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Abstract

Natural resources, especially energy resources, are often considered vital to the process of economic development, with the availability of coal considered central for the nineteenth century. Clearly, however, although coal might have spurred economic development, development might also have spurred the discovery and use of coal. To shed light on this, we suggest that the case of resource poor Denmark, which spent centuries looking for coal, is illuminating. Specifically, we emphasize that the process of looking for coal and the creation of a natural resource industry in itself is important beyond the obvious dichotomy of haves and have-nots. We seek to understand this process and find that prices proved an important stimulus to coal surveys.

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1. Introduction

The importance of coal for development in the nineteenth century has often been highlighted, see for example Cipolla (1962), Wrigley (1988, 2010), Pomeranz (2000), and Allen (2009).[3] Thus, easy availability of cheap coal contributed to England's precocious industrialization, and the early industrialization of other coal-rich countries (Kander et al. 2013). As the nineteenth century progressed, the use of steam power based on coal spread into most economic sectors, while a transportation revolution saw the spread of railroads and steamships (Kander et al. 2017). This latter meant that eventually even coal-poor countries with cheap access by water to the coal mines in England, such as Denmark, could industrialize (Henriques and Sharp 2016), although countries where more areas were further from the coast, making access to coal expensive, saw more uneven industrialization (Henriques and Sharp 2020). What determines access to coal, however? And how does a natural resource industry emerge? Malanima (2016), in a comparison of the English and Italian experiences, concludes that "Energy is a main determinant [of growth], but the determinants of this determinant are multiple and diverse." One important issue is that of reverse causality: development itself might spur the discovery and exploitation of coal.[4] In the present work, we exploit the case of Denmark, where such concerns do not apply due to the lack of coal, but where concerted attempts were made to discover it over at least four centuries.

In his analysis of natural resource exploitation and the growth of international business, Geoffrey Jones presents some common features that mining industries share, which should be stressed here, and all of which we touch on below. These include the importance of geology, the capital-intensity and high risk nature of their business, and, although there are important differences in their availability, the fact that most metals and minerals are sold on the world market (Jones, 2005: 45). He finds that mineral and metal surveys and mining have been risky businesses, which is related to the nature of their operation. The extension and composition of ores has often been difficult to know in advance and operational techniques have changed along the way. There have been many uncertainties related to such production and large capital investments have often been required. These, in turn, have involved uncertainties regarding costs, completion time and operational performance. As mineral deposits are located in remote places, and sometimes in rough terrain, challenges concerning infrastructure and logistics have also been common. Finally, fluctuations in prices represent another risk factor (Jones 2005: 52). In sum, capital, knowledge about the composition of ore, and the extension of the ore

[3] See the literature review by Fernihough and O'Rourke (2014), who find some support for this hypothesis. Other authors have disputed it, see for example Clark and Jacks (2007) and the counter examples of the US (Melosi 1982; Schurr and Netschert 1960) and Sweden (Kander 2002), where wood and charcoal proved important energy carriers.

[4] Fernihough and O'Rourke (2014) identify a causal impact of coal on development in Europe by instrumenting coal with the (often associated) presence of carboniferous rock.

deposit; as well as relevant operational techniques and infrastructure to mine and process the ore need to be in place before rational mining can occur.

Taking this as inspiration, we provide a thorough description of the process by which Denmark searched for coal and construct a database of when surveys and mining was undertaken, as well as of coal prices. Based on this, we suggest that prices were an important incentive for actually effectuating coal surveys, but these took place in an institutional and political context which allowed for this. Despite many attempts, Denmark has practically no coal, and not even the fast-flowing water which was to be so important for the hydropower of her fellow Scandinavian countries. In fact, apart from some peat production, the only potential energy sources within Denmark were to be found on the small (588 km² / 227 sq. miles) island of Bornholm in the Baltic Sea, a relic of her former province of Scania, at the southern tip of the Scandinavian peninsular, which had been lost to Sweden in 1658.

In fact, much of Danish history until the early 1700s can be seen through the prism of its conflict with Sweden, which Kjærgaard (1994) explains came close to precipitating an environmental and economic collapse. An over-populated country and excessive military expenditures by the state triggered the felling of forests (in large part to build ships for the navy), the over-grazing of pastures and inadequately fertilized soil. Sand drifted, floods developed, and cattle plague spread. Disaster was averted in the late eighteenth century by various measures both by individuals and the government, and in particular the substitution of wood alternatives, most importantly coal and iron. In the countryside, serfdom was abolished (Jensen et al 2018) and new methods of agricultural production were brought in, including superior crop rotation systems (Lampe and Sharp 2018, Boberg-Fazlic et al 2020). The increasing population was in need of energy resources and coal was used as fuel from at least the 1760s in sugar refineries, brickworks, and private households, for baking etc. This shift was detected by Jensen et al. (2020), who find that Malthusian pressures eased around this time. Ultimately, after traumatic losses during the Napoleonic Wars and to Prussia in 1864, a much-reduced Denmark developed strongly from the late nineteenth century, in particular with the rapid spread of hundreds of steam-powered cooperative creameries around the country (Henriksen 1993), and these were almost exclusively dependent on imported coal (Henriques and Sharp 2016).

This paper explores how the search for coal within Danish borders fits into this story. The coal deposits that were found in Denmark were small and of bad quality. Nevertheless, from the late sixteenth century up to the Second World War, almost seventy surveys, prospect projects and analyses of coal were carried out in Denmark, mostly in Bornholm. Some of these surveys resulted in actual coal mining projects, but they were normally closed soon after start-up and led to huge losses. Given this seeming fiasco, why did this happen in the first place? And what benefits, if any, did the country receive from

this? In the following, we provide some explanations, and argue that the process of understanding what natural resources a country does not have can have far reaching consequences and contribute to the self-discovery of what a small open economy should specialize in (see also Lampe and Sharp 2018).

