the pooled OLS are similar as for the cross-sectional analysis. Natural resource abundance has a positive effect on GDP per capita (but is lower the higher level of human capital), but this relationship is only significant for low levels of human capital. This result is similar for the marginal effect of natural resource abundance conditioned on patents and research and development (see appendix 4 tables A4.5 and A4.13). The findings for resource abundance are similar as for the cross-sectional case, and so is the economic interpretation. Natural resource dependence in all pooled OLS is insignificant and therefore not treated here.

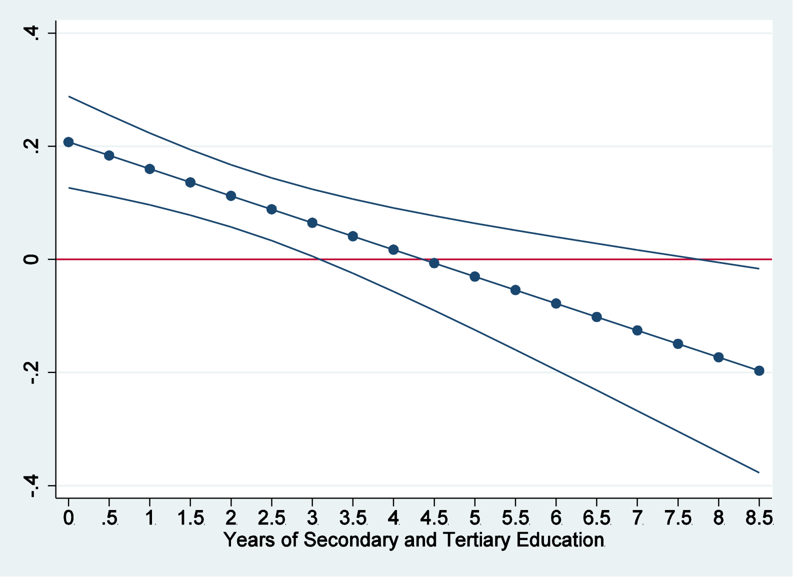

Figure 8: Marginal Effects of Resource Abundance for Pooled OLS using Equation (12)
Note: The middle line shows the marginal effects of a 1% higher natural resource income per capita on real GDP per capita at different levels of human capital. The upper and lower lines are 95 % confidence intervals

Figure 9 shows the effect associated with equation (13). The marginal effect is, as shown, not statistically significant at the 5 % level of significance. In other words, the fixed effect specification shows no relationship between resource abundance and GDP per capita. In fact, fixed effects for both natural resource abundance and natural resource dependence show up as statistically insignificant for all marginal effects specifications.[162]

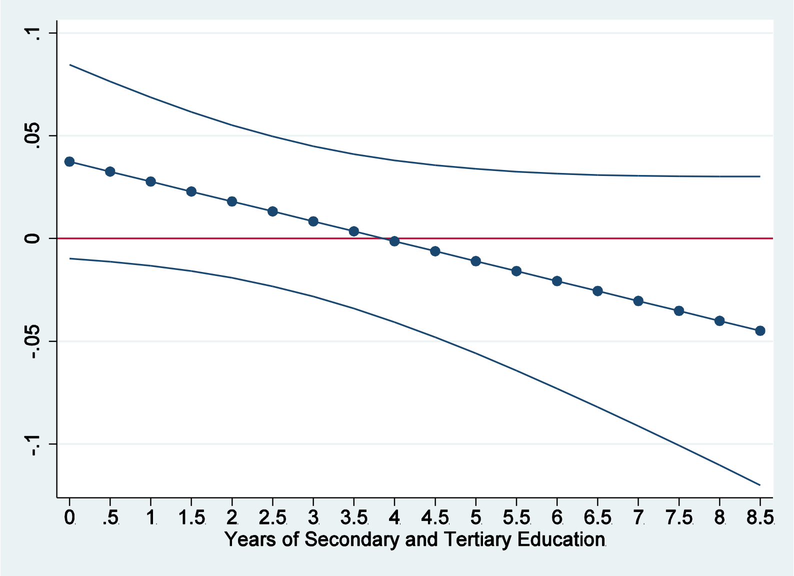

Figure 9: Marginal Effects of Resource Abundance for Fixed Effects using Equation (13)
Note: The middle line shows the marginal effects of a 1% higher natural resource income per capita on real GDP per capita at different levels of human capital. The upper and lower lines are 95 % confidence intervals

5.2.2 Marginal effects of technology

The analysis of the marginal effects of technology is done in the same manner as for the marginal effects of natural resources. I will consider the marginal effects for human capital conditioned on resource abundance for both the pooled OLS and the fixed effects results, in effect results (7-3) and (7-6) from table 7:

Pooled OLS Result (7-3):

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial Human\ Capital_{it-1}} = 0.384 - 0.0476\ln(NR\ per\ capita)_{it-1} \qquad (14)$$

Fixed Effects Result (7-6):

$$\frac{\partial ln(GDP\ per\ capita)_{it}}{\partial Human\ Capital_{it-1}} = 0.0958 - 0.00968\ln(NR\ per\ capita)_{it-1} \qquad (15)$$

Both equations predict that the effect of human capital on GDP per capita lowers with higher natural resource income per capita. Figure 10 shows the marginal effects for equation (14) and its corresponding levels of confidence. Human capital has a statistically significant impact on GDP at the 5 % level of significance for low levels of resource abundance. However, there are many observations for resource abundant countries above this level. The interpretation is that human capital only affects GDP per capita positively when resource abundance is low.

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[162] For the results of the other specifications, in effect for results (8-6), (9-6), (10-6), (11-6) and (12-6), see figures A4.2, A4.6, A4.10, A4.14 and A4.18 in appendix 4.

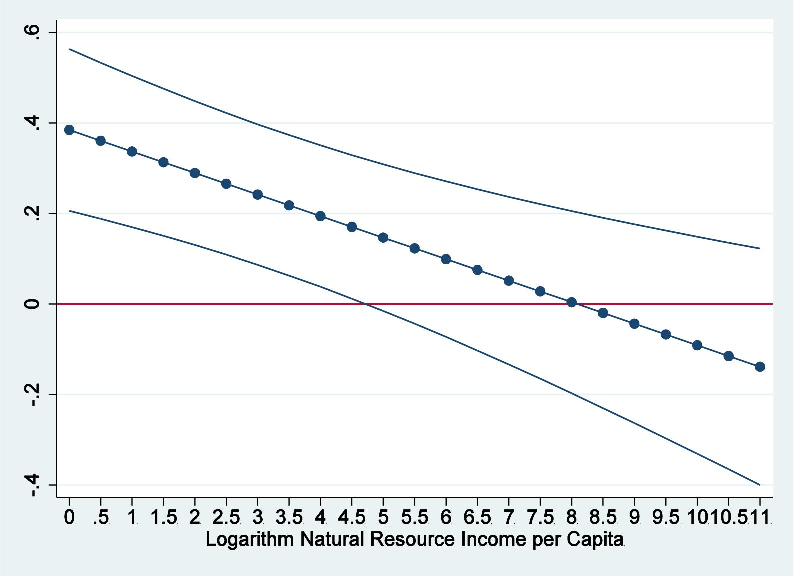

Figure 10: Marginal Effects of Human Capital for Pooled OLS using Equation (14)
Note: The middle line shows the marginal effects (needs to multiplied by 100) of a 1 year higher human capital on real GDP per capita at different levels of resource abundance. The upper and lower lines are 95 % confidence intervals

For patents and R&D, the effects are in many ways similar, but are significant for higher levels of resource abundance (see appendix 4 figures A4.7 and A4.15). The direct interpretation is that patents and R&D keep contributing at higher levels of resource abundance than does human capital. The economic interpretation is that technology is more important for GDP per capita when a country is resource poor.

