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ORIGINAL PAPER

Sicilian sulphur and mafia: resources, working conditions and the practice of violence

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Abstract

This paper reconsiders the nexus between the abundance of resources and the origins of Sicilian mafia by exploiting a new set of historical data at the municipal level on the Sicilian sulphur industry in the late nineteenth century, obtained from official reports of the Royal Corps of Mining Engineers. Our evidence confirms that sulphur favoured the rise of organized crime, as emphasized in the previous studies. However, we show that the impact of local production on mafia was smaller in the areas richest in sulphur. Moreover, mechanization in the extraction process was associated with lower incidence of mafia. Taken together, our findings suggest that larger lodes encouraged better and more orderly working conditions for the miners, possibly reducing physical and psychic strain and, consequently, their inclination to violence. In other words, the quality of working conditions affected the supply of violent individuals.

Keywords Natural resources · Working conditions · Mafia

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> *Dr. Ernesto Crisafulli, at the Medical Clinic of the University of Palermo, studied the consequences of workplace conditions for the pathogenesis of neurotic states and delinquency. He reported several examples of criminal psychosis affecting workers in several jobs, concluding that fatigue intoxication resulted in homicidal instincts, alcoholism, erotic excesses and, as for lead poisoning, kleptomania.*
>
> (Malta 2012, p. 62).

1 Introduction

Widespread consensus among historians sets the origins of the mafia at the beginning of the nineteenth century: see, among others, Gambetta (1993), Lupo (2011) and Felice (2013). However, some recent contributions claim that the blossoming of organized crime in Sicily was stimulated by the natural resource booms—driven by exports of citrus and sulphur—over the second half of the 1800s. As argued by Dickie (2004, p. 82), “like the lemon groves around Palermo, the sulphur mines were a breeding ground for criminal associations”. Indeed, citrus and sulphur stand out as typical examples of the perverse combination between rich resources and weak state, in which public officers are eventually captured by gangs exerting violence and corruption.[1]

The export of citrus towards northern Europe and the US boomed in the mid-nineteenth century. The control over its supply chain, thus, offered large rents to be reaped. Indeed, following suggestions by Lupo (2011) and Dickie (2004), the empirical analysis of Dimico et al. (2017) mainly attributes the development of modern mafia to the rural areas of western Sicily. The citrus business generated a “demand for violence". To protect themselves and their investment, local landowners (mostly noblemen) started to hire private guards, especially in the area around Palermo where citrus grew. These gunmen were meant to protect their landlords from kidnapping and, at the same time, to avoid that such a valuable cultivation could be damaged. The use of private force became an essential production factor, although—as we explain in what follows—the widespread use of private militias eventually eroded the power of the landed gentry who were, at the same time, users and victims of the gunmen they had hired.

The second half of the nineteenth century witnessed the rise of Sicily as the world leader in the production of sulphur, the focus of this paper. In 1861, Delabretoigne and De Rechter reported that the annual production of Sicilian sulphur amounted to 187,500 tons, corresponding to revenues for 32 million French Francs

[1] The combination of rich resources and bad institutions is often held responsible for the poor performance of developing countries which are big exporters of primary commodities: for a survey, see Badeeb et al. (2017).

and net profits for—at least—12 million. For a comparison, the value of the coal production in France was less than 30 million Francs, while gross profits from Belgian coal mining amounted to 17 million: see Dealbretogne and De Rechter (1861) and Squarzina (1963, p. 48). Such a huge amount of resources encouraged several forms of "rent seeking" activities along the sulphur production chain, which Parodi (1868, p. 291) plainly described as "organized theft". The importance of sulphur for the development of mafia in the central parts of Sicily (in particular, the provinces of Caltanissetta and Agrigento) has been emphasized, again, by Lupo (2011) and Dickie (2004). More recently, Buonanno et al. (2015) have argued that there is a causal relation between the presence of sulphur and the development of local organized crime, explained by a combination of resource abundance, poor institutions and miserable working conditions. On the one side, the lack of effective law enforcement on behalf of the Italian state called for private "protection" supplied by local criminal gangs. As for citrus, sulphur boosted the demand for violence. On the other side, somewhat similarly to artisanal mining in today's Democratic Republic of Congo,[2] the Sicilian sulphur industry was generally characterized by the adoption of primitive technologies, disorganization, appalling working conditions, together with scarce cooperation among co-workers and, quite often, use of violence. In this perspective, sulphur mines most often constituted an environment which favoured the supply of violent individuals. The emphasis on the quality of working conditions adds new insights to explanations that focus on the nexus between bad institutions and resource abundance.

