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# Institutional factors influencing productivity in medieval England: A case study of tin, lead and silver mining

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## Abstract

This paper fills a gap in recent literature on productivity and regional development by examining the determinants of productivity in primary industries in English regions during the Middle Ages. It provides a comprehensive review of relevant literature on the tin, lead and silver mining industries in Medieval England. Modern studies of productivity typically focus on technology, labour skills, unionization and regional economic infrastructure as key determinants of productivity growth and focus on high-technology manufacturing industries. This study of medieval mining, however, focuses on extractive industries in which advanced technologies played only a limited role. The paper shows that alternative factors contributed to the productivity of medieval mining including royal policy, the location of deposits and fluctuations in demand. Technology, investment in training and worker activism had, in contrast, little impact.

## KEYWORDS

medieval, mining, productivity

## JEL CLASSIFICATION

L23, L72, N53, O40

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## 1 | INTRODUCTION

This paper fills a gap in recent literature on productivity and regional development by examining the determinants of productivity in primary industries in English regions during the Middle Ages. It provides a comprehensive review of relevant literature on the tin, lead and silver mining industries in Medieval England and is the first paper of this kind. There is little surviving quantitative evidence on mining output in medieval England, with the exception of those relating to tin for c. 1324 to 1500 (Broadberry et al., 2015, pp. 137, 140–1, 147; Hatcher, 1973, pp. 155–6; Kowaleski, 1995, p. 18). They have been described as showing a ‘boom– to– bust trajectory’ with cyclical waves of demand (Broadberry et al., 2015, p. 137). Qualitative evidence, however, can provide additional insight into factors that contemporaries associated with productivity.

Modern studies of productivity typically focus on technology, labour skills, unionization and regional economic infrastructure as key determinants of productivity growth (Becattini, 1989; Casson, 2003; Hudson, 1986; Marshall, 1895, 1923; Parsons & Rose, 2005; Popp, 2001; Shadwell, 1913; Wilson & Popp, 2003). Modern studies also tend to focus on high–technology manufacturing industries. This study of medieval mining, however, focuses on extractive industries in which advanced technologies played only a limited role. Instead, a range of connected factors influenced productivity, including royal policy, fluctuations in demand for minerals, and the location of deposits.

The article is structured as follows. The first three sections review the evidence on each of the three industries in turn. The next four sections consider features that had the potential to impact on productivity. Section four examines technological and financial challenges, section five the division of labour, section six internal cooperation and section seven legal protection. Section eight is the conclusion.

## 2 | TIN MINING

Tin was a versatile material which used extensively for building repairs and window making (Hatcher, 1973, p. 38; Homer, 1991, p. 57). By the addition of lead or copper it could be transformed into pewter, which was used to make cutlery, trading tokens and jewellery (Hatcher, 1973, pp. 4, 34; Homer, 1991, p. 56). If copper was combined with a small amount of tin it could be turned into bronze and used to make doors, bells, fountains and sculptures (Weinryb, 2016). Devon and Cornwall were Europe's only significant tin mining locations in the period up to 1300 (Homer, 1991, pp. 57–58). The earldom (from 1337 duchy) of Cornwall was formed of 17 manors, of which 6 in central Cornwall and three in western Cornwall contained, or were close to, deposits of tin (Hatcher, 1970, pp. 24–27). Tin was traded domestically and internationally. Tin from the south–west of England, for example, was exported to Spain, for example, where it was used to make glaze for ceramics (McSweeney, 2011).

Tin mining had been undertaken by the Romans but was revived under Richard I of England (ruled 1189–1199) and his brother King John (ruled 1199–1216) (Hatcher, 1973, p. 20). Richard engaged in many overseas military campaigns throughout his reign, notably the Crusades, and was in almost constant need of funds (Gillingham, 2009). John, meanwhile, lost royal lands in France and launched many expensive campaigns to try and regain them (Gillingham, 2021). The crown did not tax production but did tax the smelting process, in which the tin was extracted from the ore.