Figure 11 shows the marginal effects using equation (15). The effect is statistically significant for low levels of resource abundance, as above. However, the fixed effects results are somewhat weaker than for pooled OLS for two reasons. First, the level of resource abundance for which the marginal effect of human capital becomes insignificant is lower than for pooled OLS. Second, patents and R&D show no similar pattern as human capital; meaning that the results might be caused by the choice of technology indicator rather than technology itself, see figures A4.8 and A4.16 in appendix 4.

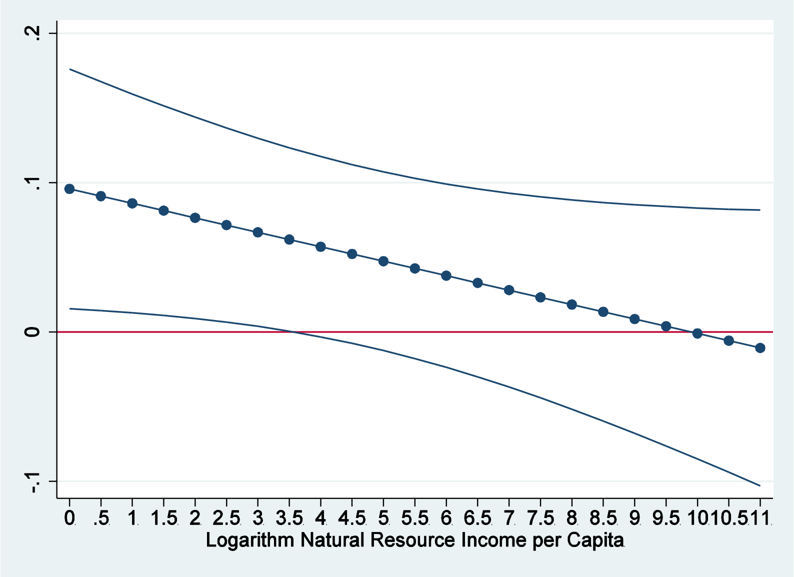

Figure 11: Marginal Effects of Human Capital for Fixed Effects using Equation (15)
Note: The middle line shows the marginal effects (needs to multiplied by 100) of a 1 year higher human capital on real GDP per capita at different levels of resource abundance. The upper and lower lines are 95 % confidence intervals

6. Comparison

In part 1, two questions were asked. The first being: 'Is the impact of natural resources on GDP per capita affected by technology?' The second being: 'Is the impact of technology on GDP per capita affected by natural resources?'

Starting with the first question, the effects of natural resources conditional on technology is summarised in table 13. There are four results that are important to take from this analysis. First, no specification showed a negative statistically significant result. In other words, there is no evidence for a resource curse. In that respect, the results of the paper are in line with a growing number of studies such as Stijns (2006) and Alexeev and Conrad (2009).

Table 13: Marginal Effects of Natural Resources on the logarithm of GDP per capita

	Cross-sectional analysis		
	Human Capital	Patents	Research and Development
Resource Abundance	Positive and declining with human capital	Positive and declining with patents	Positive and declining with R&D
Resource Dependence	Not significant	Not significant	Not significant
	Pooled OLS		
	Human Capital	Patents	Research and Development
Resource Abundance	Positive and declining with human capital; Not significant for high levels of human capital	Positive and declining with patents; Not significant for high levels of patents	Positive and declining with R&D; Not significant for high levels of R&D
Resource Dependence	Not significant	Not significant	Not significant
	Fixed Effects		
	Human Capital	Patents	Research and Development
Resource Abundance	Not significant	Not significant	Not significant
Resource Dependence	Not significant	Not significant	Not significant

Second, the fixed effects showed no significant relationship between natural resources and GDP per capita. This means that resource production within a given country is not strong enough to be positively correlated with GDP per capita. Alternatively, the processes in the different countries were diverse and cancelled each other out given the false impression of no significant relationship. This interpretation obviously depends on whether one trusts the fixed effects estimation over pooled OLS as mentioned before.

Third, for OLS and pooled OLS, resource abundance is positive and significantly correlated with GDP per capita. The correlation is lower for higher levels of technology, regardless of the measure of technology. As mentioned, the effect of technology could potentially be caused by (i) A Dutch disease effect; (ii) Poor policies; or (iii) Reflect increased diversification.

Finally, for OLS and pooled OLS, there is evidence for a positive effect of resource abundance, but no growth effect for resource dependence. Regardless of specification, resource dependence is not significant. This means that the degree of natural resource abundance is more important than being dependent on natural resources, which is intuitive. Highly resource dependent countries often have a low GDP, and the relative size of the natural resource sector might give the false impressions that they are, in fact, resource abundant.

In short, there is no evidence to support the presence of a technology 'bonus', as depicted in figure 1 Being cautious, one can argue that the middle alternative, the no correlation is the most likely as this was the result from the fixed effects estimation. However, the OLS and pooled OLS found evidence of a technology 'penalty', but only for low levels of technology.

The second question of part 1 asked: ‘is the impact of technology on GDP per capita affected by natural resources?’ Table 14 shows the effects of technology conditioned on natural resources. There are three results I find important from this analysis. First, the effect of human capital is positive and declining with resource abundance regardless of specification. It is also the case that the effect is strongest for lower levels of resource abundance. There might therefore be similar mechanisms to the ones mentioned, namely caused by (i) A Dutch disease effect; (ii) Poor policies; or (iii) Increased diversification of the production structure.