Buonanno et al. (2015) consider, as a measure of local resource abundance, the number of mines located in Sicilian municipalities in 1886 and relate it to local organized crime, as reported in Cutrera's (1900) dossier on mafia activity. Their results confirm that the density of sulphur mines favoured organized crime. However, the number of sulphur mines (567 in total, considering both the mines in activity as well as exhausted mines in 1886) might be an imperfect proxy for local resource abundance, as most of the mines exhibited scarce levels of production.[3] In fact, there exist well-established historical sources on the production of Sicilian sulphur in the nineteenth century (see Fenoaltea, 1988; Fenoaltea and Ciccarelli 2006; Ciccarelli and Fenoaltea 2009). The Rivista del Servizio Minerario provides a systematic account of the production of sulphur (thousand of tons) in the Sicilian Provinces, and, most important here, it occasionally reports data at the municipality level. Figure 1 displays the map with the amount of sulphur production at the

[2] As reported by Amnesty International (2016), a sizeable part of mining in the Democratic Republic of Congo is done by artisanal miners working by hand. Artisanal miners are generally exposed to dangerous working conditions, they do not possess any safety equipment, and receive little for the mineral (mostly cobalt) they extract. Serious and fatal accidents, as well as physical assaults and ill-treatment on mine sites, are frequent.

[3] As claimed by the Rivista del Servizio Minerario in 1899, the official report on the Italian mining industry issued by the Ministero di Agricoltura, Industria e Commercio (1900), "..in Sicily the number of mines has a very relative importance.. Indeed, the main 40 mines are sufficient to yield the 4/5 of the total production" (p. 85).

municipality level published by Ministero di Agricoltura, Industria e Commercio (1887), henceforth MAIC (1887).

We divide, for each municipality, the local production of sulphur by the area of the municipality, so to gauge a measure of the intensity of resources available at the local level.[4] Then, we reconsider the relation between sulphur and mafia. Although such a relation might be simply linear, as in Buonanno et al. (2015), a closer look at the historical literature hints to other possibilities. For example the sulphur–mafia nexus might be increasing at an increasing rate, that is when resources are very rich, they generate more and more criminality. When we go to the data, however, we find quite the opposite. The richer the sulphur production at the municipal level, the smaller the impact on local mafia activity. To tackle this puzzle, we then inquire whether, besides poor institutions and resources, there is a third element—the quality of working conditions—at play. For instance, Neumann and Nelson (1982) emphasize the positive relation between establishment size and workplace safety in the post-WWII US coal industry, while Salas et al. (2015) investigate the link between working conditions and psychological distress in some Latin American mines.

Our presumption, grounded on the historical literature that will be surveyed in what follows, is that the varied quality of working conditions can be proxied by investments in the mechanization of the production process, especially in the presence of rich lodes. To this purpose, we exploit the Rivista del Servizio Minerario (1903, pp. 97–103) to obtain data on the sulphur mines that, at the end of the nineteenth century, were carrying the ore to ground level by the "inclined shaft", powered either by steam or electrical engine. This advanced system replaced human transportation, mostly carried on the shoulders of the *carusi*, children and adolescents living in semi-slavery, after having been ceded by their families to the miners: see Franchetti and Sonnino (1876, p. 333) and Cagni (1903, pp. 174–177). Also, the implementation of inclined shafts allowed to adopt newer and safer techniques, such as "cut-and-fill" mining, the leading practice in the European mining industry of the time: see Spina (2006, p. 79).

By running OLS regressions, we confirm the central result of Buonanno et al. (2015): Sulphur had indeed a positive impact on the presence of mafia. However, we find that the impact of sulphur on mafia's presence is attenuated in municipalities that: (i) were relatively richer in sulphur and (ii) underwent more intensive mechanization. Our interpretation is that, when the local abundance of resources was sufficiently large to stimulate investment in organization and mechanization, criminal attitudes reduced. In particular, the introduction of orderly production practises under the supervision of technically qualified personnel, the demand for state police patrol in larger mines, together with the improvements in both safety and working conditions due to new technologies, possibly decreased psychological distress and inclination to violence. In short, better working conditions lessened the local "supply of violence".

[4] Our results are basically unaffected when we use as explanatory variable production divided by local population.