The remainder of this paper proceeds as follows. In the next section, we provide some international perspective on the importance of surveys for determining the extent of natural resources, and in Section 3 we discuss the institutional and political background to Denmark's attempts to find coal. In Section 4, we demonstrate that these attempts depended on coal prices. Section 5 concludes.

2. Making Mining Possible: Mineral and Metal Surveys

It has not always been obvious which natural resources a country is in possession of. This is especially the case when it came to minerals and metals, which are often underground, below the sea level and mixed with other minerals and metals, which have made them difficult to detect. Thus, before the start-up of mining projects, detailed and in-depth understanding of geology, proper analyses and knowledge about the quality and composition of existing mineral and metal deposits and their potential profits are key to beginning a rational and efficient mining project.

Early miners had little knowledge of mineralogical features and geological formation, and old prospecting methods consisted of looking for signs of minerals in the outcrop of rocks with the use of tools, such as picks, shovels and other equipment to separate minerals and metals from the gangue. As a result of gradual advances in the fields of geology and chemistry, however, geological surveys and analyses were eventually carried out in a more organized and systematic way and new and more efficient techniques to find ores were developed, such as geophysical methods. Organized and directed efforts led to discoveries of more mineral and metal deposits (Ritson 1958: 66-67).

Thus, from the mid-nineteenth century, countries established formal public national geological surveys with the aim of acquiring widespread and in-depth knowledge of minerals and metals within domestic borders. National geological surveys were essential for the advancement of mining industries, and sometimes also for the agricultural sector and infrastructure, as they led the work of making geological maps, examining the composition and grade of mineral and metal deposits and estimating potential economic profits. They worked as consultants and often gave advice to public and private companies. In turn, mining companies based their development on this type of work. It is therefore not surprising that countries which ended up with large and technologically up-to-date mining sectors, such as the United Kingdom, the United States, Australia, Germany, Norway and Sweden, began early with

systematic mapping, analyses and tests of those countries' natural resources.[5] The lack of such mapping, surveys and prospecting has been demonstrated to lead to inactivity and economic stagnation, with Chile being an important example. That country has some of the largest deposits of copper in the world, in addition to a number of other large mineral and metal deposits, as well as favourable conditions such as short distance to the sea and an abundance of hydraulic power. However, only sporadic and disorganized mapping and surveys were made and a national geological survey was not formed until the 1980s. This hindered the start-up of new mining projects and large mineral and metal deposits remained unexploited. For example, La Escondida, one of the largest copper ore deposits in Chile, and in the world, was not discovered until 1981, and that was by the North American J. David Lowell (Ferranti et al. 2002: 6; Culver and Reinhart 1989: 725).

Table 1: Selected National Geological Surveys

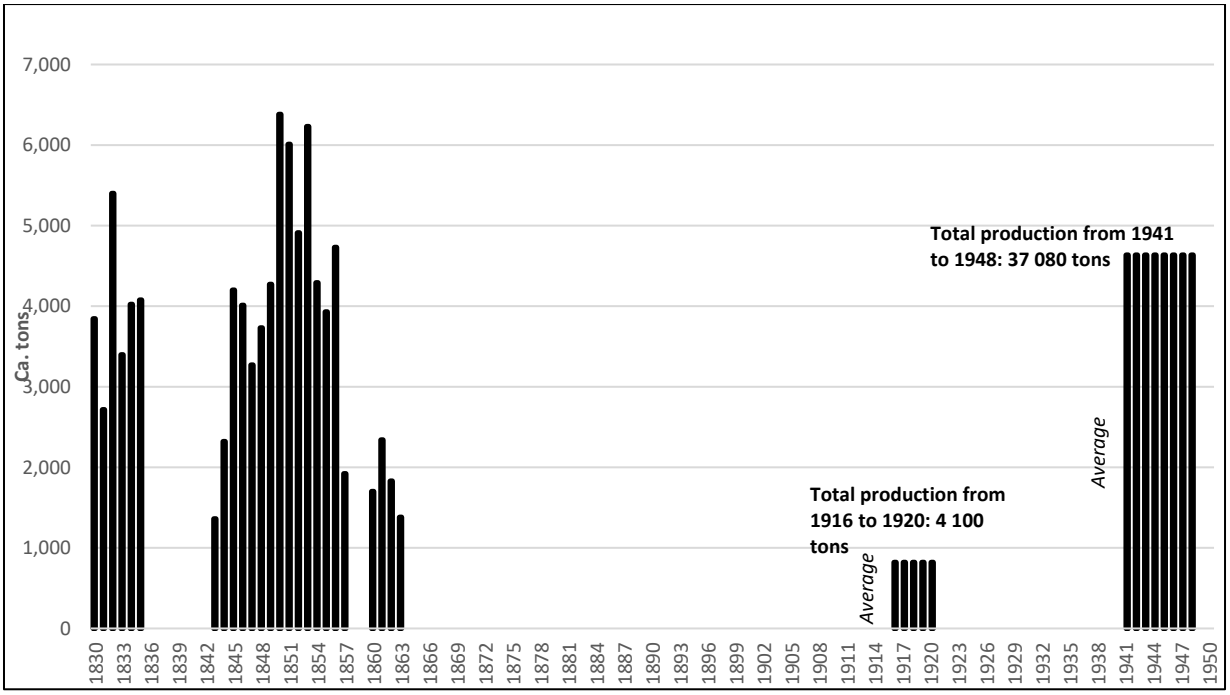
YEAR	COUNTRY	ORGANIZATION RESPONSIBLE
1835	Britain	British Geological Survey
1842	Canada	Geological Survey of Canada
1849	Austria	Federal Geological Office
1849	Spain	Commission for Geological Map of Madrid and the Realm
1851	India	Geological Survey of India
1858	Sweden	Geological Survey of Sweden
1858	Norway	Geological Survey of Norway
1867	Italy	Geological Committee
1873	Germany	Royal Prussian State Geological Institute
1877	Finland	Geological Survey of Finland
1879	United States	The United States Geological Survey
1888	Denmark	Geological Survey of Denmark
1896	Belgium	Geological Survey of Belgium
1910	Australia	Australian Survey Office

[5] For the United States see Manning (2015) and for Norway see Børresen and Wale (2008). David and Wright (1997) argue that between 1850 and 1950, the mining sector in the United States was able to benefit from its mineral resources to a far greater extent than any other country. In this respect, they emphasize the importance of mineral prospecting and find that: "(p)rovision of geological information was perhaps the most important initial step in the collective enterprise of resource discovery and exploitation."