Tin was relatively easy to mine. Tin deposits were identified from 'outcrops of tin stones' in valleys and pilot shafts sunk to check the quality of the tin underneath. If the pilots were successful, the streaming process commended (Blanchard, 1981, p. 89; Hatcher, 1973, p. 46). The top layers of soil were removed and fast flowing water used to separate out the tin ore from the sand in the lower layers. These methods remained dominant until the mid fifteenth century, when the most accessible deposits of tin were beginning to be exhausted and opencast mining and then shafts became more common (Blanchard, 1981, p. 89; Hatcher, 1973, p. 46).

There were two ways in which a tin-mine might be operated. The first was a small works run by a self-employed 'prospector', possibly with help from his family (Blanchard, 2005, p. 1534; Hatcher, 1973, p. 50). This might be combined with another occupation, notably farming (Blanchard, 1978, p. 2). In some situations a lone prospector might find a particularly rich seam, and decide to hire a couple of wage labourers to work alongside him (Hatcher, 1973, pp. 59–60). The second scenario was a larger operation involving two or more shareholders or partners (Hatcher, 1973, pp. 50, 59–60). Generally those employed wage-labourers and were financed by merchants (Blanchard, 2005, p. 1535; Fox, 1991; Miller, 1991; Lewis, 1908, pp. 188–9).

Once the ore was removed from the ground, the metal needed to be extracted from it by smelting (Finberg, 1969, p. 169). The first stage was undertaken near the mine. Tax had to be paid on tin of the first smelting before it could be sold (Finberg, 1969, p. 169; Medieval Sourcebook, 2023). The second smelting refined the tin and had to be undertaken in a nearby market town. In 1198 a tax on the second smelting was introduced (Finberg, 1969, p. 169; Medieval Sourcebook, 2023).

### 3 | LEAD MINING

Lead was an important material in building construction, where it was used for roofing, stained glass and making pipes. In England the main locations for lead mining were the North Pennines, Yorkshire, Derbyshire and the Mendips (Blanchard, 1981, pp. 80–3; Claughton, 2003, p. 56; Homer, 1991, p. 62; Raistrick & Jennings, 1983, p. xvi; Salzman, 1950, p. 67).<sup>1</sup> Lead was traded domestically and also exported, particularly from Kingston-upon-Hull and Bristol (Blanchard, 2005, p. 1413; Gough, 1930, p. 64).

It is believed that Romans mined lead in Derbyshire and in the North Pennines (Raistrick & Jennings, 1983, p. 2; Rieuwerts, n.d., p. 13). It is possible that a period of decline followed their withdrawal, but references to mining in both areas in the Domesday Book suggest a revival under the Anglo-Saxons, probably for use in the construction of churches and religious houses (Raistrick & Jennings, 1983, p. 19; Rieuwerts, n.d., p. 15). Lead was also mined in the Mendips by the Romans, but after that there is an absence of information until the late thirteenth century (Gough, 1930, p. 48).

Lead mining was surface mining in which trenches were cut into veins (Barnatt & Penny, 2004: Chapter 2.9; Blanchard, 2005, p. 1343). The miners were permitted to go as deep as they could and as wide as the vein dictated (Rieuwerts, n.d., pp. 6–7). The main exception to

<sup>1</sup> Raistrick & Jennings, 1983: xvi define the North Pennine lead mining field as the area around Alston Moor, Allendales, Derwent, Weardale and Teesdale, The Yorkshire lead mining field comprises Swaledale, Arkengarthdale, Wensleydale, Greenhow Hill and Whafedale. Derbyshire's lead mining field consists of High Peak, Ashover, Winstar and Ashbourne.

surface mining were the cavities in the hills at Matlock Bath in the Peak District, where underground mining could be undertaken.

Richard I also paid a leading role in reviving lead mining in the Mendips. The bishop of Bath and Wells was awarded a charter by Richard I in 1189/90 that permitted the bishop and his successors to mine lead wherever they found it on their lands in Somerset. This was an incentive to mine because it provided a secure legal standing. The intention seems to have been to export the lead. The charter permitted the bishop to establish a borough at Radeclive (also known as Rackely) (Gough, 1930, p. 49; Letters, 2013). The new town was intended to serve as a port, as it was located in the 'Cheddar Yeo river just above its confluence with the Axe' (Richardson, 2003, p. 3). While some development may have been initiated, the site does not appear to have taken-off and today is a hamlet, close to the ancient Somerset town of Axbridge (Richardson, 2003, p. 3). It has been proposed that it was, instead, Bristol that served as the main port for lead export (Gough, 1930, p. 64).