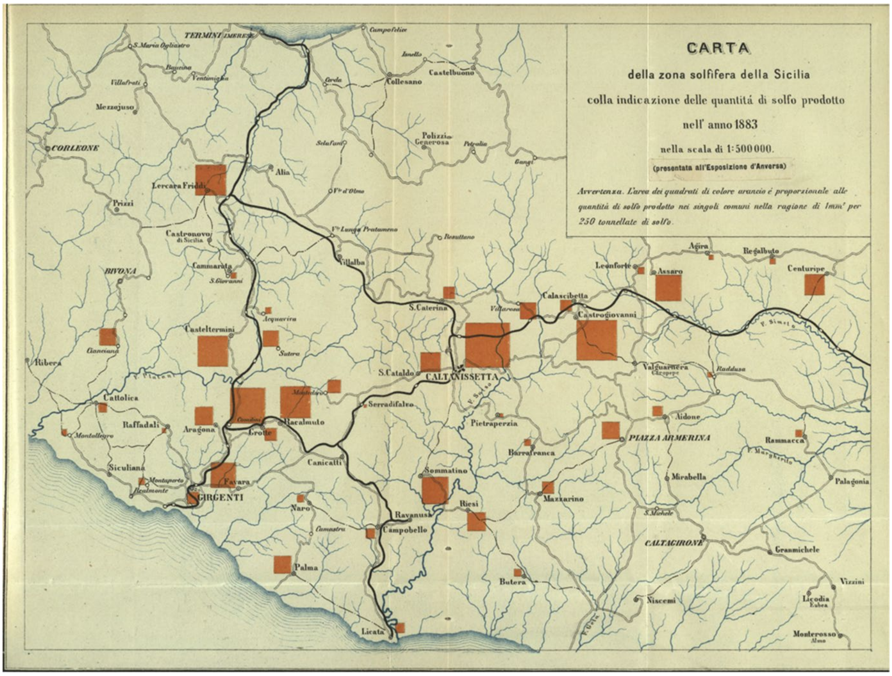

Fig. 1 Sulphur production at the municipality level in 1883. *Source*: Ministero di Agricoltura, Industria e Commercio (1887)

This paper contributes both to the literature on the curse of natural resources, such as Dell (2010), as well as on the literature on the economics of culture, as Grosjean (2014). Broadly speaking, the organization of labour matters. Dell (2010) analyses the case of silver mines in the Potosì area at the end of the sixteenth century and compares indigenous villages that were required to contribute with their male population to the production of silver with areas where large landowners sheltered their labourers from exploitation in mines, also providing some basic public goods as alphabetization and roads. The areas that were affected by the constriction still bear a gap in today's living standards. On the other hand, Grosjean (2014) suggests that aggressiveness and culture of honour were the adequate behaviour in a world, like the Scottish Highlands, where state law enforcement was absent, and herds could be stolen.[5] Thus, to deter theft, it was necessary to build a solid reputation for

[5] See also Nunn (2014, p. 381). The "code of honour" has several features which are common to the "code of the street", investigated by Anderson (1999) for the US and Brookman et al. (2011) for the UK. In environments where formal protection (police and justice system) is absent or unfeasible, the systematic use of violence against personal slights is a means to get "respect". Indeed, tough reputation deters against future attacks and builds self-reliance. Similar ideas are put forward by Gambetta (2009) in his work on prison inmates. At the same time, as suggested by Leeson (2014, Ch.7), intrinsically violent environments can lead to spontaneous forms of self-organization such as the Nuestra Familia, a prison gang in northern California which adopts a detailed constitution to regulate relationships among its members and run criminal business.

toughness. Similarly, in most of Sicilian mines, miners could have their ore stolen by others, there was competition about the best veins of mineral, and there was no external law enforcement able to protect or punish. In other words, mines were an ideal training ground for learning how to hurt people.

Some features of the Sicilian sulphur industry also relate to the economics of labour coercion, where "coercion is mainly about forcing workers to accept employment, or terms of employment, that they would otherwise reject": see Acemoglu and Wolitzky (2011, p. 557). Indeed, the relation between the pickman and his carusi was quite close to a master–slave arrangement, where the task of the slave required substantial exertion. According to Fenoaltea (1984), this form of labour coercion is mainly regulated by pain incentives since anxiety stimulates physical effort. By contrast, the use of machinery requires carefulness, which is better stimulated by rewards. In this perspective, while the abuses performed by the pickman were the means to extract effort from the carusi, mechanization of ore transportation made brutality unnecessary. On coercion in the mining industry see also Jopp (2021).

The rest of this paper is organized as follows. Section 2 provides some background about the origin and development of mafia and the Sicilian sulphur industry, while Sect. 3 presents the data. Section 4 reports and discusses the empirical findings. Section 5 concludes.