Table 1 lists the foundation year of the National Geological Surveys of selected countries. Denmark, a country with scarce natural resources, also relatively early on established a formal geological survey with the aim of carrying out scientific investigations and geological mapping of the country, but surveying and interest in coal production actually had a much longer history, going back at least to the time of King Christian IV in the sixteenth century (Chr. H., 1940) and during the 1680s Denmark completed a comprehensive survey of all agricultural land in the kingdom (Boberg-Fazlic et al 2020). Table A1 provides a summary of when surveys were carried out, with a note on the conclusions reached.

The fundamental issue was that Denmark only had small amounts of bad quality coal, mostly in Bornholm, but also some in the Faeroe islands, although it is unclear whether the latter was ever actually exploited. The coal in Bornholm normally lacked bitumen, had an earthy look and was easily broken. When heated it gave off an unpleasant odour, became acidic, and produced a lot of ash. Moreover, the coal layers were difficult to exploit, being thin and separated by sand, which reduced the usefulness of the coal. We know today that the coal that was found in Hasle, Sorthat and Bagaa in Bornholm was normally sub-bituminous coal, i.e. brown coal, and could not be compared with pit coal, which contains more carbon (Rørdam 1908-1910: 28-29). The coal could not be used to smelt iron, for example, because it contained too much sulphur (Resen 1925: 20). The bad quality of coal in Bornholm was known from early on. King Christian IV wrote it was time to "quit" after an attempt to mine coal in 1640 by the Scottish miner Robert Wright (Chr. H. 1940). Then the coal mining stopped. Then, when the Swedes invaded in 1645 they took with them everything of value, but left half a dozen barrels of coal behind. The King's clerk registered this coal and added that they were: "unsuitable to be used, as they are mined here in the country" (Chr. H. 1940). Despite this, and although coal could be imported, notably from England, but also from Sweden and Germany, many initiatives were made to search for domestic coal. In fact, from the late sixteenth century until the Second World War, almost seventy surveys, analyses of coal and mining projects were carried out within the borders of Denmark, mostly in Bornholm, but also in the Faeroe Islands and Greenland, although these were usually abandoned quite rapidly. A graph of the available information on coal production in Bornholm is given in Figure 1.

Figure 1: Coal production in Bornholm



Sources: Based on figures provided by Andersen (2001: 50, 53, 62-63 and 105).

The coal that was found was used for the most part domestically, predominantly in Bornholm as fuel and in industry, such as brickworks. It was also used by smiths and to burn cement (Thorsen 1941). But the coal far from met the demand in the country (BA 1943). Compared to Höganäs in Scania, itself a relatively minor producer, Denmark had a truly insignificant production. Höganäs began producing coal in 1797 and continued for 150 years, with a production of around 15,000-20,000 tons per year, far more than Bornholm at its peak (Andersen 2001: 34). Why was so much effort put into these unsuccessful projects? One answer lies in Table A1: surveys came up with rather different conclusions. The reports differed mainly on three points: (1) whether coal existed at all; (2) where there was coal; and (3) the quality of the coal. Thus, it was not at all obvious whether profitable mining could take place. Of course, this improved gradually over time, as new knowledge was discovered about the geological setting and there was an increased understanding of how minerals and coal were formed. In this way, new coal layers could be found and more accurate estimations made it easier to estimate the magnitude and quality of the coal. Some examples illustrate these points, but see Table A1 for a more complete survey.

Eighteenth century attempts achieved little. In 1738, for example, Count Daneskjold-Samsøe led test work carried out by German miners on behalf of the King. 3,100 *rigsdaler* were invested, but the project was abandoned shortly after start-up. In 1762, the Copenhagen Brewers' Guild attempted to

mine coal near Terkel's Mill (Bagaa Brud) in Bornholm, also with German miners. Some coal was mined, but only from the superficial coal layer near the surface. After a couple of years they claimed that there was no more coal left. Then, in 1770, the Danish Royal Agricultural Society, just one year after its foundation, promised "rewards to those, who credibly may assign some place in His Majesty's lands, where coal existed, which to real use deserved to be processed" (Andersen 2001: 21). Two men, Christian Martfeldt and Heinrich Blichfeldt were commissioned to assist with finding coal (Andersen 2001: 114). Martfeldt, secretary of the Royal Agricultural Society and employed by the Board of Trade (*Kommercekollegiet*) from 1773, and Blichfeldt, a Norwegian mining councilor, made a report about the coal in Bornholm in 1770. They confirmed that ever since the search for coal was initiated by King Christian IV, none of the work that was started was ever completed. In 1773, the mining official (*bergassessor*) Willemsen and the mining engineer Gotfried Schram were appointed by the King to investigate coal layers in Bornholm more carefully and develop coal mining. However, the work ended without any positive results after three years. In 1790, the Englishman James Davenport was given permission to search for coal in the area around Rønne to find out whether it could be mined profitably. He formed a partnership, but left in 1793, and in 1798 the operation ceased. Finally, in 1791 the Royal Prussian mining assessor F. Küster was granted permission to search for coal with two miners, but did not find anything.