The operation of lead mines varied between Yorkshire, the North Pennines and Derbyshire. In the North Pennines control of mining was largely split between the bishop of Durham and the crown. The bishop seems to have been granted lead mining rights by the crown in the twelfth century, which included the right to keep any silver found in them (Raistrick & Jennings, 1983, p. 51). These were operated directly during the twelfth and thirteenth centuries but leased during the fourteenth (Raistrick & Jennings, 1983, pp. 52–53). In other parts of the North Pennines the crown had granted land to nobles but retained the mining rights (Raistrick & Jennings, 1983, p. 52). Those rights were sometimes granted to members of the royal family, the nobility or to merchants.

In Yorkshire the crown had some mines that it operated directly or leased out. The remainder were under the control of religious houses, usually having been received as part of their endowment. Some operated them directly and others leased them out (Raistrick & Jennings, 1983, p. 66).

In contrast, in Derbyshire most of the lead mines were on crown lands, known as the King's Field. This was divided into the High Peak and the Low Peak, each of which in turn comprised other smaller units (Kirkham, 1968, p. 13; Nef, 1952, pp. 446–7). From 1265 these areas became part of the Duchy of Lancaster (Raistrick & Jennings, 1983, p. 61). There were some small private liberties in Derbyshire and in those the crown had granted both the land and the mining rights (Kirkham, 1968, p. 14).

Lead miners on the King's Field were given advantageous legal protections. 'Any man could search for lead without hinderance from the landowner', with the exception of churchyards, gardens, orchards and roads (Rieuwerts, n.d., p. 6). If the search was unsuccessful the land had to be returned to its original state. If a vein was discovered, a claim to work it needed to be registered with the Barmaster, a royal official. Payment of one dish of unsmelted ore was required. The miners were then permitted to work two tracts, known as meers, the length of which varied from 28 to 32 yards. A third meer had to be allocated to Duchy. The miners had the opportunity to purchase it, subject to valuation by the Barmaster. Alternatively, they could work through it to create further meers, but were not allowed to sell any ore from it (Rieuwerts, n.d., p. 7). A further dish of ore had to be paid to create additional meers beyond the original three (Rieuwerts, n.d., p. 7). Wooden markers in the soil allowed claims to meers to be identified. Any meer that was claimed but went unworked, for reasons other than problems with drainage or ventilation, could be claimed by other miners (Rieuwerts, n.d., p. 7).

Taxes were payable before the sale of the ore, in a similar way to tin mining. In Derbyshire cope was paid to the lord of the field by the purchaser of the ore and was usually 4d. or 6d. per

load of unsmelted lead (Kirkham 1968, p. 44). The was 'in lieu of the crown or his lessee having first right to purchase the ore' (Rieuwerts, n.d., p. 8). Lot was a fraction of the dressed ore, usually a thirteenth, and represented a payment for free access to workings, wood for fuel and water for cleaning the ore (Rieuwerts, n.d., p. 8). When these duties were owed to the crown, it tended to farm them out rather than collect them directly (Kirkham 1968, p. 44).

On one occasion at least a lead mine in the King's Field of Low Peak was run directly by the crown. An account survives from 1321/2 when the duke's rebellion Edward II resulted in royal officials being placed in charge of the Duchy's mines (Fenton, 1907, p. 329). These show that women and girls were paid daily rates to wash and clean ore before it was smelted (Fenton, 1907, p. 329).

## 4 | SILVER MINING

Silver was used for plate and for coins (Campbell, 1991, pp. 109–10). Silver mining occurred in Cornwall under the Romans and, after a gap in the records, there is evidence of it being undertaken again in the eighth century. In the middle ages two new deposits were discovered in England: in the 1130s silver–lead ore in the north Pennines and in the 1260s silver at Bere Ferrers in south Devon and Combe Martin in north Devon (Blanchard, 2001, p. 585, 673. Claughton, 2010, p. 300; Claughton & Smart, 2010, p. 113). Silver from both the Pennines and Devon as well as from Welsh mines was distributed around England for the minting of coins (Allen, 2012, pp. 238–294).