Table 14: Marginal Effect of Technology on the Logarithm of GDP per capita

	Cross-section analysis	
	Resource Abundance	Resource Dependence
Human Capital	Positive and declining with human capital; Not significant for high levels of resource abundance	Positive and increasing with human capital; Not significant for high levels of resource abundance
Patents	Positive and declining with patents; Not significant for high levels of resource abundance	Not significant
Research and Development	Positive and declining with R&D; Not significant for high levels of resource abundance	Negative and declining with resource dependence; Only significant at high levels of resource dependence
	Pooled OLS	
	Resource Abundance	Resource Dependence
Human Capital	Positive and declining with resource abundance; Not significant for high levels of resource abundance	Positive and declining with resource dependence; Only significant for very low levels of resource dependence
Patents	Positive and declining with resource abundance; Not significant for high levels of resource abundance	Not significant
Research and Development	Positive and declining with resource abundance; Not significant for high levels of resource abundance	Not significant
	Fixed Effects	
	Resource Abundance	Resource Dependence
Human Capital	Positive and declining with resource abundance; Only significant for low levels of resource abundance	Not significant
Patents	Positive and declining with resource abundance; Only significant for intermediate levels of resource abundance	Not significant
Research and Development	Not significant	Positive and increasing for resource dependence; Only significant at a low level resource dependence

Second, the effects of patents and R&D are strongest for OLS and pooled OLS. For fixed effects, R&D is not significant and patents only for intermediate levels. The reason might be that these indicators are flow rather than stock, or it might be explained by the higher degree of both patents and R&D in advanced countries.

A final result is that natural resource abundance plays a more important role in determining the effect of technology than does resource dependence. While the resource abundance results are relatively consistent, the resource dependence results vary from one specification to the next. This indicates that resource dependence has little real significance, and that the absolute amount of natural resources is more important than the resource dependence.

Figure 2 stipulated three possibilities for the impact of technology conditioned on natural resources. There is no clear evidence of a resource ‘bonus’, as only two results indicated this, which were not robust given that the other specifications failed to replicate these results. The strongest evidence for a resource 'penalty' is when human capital is used as the technology indicator.

Figure 3 described a number of potential causal links. The best evidence is for the direct links, meaning from natural resource abundance on GDP and from human capital on GDP are strong, especially the latter. For low levels resource abundance, the growth effect of human capital is high. The evidence for the other potential causal relationships (from the third to the sixth link in figure 3) are harder to differentiate. The combined effect is most likely negative, but the exact cause is beyond the scope of this paper. Given the evidence that is presented, a Dutch disease explanation is not likely as both natural resources and technology have positive correlations with GDP per capita, and no resource curse was found. The failed policy explanation is also unlikely, since no resource curse was present, and resource abundance has likely contributed to a higher GDP per capita.

The most plausible explanation is that the lower effect of resource abundance conditioned on technology and vice versa is a by-product of economic growth. As economies get more advanced and more diversified, the relative contribution of natural resources declines. Appendix 2 figure A2.1 shows a scatterplot between resource abundance and human capital, in which there is a positive correlation between the two.

Indonesia and Malaysia are two resource-abundant countries that experienced high economic growth and an improvement in the level of technology. Resource abundance, though important, plays a lesser role as these economies mature indicating that technology increasingly becomes more important the more advanced the economy. In addition, I also ran some unreported regressions of the logarithm of GDP per capita on the interaction term as the sole independent variable for all the different interactions terms, and all were highly positive significant. This means that economies, which are both resource abundant and have a high level of technology, have a higher GDP per capita than those that do not.

There are several possibilities to extend this analysis, which could be topics for future research. First, is to conduct more case studies on resource abundant countries to better understand the evolution of the level of technology within individual countries. This could be done through qualitative or quantitative studies using time-series econometrics. Case studies have the potential to be able to go more in depth into the causal mechanisms present in the different economies.

Second, I ran some unreported regressions on different types of natural resources and GDP per capita. Reporting these is beyond the scope of the study, but I did find some interesting results. Oil has a strong positive correlation with GDP per capita, while minerals have a negative correlation with GDP per capita. Exploring this link further is a promising avenue of research.

Third, I only considered linear marginal effects in this paper. There is no theoretical reason why the relationship between natural resources and technology should be linear. Understanding the true mechanics of this link is also a promising avenue of research.

Conclusion

This paper explored the link between natural resources, technology and production by analysing the question: 'How does the level of technology affect production in a country abundant in natural resources?' The first finding was that the contribution of human capital to GDP per capita is lower the higher the level of natural resources. As no evidence of a resource curse was found, these findings are most likely caused by a declining relative (but not necessarily absolute) contribution of human capital to GDP as natural resources is another factor that is correlated with a higher GDP. Countries that are maturing, in general, will most likely find that they will become less dependent on their natural resources relative to other determinants of growth.

Second, these effects were found to be robust for resource abundance but not for resource dependence. Countries rich in natural resources, in general, had a higher level of GDP, and the contribution of human capital declined with the extent of natural resources. This effect was not present for countries that are highly dependent on natural resources. One problem in the literature is that most studies measure resource abundance using a measure of resource dependence, thereby understating the true positive effect of natural resources.

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Appendix 1: Sources

Table A1: Data Description and Sources

Variable	Description and source
GDP per capita	Logarithm of GDP per capita (constant 2005 USD prices). Source: World Development Indicators (2014)
Natural resource income per capita	Logarithm of natural resource income + 1 (sum of fuel and metals) per capita (constant 2005 USD prices). Source: Haber and Menaldo (2011)
Natural resource income share	Natural resource income (sum of fuel and metals) share (% of GDP). Source: Haber and Menaldo (2011)
Natural exports per capita	Logarithm of natural exports (sum of fuel and metals) per capita (constant 2005 USD prices). Source: Calculated using data from WDI (2014)
Natural exports share	Exports resource income (sum of fuel and metals) share (% of GDP). Source: Calculated using data from WDI (2014)
Years of Schooling	Sum of years of secondary and tertiary education. Source: Barro and Lee (2013)
Patents	US Patents by Country of Origin per millionth inhabitant. Source: CANA dataset: Castellacci and Natera (2011) based on USPTO
Research and Development	R&D expenditures as a percentage of GDP. Source: CANA dataset: Castellacci and Natera (2011) based on UNESCO, OECD and RICYT
Age Dependency Ratio	Age dependency ratio (% of working population). Source: World Development Indicators online (2014)
Government Consumption	Government consumption (% of GDP). Source: UN Data National Accounts online (2014)
Investment	Gross fixed capital formation (% of GDP). Source: UN Data National Accounts online (2014)
Trade	Sum of exports and imports (% of GDP). Source: UN Data National Accounts online (2014)
Institutions	Transparency International Index, ranging from 0 (High Corruption) to 10 (Low Corruption). Source: CANA dataset: Castellacci and Natera (2011) based on Transparency International figures