Nineteenth century studies were often more inspired by scientific theory, even if this was not always correct. Thus, the factory director and industry historian Ole Jørgen Rawert and the geologist Peter Johann Gottfried Garlieb went to Bornholm to carry out new investigations in 1815. Their report describes the geology, coal layers and coal mining in Bornholm at the time. They conclude that, in the area south of Rønne, there was no "regularity in the layers' locations, or in their thickness", and thus little hope of being able to extract coal (Rawert and Garlieb 1819: 144). Rawert and Garlieb's report was influenced by the German geologist Abraham Gottlob Werner's Neptunist geological theory from the late eighteenth century which argued that rocks were formed from crystallization of minerals in the sea. This was in contrast to Plutonist theory, which held that rocks were formed during volcanic activity (Rørdam 1908-10: 12).

Nevertheless, even scientists working from the same theory could reach very different conclusions. Thus, the famous physicist and chemist Hans Christian Ørsted (who in 1820 was to publish his discovery about the relationship between electric currents and magnetic fields) and mining engineer Jens Esmarck were also influenced by Werner and carried out new investigations a couple of years later in 1818-19. The aim of the expedition was to investigate the coal, and also iron, that was found according to previous reports. They found coal in diverse, in alternating layers between sandstone (Fogh 1940), and thus concluded that profitable mining was possible (Andersen 2001: 38). In fact, they stated that

the coal deposits in Bornholm were richer than those in Höganäs in Scania (Andersen 2001: 34). The coal was found mostly under the sea and only some of it was found on the land. They argued that test work had only been done near the surface, i.e. not deep enough to reach the coal, and that it increased in quality farther below the surface. According to their work, with the right operational techniques coal as good as the English could be mined, and that this would amount to between 5-7 million *tønde kul* (1 *tønde kul* = 170 litre, and thus potentially over a billion litres of coal). The positive results led the members of the Royal Danish Academy of Sciences and Letters to ask to continue investigations (Fogh 1940).

The geologist and mineralogist Johan Georg Forchhammer assisted Ørsted and Esmarch in their surveys in 1818-19 and went to Bornholm several times. He published a report about his coal analyses and formations in Bornholm in 1837. He found that coal mining in Bornholm was not more disadvantageous than other places, although the mining should be carried out in a different way than in England and Germany, due to different geological settings. He argued, in turn, that the coal was of significantly worse quality than the English, as it weighed less, gave less heat and more ash, although it could still be mined rationally (Forchhammer 1837: 5; Ipsen 1936).

Subsequent investigations made even more optimistic predictions (Christensen 1996: 192). During the First World War, previously discovered coal layers were rediscovered in Bornholm, in addition to a continuation of the layers near Gammelværk and Birkely. Later, in 1936, it was stated clearly by *Bornholms Tidende* that although much capital had been invested in investigations, attempts and preparations over the years, the results were normally so bad that no income was made. Even the last coal mining attempt, during the Second World War, resulted in large deficits, although that time some 40,000 tons of coal were mined.[6]

3. Institutions, Financing, and the Role of the Government

The state played a significant role in enabling the surveys and mining that took place in Bornholm and elsewhere in the Danish realm, and Table 2 provides an overview of this.

[6] The most profitable coal operation was that carried out by fishermen on a small scale. They found coal that was drifting in the water as they were fishing along the coast. Especially when fishing was poor, the fishermen earned a good daily income by collecting this coal.

Table 2: Coal projects initiated by the state

YEAR	STATE ORGANIZATION	PLACE	YEAR	STATE ORGANIZATION	PLACE
1571	King Frederik II	Helsingborg	1806	The Central Government	Scania
1581	Treasury (Rentekammeret)	Bornholm	1808	The state councilor Pram	Bornholm
1626	The King	The Faeroe Islands	1815	The Factory Directory	Bornholm
1640	The King	Bornholm	1818	Rentekammeret	Bornholm
1722	The king	Bornholm	1821	The state	The Faeroe Islands
1737	The King	Bornholm	1823	The county governor in Bornholm	Bornholm
1770	The Royal Agricultural Society	Bornholm	1916	The state and County	Bornholm
1773	The King	Bornholm	1918	Rønne commune	Bornholm
1777	Bjergværksdirektoratet in Rentekammeret	The Faeroe Islands	1940	The Ministry of Commerce	Bornholm
1789	Bjergværksdirektoratet	The Faeroe Islands	1940	Brændselsnævnet	Bornholm
1798	Kommercekollegiet	Bornholm	1941	Geological Survey of Denmark	Bornholm
1798	Kommercekollegiet	Bornholm	1941	Folketinget	Bornholm
1798	Kommercekollegiet	Bornholm	1942	Teknisk Central	Bornholm
1802	Rentekammeret	Bornholm	1943	Geological Survey of Denmark	Bornholm

Source: Andersen (2001); Christensen (1996).

The area where the coal was located was mostly owned by the King, the so-called "King's ground" (kongens mark), and thus the involvement of the King in early attempts is not surprising (Forchhammer 1837: 8; Ipsen 1936). Besides owning the land, the state was directly involved in many of the coal survey and prospecting projects. In spite of the many failures throughout history, the state was highly interested in the potential profit connected to coal deposits within Danish borders. Thus, the King or one of his representatives often initiated coal mining projects. The Board of Trade initiated a number

of coal surveys in the 1790s on the land which by then had been sold off[7], and both Scottish miners and Norwegian mining engineers were sent to Bornholm, as well as members of the Board of Trade itself (Andersen 2001: 28-29). The active state continued during the early nineteenth century as the central government was eager to find out more about the opportunities for coal exploitation. Then, after a long period without surveying between 1875 and the First World War, the central government and Bornholm County took the initiative once again to search for coal on the island and asked the Geological Survey of Denmark to carry out drilling work from 1916 (Andersen 2001: 62-63). Finally, during the Second World War, various government organs, the Ministry of Commerce, the Board of Fuel, the Geological Survey of Denmark, the Ministry of Supply and "Teknisk Central" (a wartime institution formed to organize construction projects) collaborated in the implementation of coal survey and mining projects from 1940 (Andersen 2001: 64-105).