The mines in the north Pennines were either on crown lands or on ones that the crown had granted to the bishop of Durham (Claughton, 2010; Raistrick & Jennings, 1983). The ones on crown lands were known as the mines of Carlisle, and were probably operational from c. 1120 (Allen, 2012, p. 239). They were leased by the crown and contributed silver to the Carlisle and Newcastle-upon-Tyne mints during recoinages (Allen, 2012, pp. 240–241). By the early thirteenth century, however, the mine's output was very low and it seems unable to have supplied silver to the mints (Allen, 2012, p. 241). The bishop's mines seem to have supplied his mint during the twelfth century but for nearly 200 years from the early thirteenth century until the 1470 there is no reference to the use of local silver (Allen, 2012, pp. 241–243). Thus, by the time the Devon deposit was discovered, the extraction of ore from the Pennines had almost halted.

In Devon, the crown laid claim to the silver that was discovered as part of its regalian rights to precious metals, rather than as 'lord of the soil' (Nef, 1952, pp. 446–447). The Devon silver mines became operational in 1292. Combe Martin was soon abandoned as unprofitable in 1296 (Allen, 2012, p. 244). Bere Ferrers was more successful and its operations can be recreated (Blanchard, 2005, p. 1627; Claughton, 2010; Claughton & Smart, 2010). Miners were employed and paid either by wages or by piecework (Claughton, 2010, p. 300). Workers were recruited from other English mining areas, notably Derbyshire, apparently because of challenges in recruiting locally (Claughton, 2003, p. 232; Claughton & Smart, 2010, p. 116).

## 5 | CHALLENGES ASSOCIATED WITH MINING

Technology and finance created challenges for medieval industrial mining districts. Water removal and smelting were the technological challenges. Silver ore was further from the surface and, from the outset, it was necessary to dig down, leading to difficulties in pumping out water



and in providing ventilation. The Devon silver mines water were initially drained with buckets, a time-consuming and labour-intensive process. In the early fourteenth century the crown decided to invest in drainage, constructing adits that used gravity to remove water and aid ventilation (Claughton & Smart, 2010, p. 116). Despite these efforts, the issue of mine drainage was not fully resolved until the invention of the Newcomen beam engine in 1712 (Age of Revolution, 2023).

Innovations were also introduced in the process for smelting silver. Traditionally, silver and lead were both extracted by bole smelting, in which a rectangular structure was built on a hill top, with one side left open to the wind (Claughton, 1995, p. 128). However the process did not melt smaller pieces of ore efficiently. Devon silver mines also had fewer exposed sites available than the Pennine mines. As a result furnace smelting was adopted in the Devon mines for smaller pieces. Meanwhile, bole smelting was improved by the introduction of a rotating platform which could be move to face the direction of the wind.

Alongside the running costs was the risk that the deposit might be quickly exhausted. That was the case in the North Pennines, where there was an ongoing struggle to generate a profit from the mining of argentiferous lead. Deposits of 'silver-rich ore' were exhausted quite quickly (Blanchard, 2001, p. 667, 682). However the Exchequer over-estimated the profits that could be obtained and therefore charged an excessively high annual rent to those taking on the mine lease. As a result, the lessees frequently defaulted on payments to the crown (Blanchard, 2001, pp. 603–605). Rather than adjusting the farm accordingly, the Exchequer attempted to change the composition of the lessees. In 1180, for example, the king's mines in Northumberland were farmed to a 'consortium' of four lessees (Blanchard, 2001, p. 605). Blanchard argues that the motivation was that 'none of the individuals could claim, as the previous farmer presumably had, that their debts were beyond their own or their immediate circle's means' (Blanchard, 2001, p. 606).

The consortium did indeed soon start defaulting on the farm, but the sheriff continued to collect the outstanding amount owed from 1183 until 1203, when eventually the Exchequer gave up chasing the remaining debt (Blanchard, 2001, p. 606). Finally, after a default of the next lessee, the Exchequer decided to do a more thorough investigation. They allowed two of the consortium of 1180 to act as custodians of the mine, on the grounds that they had mining experience, along with a royal official, who provided the administrative experience. This experiment revealed that the farm was set at an unrealistically high level that was unlikely to be met by any lessees. Once the level was dropped the situation improved and defaults ended for a while. Ultimately, though, the yield from the mines dropped to an extent that the problem re-emerged (Blanchard, 2001, p. 606).