Table A2: Countries Included in the Study

Albania
Algeria
Angola
Argentina
Australia
Austria
Bahrain
Bangladesh
Belgium
Benin
Bolivia
Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cameroon
Canada
Chad
Chile
China
Colombia
Costa Rica
Cote d'Ivoire
Denmark
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Ethiopia (panel data only)
Fiji
Finland
France
Gabon
Gambia, The
Germany
Ghana
Greece
Guatemala
Guyana
Haiti
Honduras
Hungary
India
Indonesia
Iran, Islamic Rep.
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kenya
Korea, Rep.
Kuwait
Lao PDR
Lebanon
Lesotho
Liberia
Madagascar
Malawi
Malaysia
Mali
Mauritania
Mauritius
Mexico
Mongolia (panel data only)
Morocco
Mozambique
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Oman
Pakistan
Panama
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Rwanda
Saudi Arabia
Senegal
Sierra Leone
Singapore
South Africa
Spain
Sri Lanka
Sudan
Swaziland
Sweden
Switzerland
Tanzania
Thailand
Togo
Trinidad and Tobago
Tunisia
Turkey
Uganda
United Kingdom
United States
Uruguay
Venezuela, RB
Vietnam
Zambia
Zimbabwe

Appendix 2: Descriptive Statistics

Part 2.1: Scatterplot Natural Resources and Human Capital

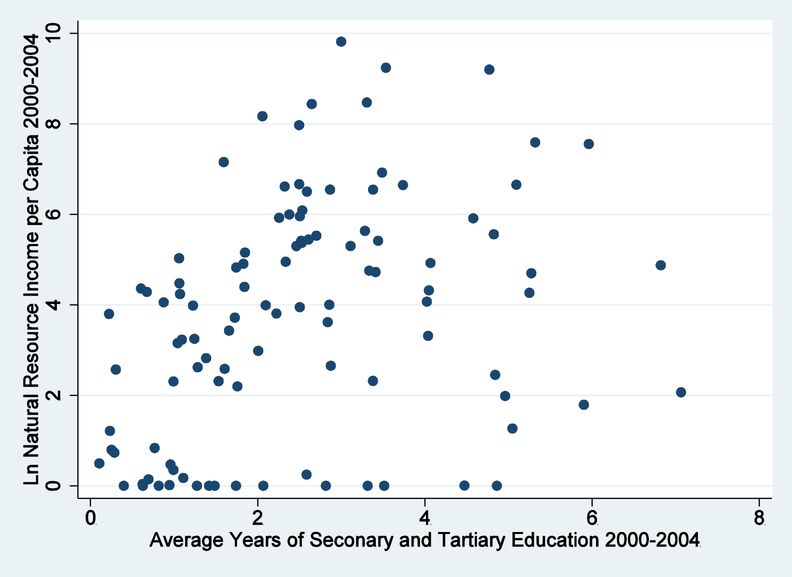

Figure A2.1: Scatterplot Resource Abundance 2000-2004 (average) and Human Capital 2000-2004 (average)

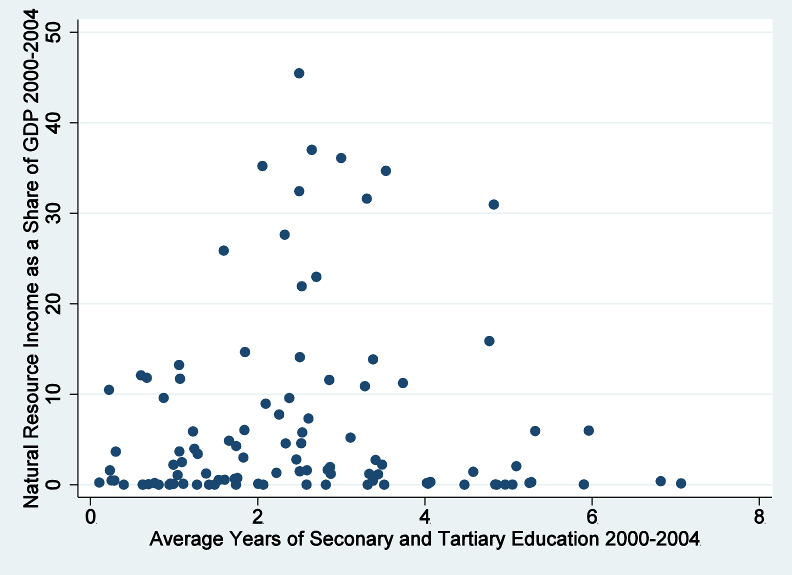

Figure A2.2: Scatterplot Resource Dependence 2000-2004 (average) and Human Capital 2000-2004 (average)

Part 2.2: Data Used in the Cross-Sectional Analysis

Table A2.1: Descriptive Statistics Data Cross-Sectional Analysis

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Logarithm of GDP per Capita 2009	110	8.155953	1.656434	5.012124	11.0835
Logarithm of Natural Resource Income per Capita 1980	110	4.205667	2.949041	0	11.10751
Natural Resource Income Share of GDP 1980	110	18.39017	30.16241	0	149.3993
Years of Secondary and Tertiary Education 1980	103	1.353559	1.221261	.0349255	6.062339
Patents 1980*1,000,000	110	10.07818	28.53786	0	200.3481
Research and Development Share of GDP 1980	75	.6056889	.704169	0	2.73721
Institutions (Corruption Perception Index) 1980	110	4.792694	2.287033	.331566	9.644138
Age Dependency Ratio 1980	110	78.7265	17.53843	46.57348	112.7663
Government Consumption Share of GDP 1980	110	16.25207	7.32312	4.277165	45.41698
Investments Share of GDP 1980	110	22.64553	7.725499	2.412204	41.43435
Trade Share of GDP 1980	110	67.16735	48.21751	11.09835	412.1636

Table A2.2: Distribution of the Logarithm of Resource Income per Capita 1980

Resource Abundance	Countries	Share	Cumulative Share
0-0.99	24	22 %	22 %
1-1.99	6	5 %	27 %
2-2.99	8	7 %	35 %
3-3.99	12	11 %	45 %
4-4.99	11	10 %	55 %
5-5.99	14	13 %	68 %
6-6.99	18	16 %	85 %
7-7.99	8	7 %	92 %
8-8.99	5	5 %	96 %
9-9.99	1	1 %	97 %
10 and above	3	3 %	100 %
Total	110	100 %	100 %

Table A2.3: Distribution of Natural Resource Income as a Share of GDP 1980

Resource Dependence	Countries	Share	Cumulative Share
0-9.9	69	63 %	63 %
10-19.9	12	11 %	74 %
20-29.9	4	4 %	77 %
30-39.9	7	6 %	84 %
40-49.9	1	1 %	85 %
50-59.9	4	4 %	88 %
60-69.9	4	4 %	92 %
70-79.9	4	4 %	95 %
80-89.9	1	1 %	96 %
90-99.9	0	0 %	96 %
100 and above	4	4 %	100 %
Total	110	100 %	100 %

Table A2.4: Distribution of Average Years of Secondary and Tertiary Education 1980