The necessary capital thus also often came from the state. The King often made a deal with private investors to either provide him with coal, or give him a percentage of the sale.[8] The King became involved in many of the projects by providing loans to actors who wished to exploit coal. This happened regularly. There are indications that most of the investments, from start to end, were lost and that the coal surveys and mining did not pay off. Probably because of this, in 1801 the King decided that coal surveys were not to be carried out at the Crown's expense (Andersen 2001: 31). In their report from 1815, Rawert and Garlieb also underlined that coal mining in Bornholm should develop naturally and that the government should not "make any installations" or support companies in this type of work, but instead guide them (Rawert and Garlieb 1819: 152). Yet, in spite of the recommendation to not get involved, the state continued to provide loans and invest in mining projects, as Table 3 makes clear.

[7] See Lampe and Sharp (2018) for more on the importance of the privatization of land in Denmark for its subsequent development.
[8] Jyske Law of 1241, until 1683: ownership of minerals was that "what no one owns, the King owns".

Table 3: Financing of operations

YEAR	INVESTMENT/LOAN	PURPOSE AND OUTCOME
1737	The state invested 3100 rigsdaler.	Count Frederik Daneskiold-Samsøe led some attempts at Sorthat at Claus Therkilds mill and at Rønne on behalf of the King. The project was abandoned after a couple of years.
1741	The King sold farmland on Bornholm, 5 property farms, 65 private farms and 151 "vornedgårde, 10 houses and 3 pieces of land in 1744, of which Ancher Anthoni Schor acquired 4000 rigsdaler.	Ancher Anthoni Schor was given privileges by the King to take over coal mines without costs. Schor did not start mining and the project was given up around 1763.
1773	The King invested in test work carried out by mining assessor Willemsen and mining engineer Gotfried Schram.	Test work was carried out, but the project was abandoned after three years without positive results.
1797	The state invested 500 pound sterling	The Scottish engineer Peter Smith with two coal miners, John Thomson and George Cunningham, was to do surveys of coal in Bornholm, but had problems with loose sand.
1819	Rentekammeret provided 400 rigsdaler silver	The English Captain David Coulthard was given permission to mine one or two deposits of coal and iron and invited to establish a partnership company in 1820 called "Det Bornholmske Steenkuls og Jernværks Interessentskab", but viable operation was not started.
1843	The state provided a loan of 12000 rigsdaler silver	Establishment of Hasle Kulværk Interessentskab. The company mined coal but was liquidated in the 1860s.
1843	The state gave a loan of 2000 rigsdaler	Establishment of Sorthat Kulværk. The company mined coal, but had deficits and a partnership took over in 1858.
1916-1920	Unknown how much was invested by the state.	Sold coal for 4 kr per hl, and made a "nice profit".
1940-1948	The state invested the following: 43 drillings 1941: 61 016 kr 19 drillings 1943-45: 43 644 kr Total: 104 660 kr Constructions, mining, work, transport etc.: 3 930 177 kr Fees and compensations: 38 800 kr Teknisk Central and Anlægsdirektoratets adm: 207 070 kr Total: 4 176 047 kr Surveys, mining: 4 280 707 kr	Income from sale of coal: 2 255 829 kr Deficit: - 2 024 878 kr

Source: Andersen (2001).

One of the main issues with successfully extracting coal from Bornholm was the nature of the deposits. The coal districts in Bornholm expanded from Hasle towards the south to Blykobbeaaen at Skovly and continued south of Rønne towards Sose Odde (Ipsen 1936). There were many small coal layers, but these went under the sea and continued uninterrupted only for short distances. While these layers elsewhere in Europe extended horizontally and did not deviate more than 20°, in Bornholm they descended at much steeper angles. In Scania, by contrast, the coal layers continued for several kilometres (Andersen 2001: 18). The steep inclination of the coal layers meant that excavating the coal soon occurred at a significant depth, which led to serious challenges in terms of removal. Another factor which made it difficult to get the coal out of the ground was the nature of the substances around the coal. In Bornholm the coal was surrounded by loose soil and sand, while most other coal deposits were surrounded by solid rock masses (Forchhammer 1837: 3-5). The result of this was that water easily came in and keeping the mines from flooding became a significant challenge.

In line with Geoffrey Jones' argument, successful mining in Bornholm would have required knowledge about local geological settings, and how to exploit the coal in such unusual circumstances, as well as significant investments and advanced machinery. These conditions were not always in place. Although leading experts of the time, also from abroad, were active, they were hampered in part by a lack of modern machinery and capital. Forchammer referred to members of partnerships who often did not agree about how to proceed and how to spend money (Forchhammer 1837: 10). Thus, the general risk involved in mining that Jones referred to was present in Bornholm and was probably greater than other places. Lifting devices, pumping machinery, wood for the shafts and tunnels inside the mine and other equipment were needed, but at the same time it was not known whether successful mining was actually possible. Another issue was that investors were assigned an area to work on by the King, but if it turned out that the coal layers expanded further from the area allotted, the work had to stop (Ipsen 1936). Such uncertainties and the fact that the coal was of bad quality, might have impeded potential investors from making investments. By 1844, technology had advanced to the extent that Hasle Kulværk installed a steam engine, which had not been used before on the island. This no doubt contributed to the relatively large yearly income and surplus the company had until the 1860s when it was liquidated and sold off following an unfortunate incident on 18 January 1857 when the steam engine machine house burned down bringing a big loss to the company (Thorsen 1941).