2 Some background on Sicilian mafia and the Sicilian sulphur industry

2.1 Origins and development of Sicilian mafia

Although "mafia" becomes the name for Sicilian organized crime only after the birth of the Kingdom of Italy (1861), its actual origin dates back to the beginning of the nineteenth century (see Lupo 2011; Felice 2013). In the aftermath of the Napoleonic period, the Kingdom of the Two Sicilies abolished feudalism and started a deep reorganization of the local administration, focusing on new norms to introduce a modern judiciary system. Such provisions, however, were never to be implemented properly. As reported in Felice (2013), the refusal of the Bourbon King to raise taxation on land implied a scarcity of public funds for the creation of a functioning state police and magistrature. These unimplemented reforms led to a pervasive weakness of the Bourbon Kingdom in Sicily, compromising its capacity to exert "abjudication", that is "the authoritative settlement of disputes among members of the subject population": see Tilly (1990, p. 97).

Since the state was far from being able to enforce a "monopoly of violence" in the island, the void was readily filled by the birth of what observers of the time termed as "violence industry" (see Dickie 2004). Indeed, the main explanations for the origins of mafia, including Acemoglu et al. (2020),[6] can be represented in terms

[6] Acemoglu et al. (2020) have recently argued that the widespread diffusion of mafia in Sicily at the end of the nineteenth century can be explained, in part, as a reaction of landowners to the rise of trade unionism in the countryside. In particular, the local elites turned to the mafia gangs to intimidate and repress the growing demands of the peasants. In the words of these authors, "Mafia spread from its original sur-

of "demand for violence". To protect themselves and their cultivations, landowners hired private militias.[7] Unfortunately, these gunmen often ended up colluding with thieves and blackmailers themselves, so to cream off part of the rural rent. For instance, bargaining between gangsters and “middlemen” over stolen goods or herds was the norm for settling thefts. This process of “democratization of violence” (Lupo 2011) created a new rural elite that was either directly or indirectly involved with criminals: see also Hobsbawn (1981, p. 87). Such an “aborted middle-class” progressively took control of cultivations and mines, mostly through local entrepreneurs (the “gabellotti”) who rented the land from the gentry. The annexation of Sicily to the Italian Kingdom after 1861 recognized the mafia as a public order problem, but it did not stop its expansion. The new state was prone to implement brutal and ineffective military repression, and it introduced mandatory 3-year draft, a very unpopular measure which put thousands of Sicilian young men on the run: see Felice (2013) and Marciante (2021). Also, the increasing political integration of Sicily to the rest of the Kingdom offered the chance of participating in the electoral game to individuals connected with organized crime. The gangs of the mafia became a systemic instrument of political struggle, often by eliminating rivals and—following the convenience of the moment—contributing to fuel or soothe local revolts against the state: see Lupo (2011). Both contemporaneous observers and historians seem to agree that the birthplace of mafia was located in the Palermo’s urban and rural areas (see, e.g. Lupo 2011). The presence of the harbour favoured both tobacco smuggling and control over the shipment of citrus, which was mainly produced in the rural areas around the town. Differently from citrus, sulphur was located in the central part of the island, and its boom on international markets occurred from the 1860s onwards. Notwithstanding the geographic distance from Palermo, the sulphur area witnessed the development of forms of organized crime that had substantial similarities to the mafia organization of the Palermo area. In most sulphur mines, the ability to exert violence was, if possible, even more relevant than in agriculture, as emphasized since 1862 by an official report to the Italian Parliament in MAIC (1862, p. 18). The centre stage actor in the sulphur industry was the pickman (“picconatore”), a small entrepreneur who acquired the right to extract the ore with the support of few assistants: see Cagni (1903, p. 173) and Dickie (2004). As argued by Lupo (2011), the pickman exerted violence in order to “regulate” the competition from other pickmen over the best lodes. The majority of sulphur mines were an ideal training ground for criminal practice, thus raising the “supply of violence".[8] At the

Footnote 6 (continued)

roundings in the most urban parts of Sicily and some of the mining areas to the more rural parts of the island" (p.541). Indeed, the baseline specification in Acemoglu et al. (2020) includes sulphur production among the determinants of mafia. Even after accounting for such political motivations, the role played by sulphur maintains its relevance.

[7] See Gambetta (1993) and Hobsbawn (1981, p. 36; pp. 89–91). Bandiera (2003) argues that the abolition of feudalism produced a dramatic increase in the number of landowners. In turn, land fragmentation promoted mafia activity by increasing the demand for private protection.