Tin mining also had a financial challenge. Tin could not leave Devon and Cornwall to be sold until the tax on smelting was paid. But it was difficult to raise the funds to pay that duty before selling the tin (Hatcher, 1973, p. 51). The solution was for tin-dealers, who were usually from London or were foreign merchants, to loan the merchant-tinners the money for the tin in advance, with the tin acting as security (Hatcher, 1973, p. 51). The merchant-tinners were expected to deliver to the tin-dealers 'white, pure, smelted tin on which the duty had been paid' (Hatcher, 1973, p. 51). In turn, the merchant-tinners lent money at interest to the labouring tinners (Hatcher, 1973, p. 51, 56). The labouring tinners were required to deliver 'black tin ore, dressed and pulverised but not smelted; to the merchant tinners' (Hatcher, 1973, p. 51). It is likely that some interest was charged on these loans, which was paid by the delivery of extra tin (Hatcher, 1973, pp. 52–5).



## 6 | THE ROLE OF DIVISION OF LABOUR

In medieval mining districts the division of labour took three forms: specialization within plants to separate different manual tasks, specialization between plants to separate successive stages of the mining process, and specialization within a sector to separate manual work from administrative work.

It seems likely that the tin and lead mining plant that employed wage labourers would have made use of horizontal integration in manual work. That would have involved workers collaborating together to perform a tricky task like preparing an area for streaming. In silver mining greater use may have been made of vertical integration, with the product passing through the plant and workers employed at each stage. The Kutná Hora Illumination, produced in the Czech lands during the 1400s, for example, documents a silver mine and depicts a range of processing tasks, such as cleaning the ore (Agricola, 1556 and 1950; Gallery of the Central Bohemian Gallery of the Central Bohemia Region, 2023). However the sinking of deep shafts is likely to have required horizontal integration.

The division of labour between manual work and administrative work was particularly notable in tin mining at the sector level. The king was very interested in delegating the manual work but recognised that an experienced administrator was needed revive the industry and to deal with local opposition to its environmental impact, as detailed below. In 1198 Richard I therefore appointed William de Wrotham as warden of the stanneries in 1198, a position that he held until 1215 (Golding, 2004; Powell, 1956, p. 181). Wrotham had relevant experience in metallurgy and also valuable local knowledge. He had been joint sheriff of Devon and Cornwall in 1198–9, keeper of the fifteenth on merchants (a duty on exports and imports) in 1202 and organiser of the assize of money and operator of the mints of London and Canterbury in 1205 (Golding, 2004; Powell, 1956, p. 182).

In tin-mining there is also an indication of vertical division of labour between plants, which developed from the need to pay tax on the tin before it could leave Devon and Cornwall to be sold. The division was based on the stages of mining, processing and marketing. As discussed above, labouring tanners dressed and pulverised the ore but did not smelt it. The smelting was then undertaken by the merchant tanners, who then paid the necessary tax. The smelted ore was then ready to be distributed by the tin-dealers.

## 7 | INTERNAL CO-OPERATION TO ENHANCE EXTERNAL COMPETITIVENESS

Literature on productivity in the industrial districts of the nineteenth and twentieth centuries has noted the importance of cooperation between different establishments within the district, particularly with regard to the provision of training (Carnevali, 2004). There is, however, little evidence of such cooperation within the medieval mining districts studied. One explanation is that both the king and major landowners controlled so many aspects of the industry that there was little scope for local co-operative initiatives. Another possibility is that some miners, notably self-employed tin and lead prospectors, undertook mining alongside agricultural work. There was perhaps therefore little motivation for them to acquire further skills in an industry that they only engaged in intermittently. The miners who worked for wages were often itinerant this may have hindered the ability to foster collaborative relationships or undertake training.

## 8 | LEGAL PROTECTION

Miners of both tin mining and lead benefitted from receiving legal protection from the crown. This provided an incentive for individuals to become miners, and prevented interference from local groups opposed to the process.

Tin mining was the subject of regular complaints to parliament from the residents of Devon and Cornwall for its disruption to agriculture and transport infrastructure (Hatcher, 1973, p. 45, 48). The tin miners of Devon were accused of 'laying waste annually a total of three hundred acres' (Given Wilson et al. (eds), 2005: January 1315 Membrane 7). The streaming process removed so much soil that the land could rarely be returned to cultivation afterwards (Hatcher, 1973, p. 45, 48). The refuse from the process, meanwhile, was said to be responsible for clogging up harbours (Hatcher, 1973, p. 45, 48).