Decades later, in 1917, when the Anker brothers resumed the work at Hasle, technology again proved a barrier. They completed test work and dug three shafts at the coast north of Leuka. It was confirmed that coal steams existed deep down, which had not yet been exploited. The project was described in an article in *Bornholms Tidende*. A company was established, which had ½ million kroner available. A machine house with two big steam boilers were installed with steam engines, which were to operate

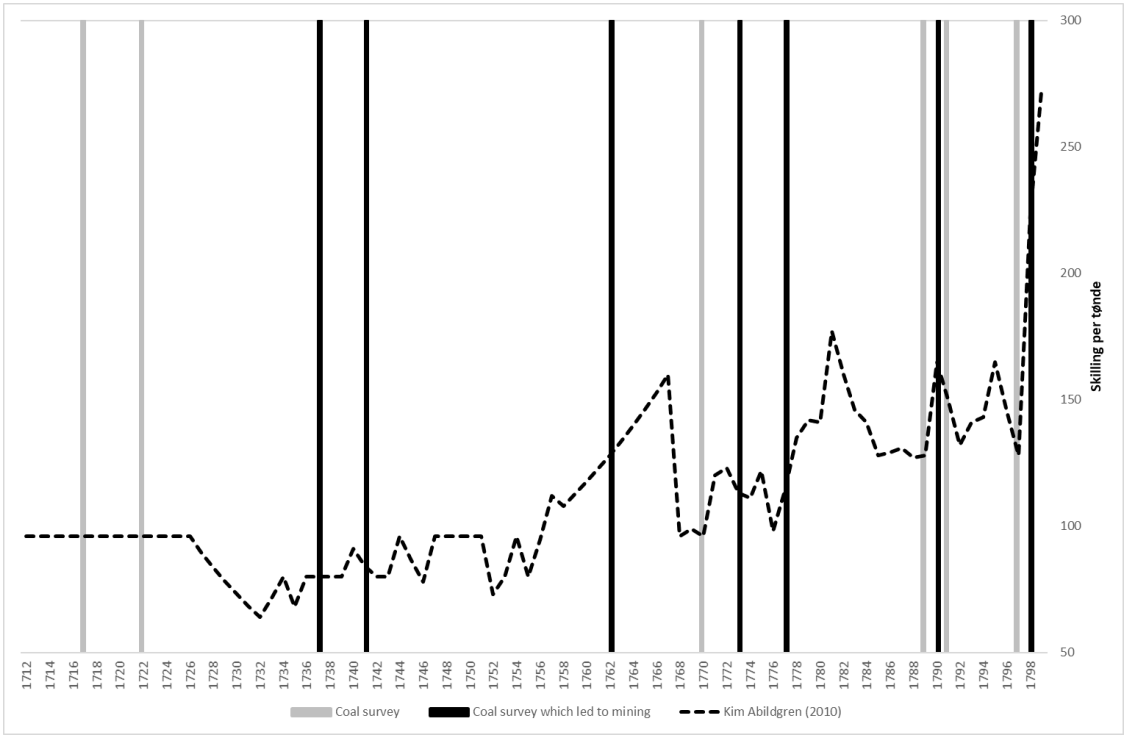
an electric generator to a power station which was to deliver electricity to pumps and lift installations at the mine. A shaft was made, but after a short while it was clear that the work was much more difficult than expected. The water entered, and it was impossible to keep it away, even with the new and powerful pumping devices, since it brought with it a lot of sand, which the pumps were not able to remove. The further down the miners came, the more difficult the conditions proved to be. This episode illustrates the importance of local knowledge. The work was led by professional engineers with help from foremen from Sweden. However, they only had experience with coal mining in Sweden, and had never reached the depths which were required in Bornholm. In total, 60,000 hl coal was mined and sold to be used as fuel in Bornholm and a small part was sent to the King (Ipsen 1936). The most successful attempt came during the Second World War, when a number of ore test works were carried out. Electric power was used in operation and the drilling and drainage machinery was more powerful and efficient than before (Fogh 1940). Some 40,000 tons of coal were mined, yet even this relatively large project resulted in a deficit.

4. Coal Prices as a Determinant of When Surveys and Mining were Initiated

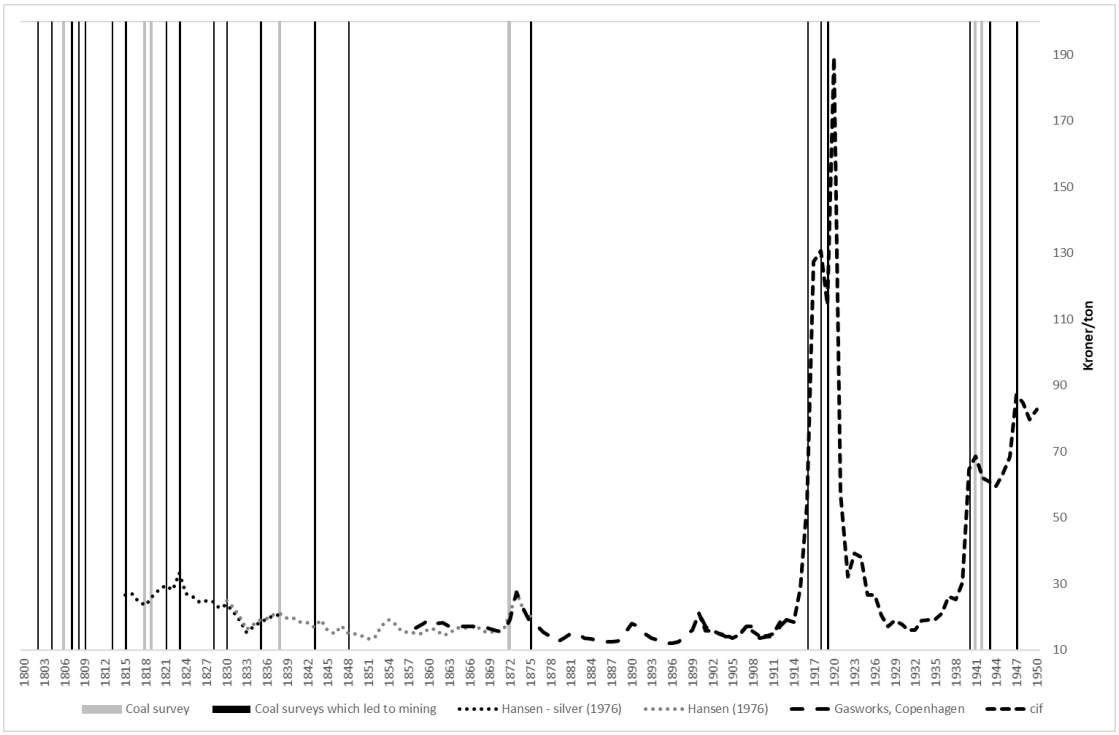
Although the institutional and political framework can explain how and why coal exploration proceeded, it fails to explain why it happened exactly when it did. In order to understand this, we collected data on prices of coal and the timing of when surveys were conducted. For the latter, we differentiate between those that led to actual excavation (however little), and those that did not, with the idea that the former might be seen to reflect more serious or extensive surveying than the latter. We plot these data in Figure 2.