[8] Recently, Marciante (2021) has proposed another mechanism for the supply of violence in the nineteenth century’s Sicily. He argues that the desire to escape the compulsory draft—which had been imposed by the newly-born Italian Kingdom—pushed a considerable fraction of male youth to become outlaws on the run. In his overview of the development of European states, Tilly (1990, p. 99) argues

same time, such a consistent use of violence was associated with gangs' membership, like the Favara Brotherhood ("Fratellanza di Favara"). As reported by Dickie (2004), of the 107 men tried in 1883 for the membership of the gang, 72 worked in the sulphur industry. As for the origins of the mafia in sulphur areas, since violent confrontation can be extremely costly (see, e.g. Maynard Smith and Price 1973; Konrad and Morath 2016), the brotherhood was a device to mediate disputes among members and subjugate nonmembers.[9]

2.2 The variegated sulphur industry

The history of Sicilian sulphur mining dates back to 900 BC, but it was only in the last decades of the 1700s that—after many centuries of abandonment—there was a significant increase in extraction, driven both by the production of gunpowder and the increasing needs of the French and British chemical industries (see Ferrara 2016, p. 111). After 1830, the rapidly expanding demand for sulphuric acid led to a remarkable acceleration in Sicilian mining (see Squarzina 1963, pp. 22–23) although, until 1870, the depth of drillings in mineral explorations remained quite limited: see Parodi (1873, p. 7). During the industrial development taking place over the nineteenth century, Sicily was the monopolistic producer of sulphur, supplied to an increasing world demand.[10] The mineral was often located a few metres below the surface. Thus, until 1850, the extraction technology was very rudimentary and required little investment. Since 1860, the sulphur industry boomed, also due to increasing exports towards the USA. Progressive mechanization started quite late, after 1867, mostly implemented in a few large mines controlled by foreign investors, who also hired personnel with technical education: see Parodi[11] (1873, p. 28) and Squarzina (1963). As a result, the Sicilian sulphur industry was characterized by remarkable heterogeneity. On the one side, there was a multitude of mines that were

Footnote 8 (continued)

that, in rural regions, rulers were more prone to exert coercion and extract resources also through conscription. By contrast, in urban (capital intensive) areas, the state control over individuals and households was limited by substantial municipal organizations. On rulers' incentives to coerce see the theoretical model in Dalmazzo and de Blasio (2003).

[9] According to Hobsbawn (1981, p. 40), the mafia can also be seen as a body of "unofficial mutual defence". Leeson (2014, Ch.6–7) analyses "outlaw societies", like those formed by Caribbean pirates in the seventeen and eighteen centuries. Such societies were "composed exclusively by bad apples in trying to achieve social order through self-governance". Indeed, the effective organization of banditry required "mechanisms of self-governance"—like written democratic constitutions—"to prevent internal predation, minimize crew conflict and maximize piratical profit". Written and unwritten "criminal constitutions" have also been adopted by the Sicilian mafia.

[10] The Sicilian monopoly on sulphur ends with the introduction of the Frasch extraction method in Louisiana at the beginning of the twentieth century: see Fenoaltea and Ciccarelli (2006).

[11] Lorenzo Parodi, member of the Royal Corps of Mining Engineers and director of the Solfara of Grottacalda, was appointed by the Italian government in 1872 to report on the conditions of the Sicilian sulphur industry and recommend possible amendments to extraction methods.

inefficiently small[12] while, on the other side, industrial groups emerged. As noted by Squarzina (1963, pp. 106, 116), such an heterogeneity implied deep differences not only in the degree of mechanization, but also in the organization of the extraction. The situation was pretty wretched in small mines, which in 1893 represented the 90% of all mines for a production that barely accounted for the 30% of the total (see Squarzina 1963, p. 116). The excavation procedures that characterized small mines were quite chaotic, suffering from the improvisation and disorder that arose from the advice of uneducated foremen. As reported by Ferrara (2016, p. 114), under the piece rate system of remuneration, "miners were allowed to dig wherever they found a sulphur vein without any geological study or preparatory plan and with no regard for the safety or the future of the mine". Mechanization was nil, and working conditions were miserable. Tunnels were not reinforced, floodings and fires were frequent, air circulation was scant and the material dug by the pickman (*picconatore*) was carried outside on the shoulders of children, the *carusi* (Ferrara 2016, p. 115).[13] Since mines were mostly located in the countryside, mineworkers did not have access to decent shelter over the working week. As a result, many Sicilian mines had barely tolerable living conditions, associated with insalubrity, analphabetism and propensity to crime and violence (Squarzina, 1963, pp. 127–8; Franchetti and Sonnino 1876, p. 334). In short, many suphur mines were a sort of hellhole where homicide, revenge, theft, sexual abuse and male prostitution were common: see Strappa (1975).