Human Capital	Countries	Share	Cumulative Share
0.00-0.49	24	23 %	23 %
0.50-0.99	26	25 %	49 %
1.00-1.49	20	19 %	68 %
1.50-1.99	13	13 %	81 %
2.00-2.49	5	5 %	85 %
2.50-2.99	5	5 %	90 %
3.00-3.49	2	2 %	92 %
3.50-3.99	2	2 %	94 %
4.00-4.49	4	4 %	98 %
4.50-4.99	0	0 %	98 %
5.00-5.49	0	0 %	98 %
5.50-5.99	1	1 %	99 %
6.00-6.49	1	1 %	100 %
Total	103	100 %	100 %

Table A2.5: Distribution of Patents 1980 * 1,000,000

Patents	Countries	Share	Cumulative Share
0-24.9	97	88 %	88 %
25-49.9	8	7 %	95 %
50-74.9	2	2 %	97 %
75-99.9	1	1 %	98 %
100 and above	2	2 %	100 %
Total	110	100 %	100 %

Table A2.6: Distribution of Research and Development as a Share of GDP 1980

R&D	Countries	Share	Cumulative Share
0.00-0.49	44	59 %	59 %
0.50-0.99	16	21 %	80 %
1.00-1.49	7	9 %	89 %
1.50-1.99	0	0 %	89 %
2.00-2.49	7	9 %	99 %
2.50-2.99	1	1 %	100 %
Total	75	100 %	100 %

Part 2.3: Data Used in the Panel Data Analysis

Table A2.7: Descriptive Statistics Panel Data Analysis Five-Year Averages

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Logarithm of GDP per Capita	560	7.886438	1.682152	4.536734	11.10468
Logarithm of Natural Resource Income per Capita	560	3.759929	2.62898	0	10.55898
Natural Resource Income Share of GDP	560	8.509861	14.06692	0	100.6234
Years of Secondary and Tertiary Education	520	1.941025	1.443419	.0349255	7.064361
Patents*1,000,000	560	14.8116	38.092	0	300.2491
Research and Development Share of GDP	385	.7426906	.8226598	0	4.577112
Institutions (Corruption Perception Index)	560	4.466476	2.191217	.8239715	9.8
Age Dependency Ratio	560	72.753	19.33401	38.05759	112.6323
Government Consumption Share of GDP	560	16.53533	7.546532	3.783005	72.70576
Investments Share of GDP	560	20.7962	7.154	2.359344	63.15103
Trade Share of GDP	560	67.5387	43.53405	7.65095	378.361

Table A2.8: Distribution of the Logarithm of Resource Income per Capita Five-Year Averages 1980-2004

Resource Abundance	Observations	Shares	Cumulative Share
0-0.99	128	22.9 %	22.9 %
1-1.99	44	7.9 %	30.7 %
2-2.99	51	9.1 %	39.8 %
3-3.99	51	9.1 %	48.9 %
4-4.99	76	13.6 %	62.5 %
5-5.99	92	16.4 %	78.9 %
6-6.99	59	10.5 %	89.5 %
7-7.99	26	4.6 %	94.1 %
8-8.99	22	3.9 %	98.0 %
9-9.99	10	1.8 %	99.8 %
10 and above	1	0.2 %	100.0 %
Total	560	100 %	100 %

Table A2.9: Distribution of Natural Resource Income as a Share of GDP Five-Year Averages 1980-2004

Resource Dependence	Observations	Shares	Cumulative Share
0-9.9	413	73.8 %	73.8 %
10-19.9	62	11.1 %	84.8 %
20-29.9	35	6.3 %	91.1 %
30-39.9	25	4.5 %	95.5 %
40-49.9	11	2.0 %	97.5 %
50-59.9	8	1.4 %	98.9 %
60-69.9	2	0.4 %	99.3 %
70-79.9	2	0.4 %	99.6 %
80-89.9	1	0.2 %	99.8 %
90-99.9	0	0.0 %	99.8 %
100 and above	1	0.2 %	100.0 %
Total	560	100 %	100 %

Table A2.10: Distribution of Average Years of Secondary and Tertiary Education Five-Year Averages 1980-2004

Human Capital	Observations	Shares	Cumulative Share
0.00-0.49	68	13.1 %	13.1 %
0.50-0.99	92	17.7 %	30.8 %
1.00-1.49	82	15.8 %	46.5 %
1.50-1.99	66	12.7 %	59.2 %
2.00-2.49	65	12.5 %	71.7 %
2.50-2.99	42	8.1 %	79.8 %
3.00-3.49	30	5.8 %	85.6 %
3.50-3.99	15	2.9 %	88.5 %
4.00-4.49	24	4.6 %	93.1 %
4.50-4.99	16	3.1 %	96.2 %
5.00-5.49	6	1.2 %	97.3 %
5.50-5.99	8	1.5 %	98.8 %
6.00-6.49	2	0.4 %	99.2 %
6.50 and above	4	0.8 %	100.0 %
Total	520	100 %	100 %

Table A2.11: Distribution of Patents * 1,000,000 Five-Year Averages 1980-2004

Patents	Observations	Shares	Cumulative Share
0-24.9	478	85.4 %	85.4 %
25-49.9	29	5.2 %	90.5 %
50-74.9	19	3.4 %	93.9 %
75-99.9	13	2.3 %	96.3 %
100-124.9	3	0.5 %	96.8 %
125-149.9	2	0.4 %	97.1 %
150-174.9	7	1.3 %	98.4 %
175-199.9	4	0.7 %	99.1 %
200-224.9	2	0.4 %	99.5 %
225-249.9	0	0.0 %	99.5 %
250 and above	3	0.5 %	100.0 %
Total	560	100 %	100 %

Table A2.12. Distribution of Research and Development as a Share of GDP Five-Year Averages 1980-2004

R&D	Observations	Shares	Cumulative Share
0.00-0.49	220	57.1 %	57.1 %
0.50-0.99	67	17.4 %	74.5 %
1.00-1.49	30	7.8 %	82.3 %
1.50-1.99	24	6.2 %	88.6 %
2.00-2.49	21	5.5 %	94.0 %
2.50-2.99	17	4.4 %	98.4 %
3.00-3.49	4	1.0 %	99.5 %
3.50-3.99	1	0.3 %	99.7 %
4.00 and above	1	0.3 %	100.0 %
Total	385	100 %	100 %

Appendix 3: Cross-Sectional Analysis

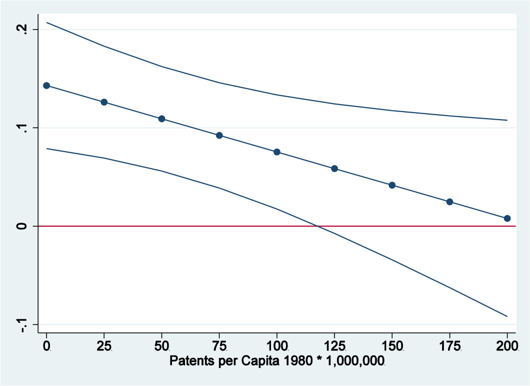

Figure A3.1: Marginal Effect of Natural Resource Abundance Using Result (4-3) from Table 4