Figure 2: Coal surveys/mining start-up and prices

(a) 1712-99



(b) 1800-1950



Source: Surveys from Andersen (2001). Prices from Abildgren (2010), Hansen (1976), Københavns Belysningsvæsen (1932), Statistics Denmark (1959).

Unsurprisingly, there is a clear tendency towards more surveying during times of high prices, although it is not clear that actual excavation necessarily corresponds to particularly high prices, with the exception of the two World Wars. Imports of coal would have been cheaper in times of peace and in general when coal prices were low. When prices increased, and war hindered trade between countries, the motivation to search for domestic coal increased, and government often supported or initiated these efforts. As transportation technology improved over time, the technological barriers to accessing foreign coal were also falling, decreasing the incentives to invest in finding coal in Denmark.

There is clearly a gradual increase in the number of initiatives as prices went up during the environmental crisis of the eighteenth century and an intensification during the French and Napoleonic Wars. Subsequently, perhaps in part due to increased motivation given the technologies being developed during the industrial revolution in Britain, but also because prices were high (Andersen 2001: 44), activity continued to be frequent. A newspaper account from the 1940s in *Nationaltidende* provides a description of the long history of the search for coal search in Bornholm. It is explained that during the troubling times of the Napoleonic Wars, English coal was difficult, or impossible, to acquire and there was a strong demand in Copenhagen for Scanian (Southern Swedish) coal, motivating an increase in coal projects (Nationaltidende 1941). Moreover, one result of the Napoleonic Wars and the Treaty of Kiel in January 1814 between Great Britain and Sweden on one side and Denmark-Norway on the other, was that Denmark had to give up Norway, which had supplied the country with resources, to Sweden. These circumstances might have inspired further coal projects.

Subsequently, surveys and excavation can be seen to have taken place in conjunction with spikes in the price relating to difficulties in obtaining supplies. First, possibly in relation to the First Schleswig War of 1848-51 during which the fuel supply from Bornholm became of some importance, although the Crimean War between England and Russia in 1855-56 has been suggested to have had the opposite effect (Thorsen 1941). Second, in the wake of Denmark's loss of the Duchies of Schleswig and Holstein in 1868 and almost certainly more importantly the Franco-Prussian war of 1870-71, when prices increased again, and new coal surveys and mining projects began. By that time, the rise of steam shipping and the take-off of Danish direct trade with the UK (Lampe and Sharp 2015) meant that it was far more cost effective to import coal, although when the British mines were cut off during the World Wars, prices again spiked and more serious efforts resumed, a point again noted in contemporary newspapers. For example, on 7 April 1940 *Socialdemokraten* wrote that the intensified war at sea and ice formations in the Danish waters led to high fuel prices comparable to those after the First World War, and "Therefore, we ask how we can best obtain domestic fuel" (Fogh 1940). A little over a year later, Keyser from "Teknisk Central" confirmed to the newspaper *Bornholms Socialdemokrat* 9 October 1941 that:

> "I can tell you that coal deposits of such an extent is now found, that we at the Technical Central have communicated to the Ministry of Public Works, that the coal should be exploited. It is our perception that with the current coal prices it will be profitable to exploit coal, and it will be the Ministry's estimation, which would be essential as to whether we can count on the current high coal prices for such a long time that production should start."

Reading this one might speculate how much had really been learned since the sixteenth century, but we choose to conclude on a more optimistic note.

5. Conclusion

In line with Geoffrey Jones, there were certain common features that mining industries share, including the importance of knowledge of local geological settings and access to capital and efficient technology. Denmark made frequent attempts to discover and exploit coal and in this respect was not too unlike other countries which ended up having large and technologically up-to-date mining operations, such as the United States, Australia, Germany and Sweden. These also began early with systematic mapping, analyses and tests of their countries' natural resources, and it is well-known that the knowledge this created revealed the potential profits and provided a key incentive for the development of their extractive industries. The causality in this argument has been disputed, since the availability of coal in itself might have stimulated development, in turn giving rise to efficient mining sectors. The case of Denmark demonstrates that it was possible for a country to begin early with mapping and prospecting the country's resources, while not developing an advanced mining sector, simply because such resources were largely nonexistent or difficult to exploit.