The legal protections awarded to tin miners are outlined in a charter of 1201 (Anon, 1908, p. 380; Lewis, 1908, p. 238.). This permitted tin miners to 'dig for tin, and for turf for smelting it, at all times freely and peaceably without hindrance from any man, on the moors and in the fiefs of bishops, abbots, and earls', and allowed them to divert streams for their works (Anon, 1908, p. 380; Lewis, 1908, p. 238, Medieval Sourcebook, 2023). The need of the crown for tin thus overtook the use of the land for any other purpose, including cultivation.

The charter of 1201 also provided the miners with their own courts, which fell under the jurisdiction of the warden of the stanneries, and 'removed them from pleas of villeinage' (Beare, 1994, p. xiv; Hatcher, 1973, pp. 47–8; Lewis, 1908, pp. 37–38). These protections again reduced the potential for interference with the mining from local lords (Kaye, 2009, p. 265)

Lead mining on the King's Field Derbyshire shared a similarity with tin mining in Devon and Cornwall in the scope of investigation that was allowed. The customs of the lead miners of Derbyshire were recorded in 1288 as the result of inquiry into the source of the liberties claimed by the miners (Rieuwerts, n.d., p. 20). The customs outlined how the miners were free to search for lead throughout the royal demesne and covered in detail the process for laying a claim to a vein, including the allocation of a third of it to the king (Fenton, 1907, p. 326; Kirkham, 1968, p. 35).

Two courts operated in the Derbyshire lead fields. The oldest was the Small Burmote court which met every 3 weeks and heard disputes between miners. It may have roots back to the period 900–1066 (Rieuwerts, n.d., p. 17). The Great Burmote court may have developed from the inquisition of 1288 (Rieuwerts, n.d., p. 2). It met twice a year and dealt with procedural issues such as payments to the crown (Rieuwerts, n.d., p. 17).

Customs for the lead miners of Mendip are recorded in a document dated 1461–1485, although they are likely to have earlier origins (Raistrick & Jennings, 1983, p. 104). The king had sent the chief justice of England to resolve a dispute over grazing rights between the commoners of the forest of Mendip and the Prior of Green Oare (Gough, 1930, p. 69; Raistrick & Jennings, 1983, p. 104). The four main landowners in Mendip were called to give their opinion and, after the resolution of dispute, the lords and their tenants put on record the local mining customs (Gough, 1930, p. 70). These mention the need to obtain a licence from the lord of the soil or his representative before commencing to operate as a miner. When the permission was received, the miner may 'break ground' in any location (Raistrick & Jennings, 1983, p. 105).

The lead miners of Mendip were also granted their own courts by the king (Gough, 1930, p. 67). The Mendip was divided into four areas, each of which 'had its own officers, called lead-reeves', and its separate mineral court which was permitted to make its own additional rules for miners in its area (Gough, 1930, p. 67).

Silver mining offered fewer legal protections to miners, possibly because the mines were relatively contained with minimal impact on the surrounding countryside. However when Bere Ferrers became active in 1292 a series of privileges of exemption from local taxation and 'right of redress in a specially designated court' were granted for fixed terms (Claughton, 2003, pp. 232–233). The king seems to have been careful to have ensured that these remained time-limited privileges and did not evolve into the long-term customs that applied in the case of tin and lead (Claughton, 2003, pp. 232–233). The main source of complaints about the mine came from the Abbot of Buckland, whose woodland provided the main source of fuel for smelting when the mine opened (Claughton & Smart, 2010, p. 118). The king intervened in 1301, permitting the mine to instead draw on woodland from the crown manor of Calstock (Claughton & Smart, 2010, p. 118).

## 9 | CONCLUSIONS

It is difficult to assess how far the organisation of medieval mining may be deemed 'successful' given that there is not ready comparator. Comparisons can be made across regions, but the uniformity of royal policy means that in practice that there is little difference between the English regions. Comparisons with continental systems can be difficult due to differences in the legal and institutional framework (Graulau, 2019; Nef, 1952). Drawing on our evidence we can, however, propose some factors that influenced productivity.