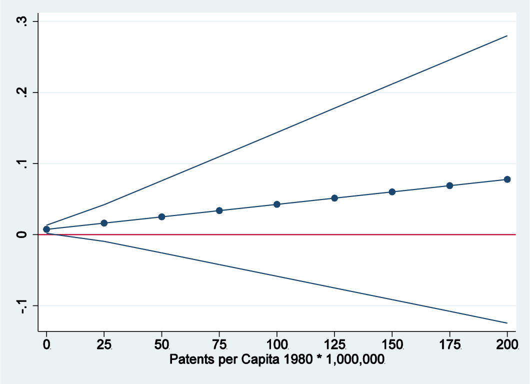

Figure A3.2: Marginal Effect of Natural Resource Dependence Using Result (4-4) from Table 4

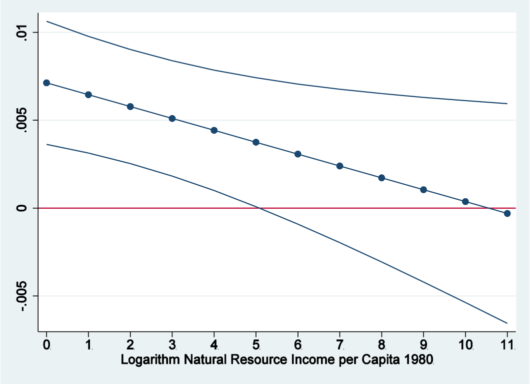

Figure A3.3: Marginal Effect of Patents Using Result (4-3) from Table 4

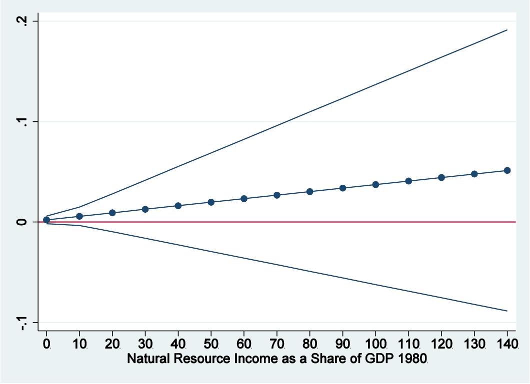

Figure A3.4: Marginal Effect of Patents Using Result (4-4) from Table 4

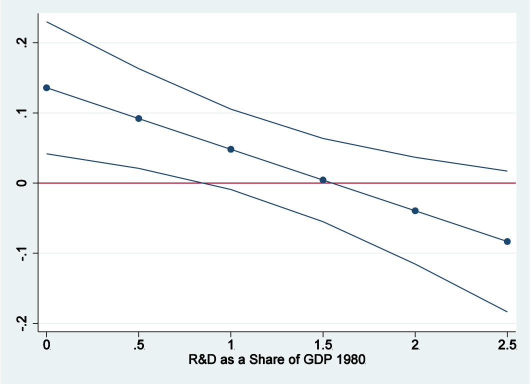

Figure A3.5: Marginal Effect of Natural Resource Abundance Using Result (4-5) from Table 4

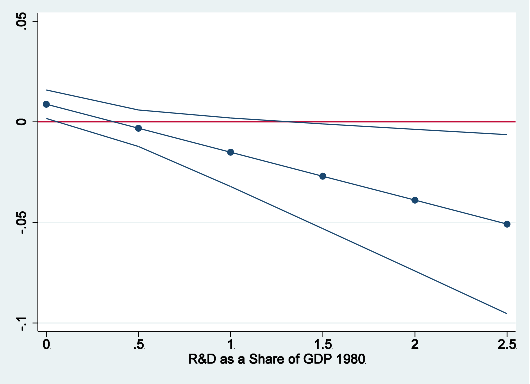

Figure A3.6: Marginal Effect of Natural Resource Dependence Using Result (4-6) from Table 4

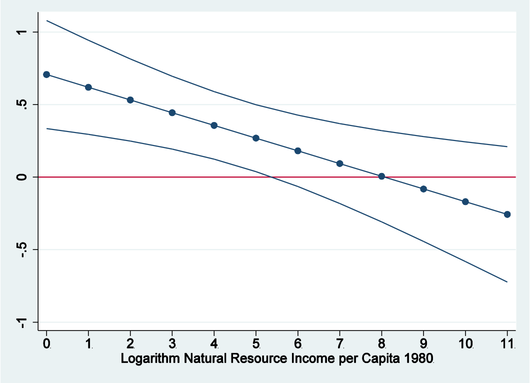

Figure A3.7: Marginal Effect of R&D Using Result (4-5) from Table 4

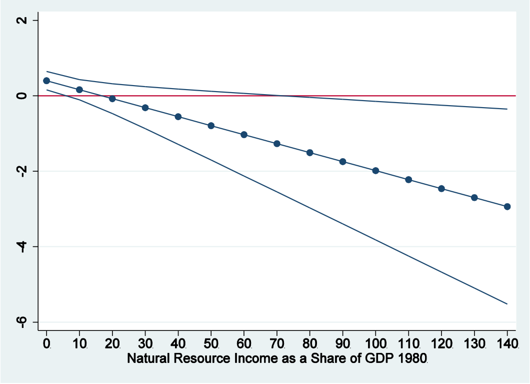

Figure A3.8: Marginal Effect of R&D Using Result (4-6) from Table 4

Appendix 4: Marginal Effects Panel Data Analysis

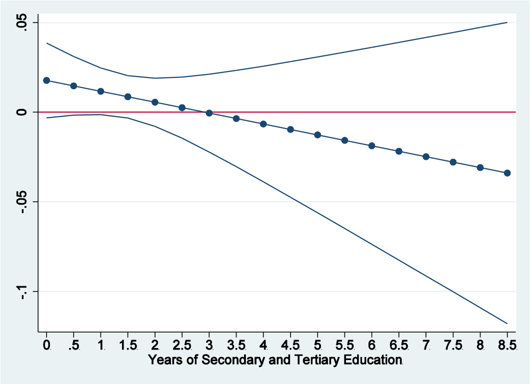

Figure A4.1: Marginal Effect of Natural Resource Dependence Using Result (8-3) from Table 8

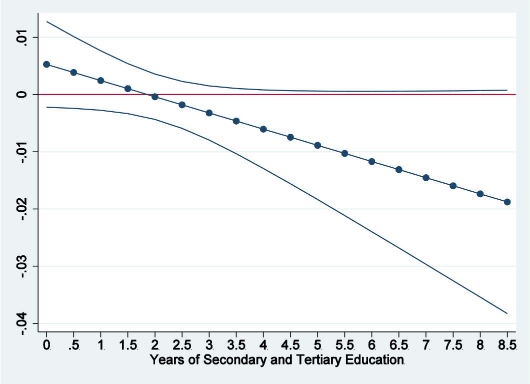

Figure A4.2: Marginal Effect of Natural Resource Dependence Using Result (8-6) from Table 8