By contrast, large mines were mainly organized along the lines of rationally planned industrial production and were often patrolled by the sovereign police (*Carabinieri*), which enforced the rule of law: see Strappa (1975). Also, large and deep mines had a scale fit for investment in mechanization, which progressively led to the adoption of "more rational and modern transportation techniques": see Ferrara (2016, p. 116). At the end of the nineteenth century, all the large mines had extraction equipment, thus replacing transportation on the shoulders of *carusi*: see Ferrara (2016, p. 118). Here, we suggest that the introduction of rational and advanced production methods improved working conditions in large mines[14], and at the same time, it eradicated juvenile's employment in tasks exposed to confrontation

[12] According to the Repertorio delle Miniere (1875, pp. 418–419), the fragmentation of land into a large number of properties often favoured the proliferation of small mines managed by contractors (gabellotti) who had low incentives to make adequate investments both for the extraction of crude ore and for the dewatering of mines. Already in 1862, a report to the Chamber of Deputies (MAIC 1862) had emphasized that fragmentation was going to reduce even further the incentive to create consortia among producers. Cagni (1903, pp. 165–168) indeed argues that underinvestment was induced both by liquidity constraints due to bank credit rationing and by the excessive shortness of the rental contracts that landowners were willing to grant. See also Zingali (1927, p. 169).

[13] As reported by Malta (2012, p. 96), the exposition of pre-pubertal youth to such wearying tasks often led to subsequent discharge from the military draft. Mostly due to short height and thoracic deformity, the rate of ineligibility among young sulphur workers was higher than 40 per cent, while the corresponding figure among peasants was around 20 per cent.

[14] As for the relevance of progresses in mechanization, Murray and Silvestre (2015) and Silvestre and Murray (2022) emphasize that, from the 1850s, the adoption of ventilation machines improved breathing conditions and, even more important, greatly reduced deaths caused by firedamp explosions in European and the US coal mining industries.

and violence. In our perspective, it is not only formal institutions that can affect the evolution of cultural traits (see Nunn 2014). Other microeconomic factors are also crucial. For instance, the transition to organized and mechanized production methods can contribute to a safer and disciplined workplace, where employees are less exposed to fatigue and distress, and children are excluded from jobs that require extreme strain. In such circumstances, the private interest of large producers who are ready to make substantial investments for their own profit may have positive social and economic spillovers, as in the case of Peru's big farmers investigated by Dell (2010) or as in the case of the United Fruit Company in Costa Rica analysed by Méndez and Van Patten (2022).

Interestingly, the small sulphur mines of the nineteenth century Sicily have several aspects that resemble contemporary artisanal mining in the Democratic Republic of Congo (DRC). Artisanal mines account for 20 per cent of the total production of cobalt in the DRC, the world's leading producer, and employ some 130,000 miners, of whom 40,000 are children (Amnesty International 2016). Excavations are messy and performed by hand-held tools, making such mines unsafe and unhealthy workplaces. As reported by Niarchos (2021), artisanal miners (the so-called *creuseurs*) are notoriously prone to violence. On the other hand, to contribute to the subsistence of their families, children in the cobalt industry—like the *carusi*—carry heavy loads of ore over long shifts, suffer beatings (mostly by security guards, in this case) and get intoxicated by chronic exposure to dust containing cobalt: see Amnesty International (2016) and Van Brusselen et al. (2020).

3 Data

Here, we make substantial use of new data by going back to historical sources. In particular, we consider two measures of sulphur production and a variable capturing the presence of mechanization in the local sulphur industry. The first measure of production, thousands of tons in 1883 at the municipality level, was originally provided by the Rivista del Servizio Minerario in 1885, published by MAIC (1887), in a detailed historical map in Table A at page VII, where a coloured square placed over each municipality represents the amount of sulphur produced.[15] The second measure of production is recovered from the report drawn up for the Italian Parliament by Parodi (1873). The document reports the average amount of quintals of sulphur produced at the municipality level in the period 1868–1870. In the empirical analysis, both these measures are normalized by dividing local production by the area of the corresponding municipality.