Firstly, tin, lead and silver were all recognised as strategic resources in medieval times. Landowners held land from the king who, as defender of the realm, was the ultimate owner of all the land, except for that acquired by, or gifted to, the Church. Some lands which held important mineral deposits, such as the Duchy of Cornwall, were in the hands of the king's family, while others were held by earls and other members of the military aristocracy. These landowners could lease to others, who could in turn lease to sub-lessees. The king, however, generally maintained control of lands which contained strategic resources. The crown either extracted those resources directly, offered incentives to others to extract them or leased the rights.

Smelting was crucial to extracting the metal from the ore and the king often supported large-scale smelting with grants of turf or of timber from royal forests. These grants were very significant because timber was also required building ships, bridges, housing and other high-priority uses, while forests were an aristocratic playground for the hunting of deer (Johnson, 1882).

It seems that the king conceived medieval mining as a set of regional mega-projects designed to secure a steady supply of strategic metals that were crucial in furthering the interests of the state. These interests included generating income from taxes or from leases to support military campaigns, and the acquisition of foreign coinage from an export trade.

Secondly, demand for mining output in the medieval economy was fluctuating, or cyclical, being driven partially by the need to fund military campaigns (Gillingham, 2009, 2021). Maintaining productivity required considerable flexibility in scaling up production at short notice and, equally, shutting down production when required. Warfare was common in medieval times, and demand for minerals remained volatile throughout the medieval period.

In some locations mining activity was intermittent. It seems like that the most productive mines were maintained in continuous operation with the less productive being brought into use as and when required. Metal ingots were regulated and traded in ports and major commercial

centres, and it seems to be there that prices for the industry were chiefly set. These prices would reflect fluctuations in demand and supply. It seems likely that prices would be driven up by warfare and rising export demand, and reduced by disarmament and increased imports. These prices would translate directly into the value productivity of mining labour through the output response of the mine-owners.

Flexibility, it seems, was facilitated by drawing upon an itinerant workforce. There is evidence of a division of labour between prospectors, construction workers, miners working at the face, miners working on the surface, and service workers who processed the extracted ore and prepared it for smelting. It seems that skilled workers were relatively mobile, as they were regularly required at different locations where new mines were to be developed or existing ones improved. Unskilled manual workers appear to have been less mobile, but may have had by-employments (for example seasonal opportunities for harvesting crops) to support them through hard times.

Where operatives were concerned, the guiding principle was generally 'payment by results'. For self-employed tin and lead miners', and for some silver miners on royal mines, earnings stemmed from the weight of the unsmelted metal produced. There is no evidence of formal compensation for injury or loss of life, although some owners may have been more compassionate than others. This could be construed, by a ruthlessly efficient mine-owner, as a personal incentive to follow safe-mining practices. In practice, however, it was not quite so simple as that, because the calculation provided no incentive for a miner to factor the lives of others that were put at risk by irresponsible working practices.

Thirdly, location of mining was dictated by geology. The location of industries that make use of minerals (such as the coal-fired steam-powered textile mills of the Industrial Revolution) was also influenced by geography, of course, but these merely needed to be close to their key resources. Factory-owners had an option to agglomerate in a specific town if there was some specific advantage to it, whereas for mine-owners agglomeration was normally obligatory. Thus factory-owners could agglomerate if they wished and at a place they chose, while mine-owners had to agglomerate according to the dictates of geology. The analogy between a mining district and an industrial district is therefore somewhat weaker than might be thought.

Fourthly, the location of mineral deposits was often remote. Geology caused mines to be concentrated in certain areas – often mountainous regions where roads were poor. Apart from mining there were few local jobs other than in farming. Job security was limited and local labour markets were relatively small. To attract workers to mining areas in times of peak demand high wages therefore had to be paid. Skilled workers tended to be itinerant, and so a stable group of skilled workers was difficult to sustain.

Fifthly, there had been little technological progress in the medieval mining industry since Roman times. The notion of the industrial district as an incubator of innovation seems to have no relevance to the medieval period. Improved technology did not therefore provide a solution to labour shortages. Nevertheless there was some specialization based on a division of labour. The least skilled workers cleaned and processed the ores, the semi-skilled workers mined the ores, and the most skilled workers smelted them. Smelting was usually carried out locally, to reduce the weight and bulk of the product, and increase its value, prior to transport to market.