We explored the motivations for and efforts behind the attempts to develop a natural resource industry in Denmark, namely coal mining. From the late sixteenth century up to the Second World War, almost seventy surveys and analyses of coal were carried out in Denmark, mostly in Bornholm, by mining engineers, scientists and miners, either on behalf of the state or private investors from Denmark, Norway, Great Britain and Germany. The surveys included long-lasting examinations of the ground, analyses of the content of ores, the quality of the coal and estimations of profits. The geological investigations were complicated and time-consuming, required scientific knowledge as well as long practical experience, and involved large investments. In spite of this, only a couple of these surveys resulted in small-scale coal production, and more commonly the surveys did not lead to actual production, or ended shortly after start-up and the mines were abandoned. Small and scattered deposits of low quality coal, in addition to complicated geological conditions, made it difficult to make a profit. It was not until the First and Second World Wars that coal mining of some scale was carried out with machinery and equipment powerful enough to drain the groundwater from the mines.

We find that it was not at all obvious whether profitable mining could take place in Bornholm, and Denmark more widely. Practical workers, scientists and engineers often disagreed on the size of coal deposits, their characteristics, grade and direction. Yet searching for and analyzing coal was part of the mapping of the country's natural resources. To figure out and estimate the industrial production which Denmark potentially could develop and specialize in, knowledge about the natural resources available in the country was required, but also the natural resources which the country was *not* in possession of. We find that surveys and the start-up of coal mining in Denmark were initiated in periods in which coal prices were high and argue that import barriers initially motivated the search for minerals at home. We consider the search for coal to be one of many measures to alleviate the country's lack of raw materials and energy shortage. Thus, although the coal mining projects in Denmark failed, they must be seen in a wider context in which public and private actors sought knowledge about the possibilities for exploiting natural resources and the country's comparative advantages. Understanding what the country did not have, as well as what she did, meant that the government and private actors from an early date were able to make rational decisions about which industries to specialize in, i.e. agriculture, and how to fuel the mechanization of this sector during the last decades of the nineteenth century, when large and cheap imports of coal from the UK became increasingly important.

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Table A1: Coal surveys and their results

Year	Location	Conclusion of coal survey	Year	Location	Conclusion of survey
1571	Helsingborg	There was coal	1804	Bornholm	No coal
1581	Bornholm	There was pit coal (stenkul)	1806	Scania, northern Zealand, Hornbæk, Risskov at Århus and Fur	No coal
1626	The Faeroe Islands	Unknown	1815	Bornholm, south of Claus Therkilds mill	No coal layers of importance
1650	Helsingborg	Unknown	1818	Bornholm, the church south of Rønne	Bad quality coal was found
1657	Bornholm	Unknown	1818	Bornholm	Different types of coal were found, but it was suggested that there were large deposits of pit coal in southern Bornholm and brown coal in the western part of the island. Coal was to be found at a deeper level.
No coal surveys			1821	The Faeroe Islands	It was suggested that the coal deposits were six times bigger than what was previously

					thought, i.e. 72 million tons.
1717	Bornholm	Unknown	1823	Bornholm, Nestvedt stenkulværk	Bad quality coal was found
1722	Bornholm	Samples of pit coal were taken	1835	Bornholm, Sorthat area	Three new coal layers were found, probably part of the Sorthat system
1737	Scania	Unknown	1838	Bornholm	The survey ended at an initial stage
1762	Bornholm: south and north of Rønne	Found 1,4 meter thick coal layer at Sorthat and 2,5 meter thick coal layer at Claus Therkilds mill between sand and clay.	1872	Skagen, around Frederikshavn, Råbjern county	It was suggested that Bornholmian and Scanian coal layers extended northeast under Kategat. He did not found coal, but in 1949 coal was found in this area at 300-400 meters deep.
1770	Bornholm	Bad quality coal lay near the surface and pit coal (stenkul) was found deep underground. The coal veins continued from Polschøt in Scania southeast to Bornholm. Further surveys were required.	*No coal surveys*		
1773	Bornholm, Pytthuset, around 3 km	There was a lot of bad quality coal in Bornholm. The coal that was found deeper down (61 meters)	1916	Nornholm, near the beach between Hasle	The previously known coal layers were rediscovered, in

	southeast of Rønne	was not of better quality than the coal on the surface.		Lystskov and Levka	addition to a continuation of the layers near Gammelværk and Birkely
1777	The Faeroe Islands	The Faeroese mountain contained 12 million tons coal (more or less the same as Ørsted calculated for Bornholm). Together, Bornholm and the Faeroe Islands would cover the consumption of coal in Denmark for 10 years.	*No coal surveys*		
1789	The Faeroe Islands	The coal layers continued through the basalt mountain, but was not always visible on the surface.	1940	Bornholm	Systematic mining of the coal in Hasle would be financially possible
1791	Bornholm	The sand and clay found in Rønne and Hasle would have origin another place in Bornholm or Scania, deeper down. However, there were no big deposits of pit coal on Bornholm.	1940	Bornholm	Coal was developed in sea pools by sedimentation of plant rests. The coal veins did probably not continue over long distances.
1797	Bornholm, Claus Therkilds mill	Coal tests	1941	Bornholm, south of Hasle Lystskov	A significant coal layer in a depth of 35-40 meters
1798	Bornholm, Claus Therkilds mill and 16	No pit coal was found, but a large deposits of bituminous coal	1941	Bornholm, near Hasle	The coal layer inland south of Hasle Lystskov existed, yet it was

	km southeast of Rønne				not recommended to start mining.
1798	Bornholm	Disagreement within in the commission between those who believed that there were large amounts of pit coal in Bornholm and that rational mining could be carried out, and those who did not recommend mining. Coal was tested chemically and found that it was of lower quality than the English “kakkelovnkul” because it contained less carbon and because of higher ash content.	1942	Bornholm	Acquired information about the coal deposit between Hasle district and Haslefabrikken
1802	Bornholm, Claus Therkilds mill	Tested already known coal deposits	1943	Bornholm, Anholt and towards the coast	The coal layers thinned out in a number of fractures. The thick coal layers that had previously been found, was not to be found.

Sources: Andersen (2001); Christensen (1996).

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