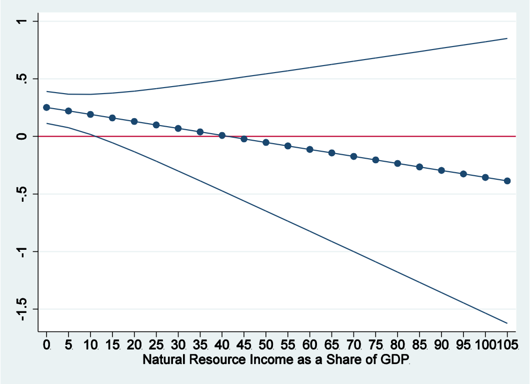

Figure A4.3: Marginal Effect of Human Capital Using Result (8-3) from Table 8

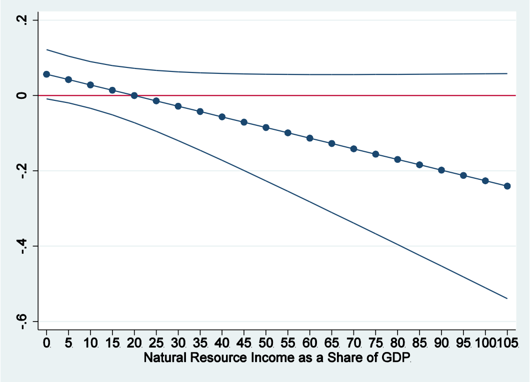

Figure A4.4: Marginal Effect of Human Capital Using Result (8-3) from Table 8

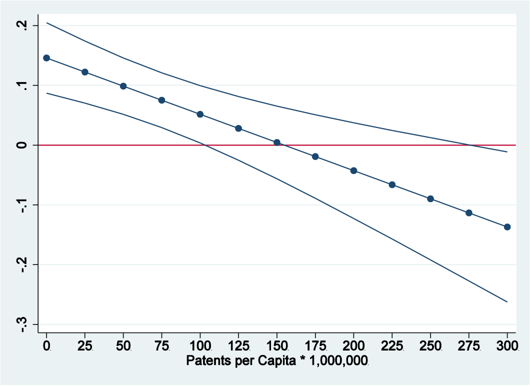

Figure A4.5: Marginal Effect of Natural Resource Abundance Using Result (9-3) from Table 9

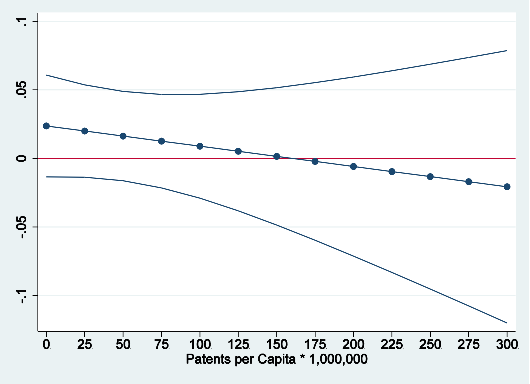

Figure A4.6: Marginal Effect of Natural Resource Abundance Using Result (9-6) from Table 9

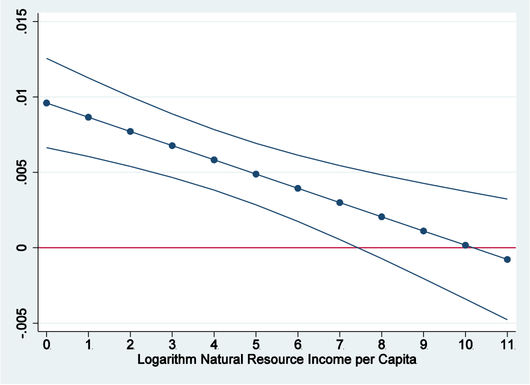

Figure A4.7: Marginal Effect of Patents Using Result (9-3) from Table 9

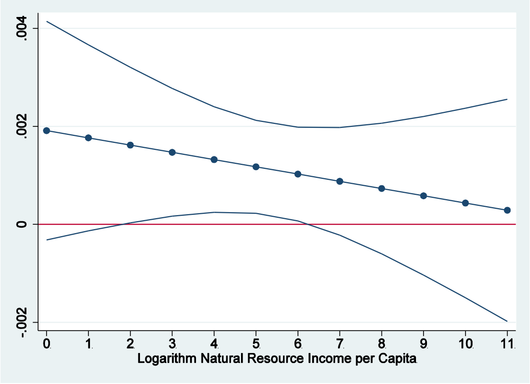

Figure A4.8: Marginal Effect of Patents Using Result (9-6) from Table 9

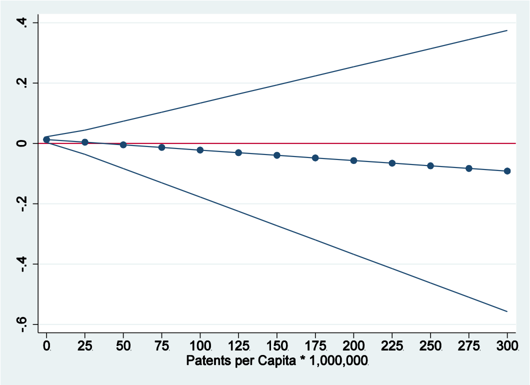

Figure A4.9: Marginal Effects of Natural Resource Dependence Using Result (10-3) from Table 10

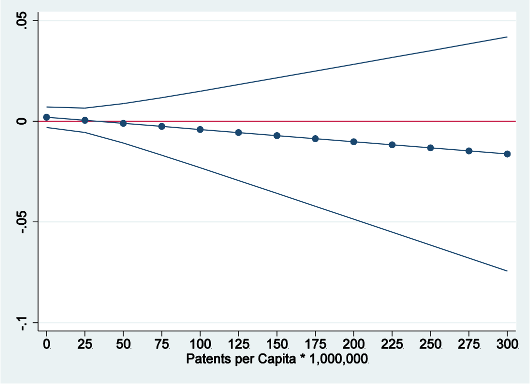

Figure A4.10: Marginal Effects of Natural Resource Dependence Using Result (10-6) from Table 10