Further, to capture the impact of mechanization on local working conditions, we consider the number of inclined shafts (*piano inclinato*). This variable is recorded at

[15] See Fig. 1 in the introduction. This map allows us to geolocalize the production of sulphur, since the corner of each square touches the corresponding municipality. Squarzina (1963, p. 66) re-edited this map indicating, for each municipality, the production of sulphur with a number of little squares, each representing 250 tons of material. Each millimetre squared of the area corresponds to 250 tons of sulphur.

the municipality level and available from Rivista del Servizio Minerario (1903) in MAIC (1904) at pages 97–103. It refers to all mechanized inclined shafts installed or under completion between 1873 and 1903. As reported in MAIC (1904, p. 97), at the end of the nineteenth century, inclined shaft transportation accounted for more than 40% of the entire production. This system replaced human transportation of ore with carriages on rail pulled by engine power, and at the same time, it imposed the implementation of safety devices for the prevention of accidents: see Cagni (1903, pp. 80–81). The adoption of inclined shafts had another important implication for the organization of production in sulphur mining. As reported by Spina (2006, pp. 78–79), the loading capacity of inclined shafts allowed to implement a new production technique. The "obsolete, dangerous and inefficient" room-and-pillar mining was abandoned to adopt cut-and-fill mining, the most widespread methodology across Europe.[16] Following the definitions from the Encyclopedia Britannica, in the room-and-pillar system, "a series of parallel drifts are driven, with connections made between these drifts at regular intervals... The pillars of ore are left to support the overlying rock". By contrast, in cut-and-fill mining, "the ore is removed in a series of horizontal drifting slices. When each slice is removed, the void is filled (generally with waste material from the mineral-processing plant), and the next slice of ore is mined". Consequently, cut-and-fill mining reduced the likelihood of collapses, especially in areas more exposed to seismic risks.

As in Acemoglu et al. (2020) and Buonanno et al. (2015), we use the local intensity of mafia in the late nineteenth century from Cutrera (1900) for 282 Sicilian municipalities, as measured by a scale ranging from 0 (no mafia) to 3 (high intensity of mafia).[17] We also exploit the cross-sectional data in Buonanno et al. (2015). Their dataset contains information at the municipality level on the number of mines (from Squarzina, 1963), terrain ruggedness, difference in elevation within a given area, suitability of local land for cereals, citrus and olives, access to the postal roads and distance from non-seasonal rivers and ports. The measures of crop suitability used by Buonanno et al. (2015, p. F187) are largely determined by "exogenous soil properties and climatic conditions" to reduce concerns about reverse causation (i.e. the possibility that local mafia's presence induced the prevalence of particular crops).

Table 1, Panel A, reports the descriptive statistics for the sample of 282 municipalities considered in the regressions. Panel B provides the descriptive statistics only for the 40 sulphur-producing municipalities, focusing on the main variables we introduce in this study. The figures in Panel B emphasize the huge heterogeneity in

[16] Technical details on the relative advantages of alternative excavation methods are discussed in Archivio Centrale dello Stato (1875): see Section 6, "Sui metodi di lavorazione da adottarsi", pp. 79–87. As claimed by Undeground Coal (www.undergroundcoal.com.au), "a major advantage of inclined shaft access versus vertical shaft access is the ability to move large volumes of equipment, materials and personnel in a properly designed shaft". Slope mining techniques, such as "longwall mining" (in Britain the Ruhr) and "cut-and-fill stoping" (mostly in Belgium), led to the replacement of room-and-pillar mining in the coal industry starting from the 1880s: see Murray and Silvestre (2015, pp. 892–893).

[17] Cutrera, an eminent expert of the phenomenon in his time, assessed the intensity of mafia activity for each municipality over the last decades of the nineteenth century on a four-value scale. The map reporting mafia intensity is available at https://upload.wikimedia.org/wikipedia/commons/d/d7/SicilianMafia1900Cutrera.jpg, last accessed 25 May 2022.

the Sicilian sulphur industry: Half of these municipalities exhibited low production and no mechanization.

4 Empirical findings

In the light of the heterogeneity of the Sicilian sulphur industry, should we necessarily expect a simple linear relation when we investigate the nexus between resource abundance and criminality? Or, instead, can this relation exhibit substantial nonlinearity? In principle, growing abundance of resources may be associated with elements which either exacerbate or moderate outcomes such as crime.[18] Motivated by this observation, we will test whether the impact of sulphur availability on organized crime is better described by a quadratic relation, and then, whether the mechanization of ore transportation by inclined shafts is related to the presence of mafia activity. The potential relevance of technological advancements able to improve working conditions has been, so far, an unexplored issue in this literature.

In Sect. 4.1, we present OLS regressions which include a quadratic production term and the number of inclined shafts. In Sect. 4.2, we test our findings with a variety of robustness checks. In particular, we ask whether our results are driven by outliers, and then, we address the possible endogeneity of mechanization.