Sixthly, mines could be quickly exhausted; mineral deposits take millennia develop, and cannot be replaced. While fluctuations often reduced demand in the short run, exhaustion inevitably reduced supply in the long run. Furthermore, it was difficult to predict the extent and depth of a mineral deposit; this was not normally revealed until the point of exhaustion had been reached. Unpredictable exhaustion therefore aggravated the financial risks of mining.

Seventhly, given the fluctuations in the demand for labour, and the mobility of many workers, there was little or no investment in local facilities. Nearby villages may have offered inns and churches, and possibly a local market, but there is no evidence of specific investments for mineworkers. Facilities provided in times of boom could decay in times of decline, and in the event of exhaustion they would have no future at all. The popular notion of an industrial district, where employers share information and collaborate to provide technical education for their employees, does not seem to apply to these early mining districts. Because of the transitory nature of the working population there is no evidence of organized workers' activism either.

In the best documented locations there is little evidence of facilities before the development of miners' libraries in the eighteenth centuries, and even these were mainly financed by the miners themselves. Like a conventional nineteenth-century industrial district, a mining district had certain key facilities, such as courts of law and smelting facilities. It did not, however offer formal education or general social facilities (Carnevali, 2004). Miners served as jurors at local mining courts, but there were few other opportunities for socialisation.

Eighthly, mining was a dangerous and risky business for both investors and workers. Mine-owners were not technically owners but rather franchisees who held from a local aristocrat or directly from the king. They bore the commercial risks associated with fluctuations in the prices of metals they produced, and losses incurred by theft, loss in transit, collapse of the mine, flooding or fire. They also bore the uncertainty associated with the amount of ore to be discovered in the mine, and the ease of access to it. Equally, mining was dangerous for the underground worker because of the risk of injury from falling rocks, flooding, or explosions caused by poor ventilation.

Ninthly, mining often generated conflicts over property rights. There were two main aspects to this. The first was the question of who owned the right to mine; the landowner, under whose land the mine was driven, or the king, or was there a common right to mine? Mining rights were potentially very valuable, then as now, for the reasons explained above, and so it is no surprise that common ownership was unknown. Mineral deposits were simply too valuable for rights to remain unappropriated. Mining rights were appropriated by the most powerful actor; in medieval times they were appropriated by the king and in modern times by the state.

The second aspect of property rights concerns the management of nuisances, namely the negative externalities associated with a mine. Surface mining is particularly damaging to landed interests, particularly where the soil removed is fertile; indeed, the threat of damage to agricultural land and the landscape may then, as now, have deterred private investment in farms and country parks. In medieval times the management of nuisances was the responsibility of the king, and the king decided, in his own interest, that the defence of the demand demanded a cheap supply of armaments and that justified the erosion of land through surface mining.

Conflict resolution was a major managerial role, reconciling the national interest with local interests, resolving disputes between miners, and between miners on the one hand and local aristocrats and their tenant farmers on the other. Special courts were created to administer justice quickly, using the local expertise of the jurors. These courts also steered disputes between miners, such as over their territorial rights. Where legislation was ambiguous, visitations might be carried out by royal officials who would collect information and provide a written judgement.

Finally, the role of the 'mining metropolis' was important. A mining metropolis can be defined as a large town or city which is either near to a mining district or is the nearest and most convenient of the various towns that lie some distance away (for example Tavistock for Cornish tin and Bristol for Somerset lead). A mining metropolis acted as a regional commercial centre where various legal financial and managerial functions pertaining to the mining district are



carried out. The mining metropolis was either a port through which mining products, such as metal ingots are exported, or a transport hub through which they are consigned to other towns. In some cases it was where processing activities were often carried out there to add further value to the product and where excise taxes were administered by royal or state officials.

This paper has provided evidence that all the factors identified above were, either directly or indirectly, relevant to the productivity of medieval mining. Sustained productivity growth was inhibited by cyclical demand, which acted as disincentives to long term investment and the creation of a stable labour force. National policy attempted to compensate for this by conferring privileges on mining interests, for example, upholding the rights of miners against the interests of local landowners.

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