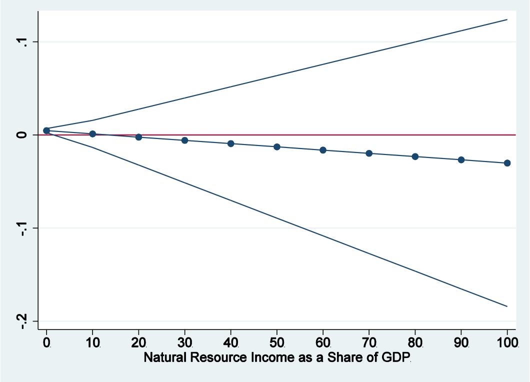

Figure A4.11: Marginal Effects of Patents Using Result (10-3) from Table 10

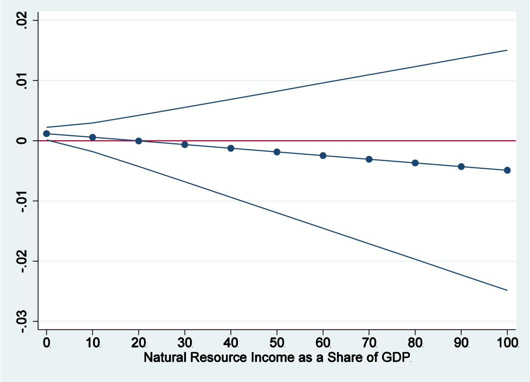

Figure A4.12: Marginal Effects of Patents Using Result (10-6) from Table 10

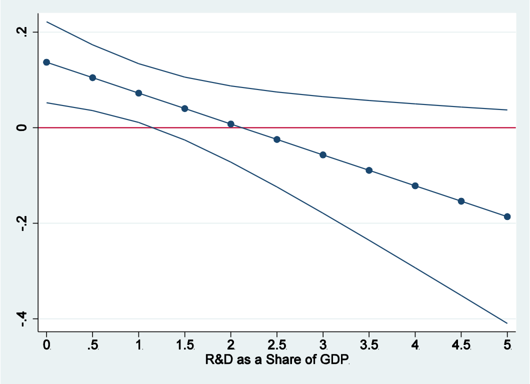

Figure A4.13: Marginal Effects of Natural Resource Abundance Using Result (11-3) from Table 11

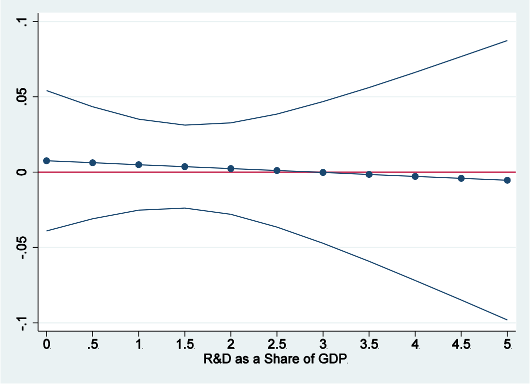

Figure A4.14: Marginal Effects of Natural Resource Abundance Using Result (11-6) from Table 11

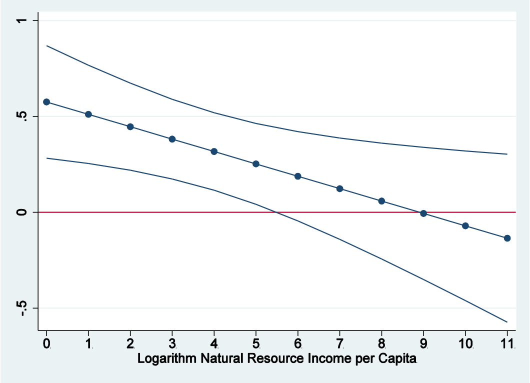

Figure A4.15: Marginal Effects of R&D Using Result (11-3) from Table 11

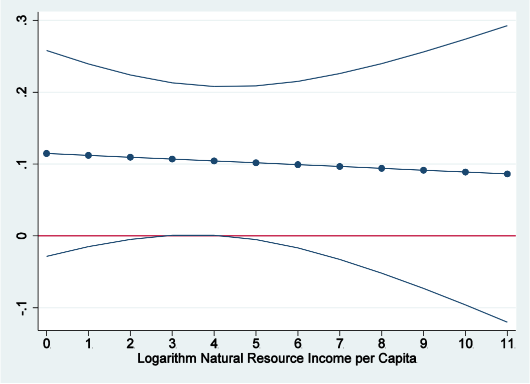

Figure A4.16: Marginal Effects of R&D Using Result (11-6) from Table 11

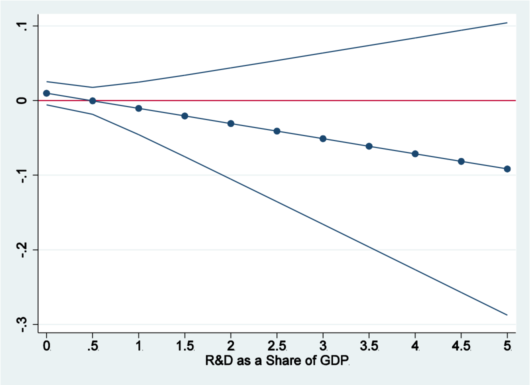

Figure A4.17: Marginal Effects of Natural Resource Dependence Using Result (12-3) from Table 12

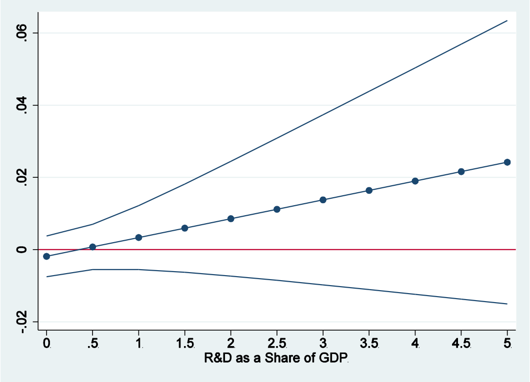

Figure A4.18: Marginal Effects of Natural Resource Dependence Using Result (12-6) from Table 12

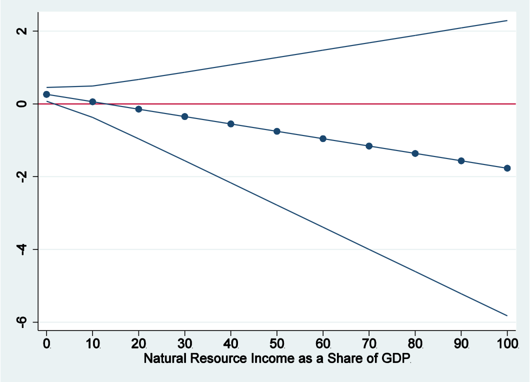

Figure A4.19: Marginal Effects of R&D Using Result (12-3) from Table 12

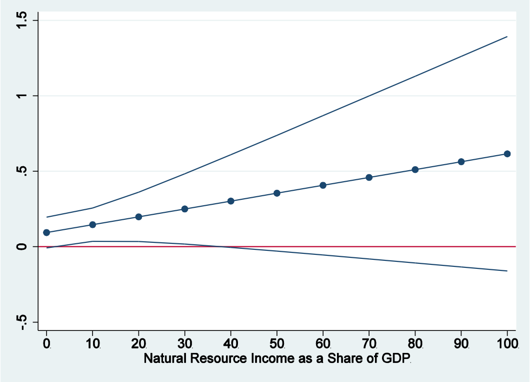

Figure A4.20: Marginal Effects of R&D Using Result (12-6) from Table 12