4.1 Main results

We run OLS regressions using the sample of municipalities exploited in Buonanno et al. (2015, Table 3). As in Buonanno et al. (2015) and Acemoglu et al. (2020), the dependent variable is the measure of mafia activity in 1900 reported by Cutrera (1900).

Table 2 reports our main results. Here, the main regressor of interest is the production of sulphur (in tons per square km) in 1883, obtained from MAIC (1887). We include the full set of controls used in Buonanno et al. (2015) and control for department fixed effects in the even columns.[19] Columns 1–4 report the estimates from a linear specification in sulphur production. The coefficient of sulphur production is always positive and significant.

Columns 3, 4, 7 and 8 include the number of inclined shafts, our measure of mechanization. The coefficient of this regressor has always a negative sign and has a significant impact on mafia activity in columns 7 and 8. The last four columns report estimates from a quadratic specification in production. The square

[18] For example the vast amount of public spending that followed the 1980 earthquake in Campania (Italy) was a watershed that boosted the activity of the "Camorra", the Neapolitan organized crime: see, e.g. Saviano (2007).

[19] The departments (*circondari*) were the intermediate level of administrative division below provinces. Sicily was organized in seven provinces and 24 departments.

Table 1 Descriptive statistics

	Mean	St dev	Min	Max	Percentiles				
					5th	10th	50th	90th	95th
PANEL A: All municipalities									
Mafia intensity in 1900[a]	1.43	1.14	0	3	0	0	1	3	3
Number of mines[b]	1.99	7.1	0	61	0	0	0	5	12
Sulphur prod. 1883[c]	.016	.0791	0	.973	0	0	0	.0149	.0907
Sulphur prod. 1868–70[d]	.0104	.0526	0	.676	0	0	0	.00784	.0533
Inclined shaft (1873–1903) [e]	.152	.741	0	7	0	0	0	0	1
Citrus suitability[f]	15.6	7.66	0	48	1.96	5.36	16.7	24.1	26.7
Cereal suitability[f]	17.7	11.1	1.49	66.4	4.09	5.59	15.1	32.8	38
Olive suitability[f]	30.9	12.1	3.48	69.3	10.6	13.7	32	43.8	48.1
Water scarcity[g]	.702	.458	0	1	0	0	1	1	1
Ruggedness[h]	219	105	31.9	578	65.9	85.3	212	366	406
Different elevations[h]	797	519	48	3232	246	330	672	1295	1528
Postal road[i]	.55	.498	0	1	0	0	1	1	1
Distance to rivers[l]	9.28	7.25	.993	42.1	1.51	2.07	7.62	19	21.8
Distance to port[l]	37.9	19.4	.132	83.9	7.75	12.4	36.5	65.1	72.1
Urban[m]	.124	.33	0	1	0	0	0	1	1
Population density[n]	132	127	4.86	1178	29.5	35.6	97.9	246	356
Seismic risk[o]	1.94	.506	1	3	1	1	2	2	3
Altitude[p]	419	276	2	1150	10	30	420	753	920
N. obs	282								
PANEL B: Only municipalities with positive sulphur production									
Sulphur prod. 1883[c]	.113	.184	.00194	.973	.00268	.00435	.0403	.308	.476
Sulphur prod. 1868–70[d]	.0726	.124	0	.676	0	0	.026	.189	.283
Inclined shaft (1873–1903)[e]	1.07	1.72	0	7	0	0	0	4	5
N. obs. [q]	40								

Panel A reports the descriptive statistics for the sample of 282 municipalities used in the regressions. The variables that are core to our analysis are reported in italics. Panel B reports descriptive statistics of sulphur production (thousands of tons per square km) in 1883, in 1868–1870, and the number of inclined shafts only for the subset of sulphur-producing municipalities

[a] Mafia intensity in 1900 from Cutrera (1900), measured on a scale from 0 (no mafia activity) to 3 (large mafia activity), available from Buonanno et al. (2015)

[b] Number of mines from Squarzina (1963), from Buonanno et al. (2015)

[c] Sulphur production in 1883 (thousands of tons per square km) from MAIC (1887)

[d] Sulphur production in 1868–70 (thousands of tons per square km) from Parodi (1873)

[e] Number of inclined shafts in the municipality in 1873–1903 from MAIC (1904)

[f] Index on land suitability for the cultivation of citrus, cereals and olives (from Buonanno et al., 2015)

[g] Dummy for water scarcity (from Buonanno et al. 2015)

[h] Indexes on terrain ruggedness and maximum difference of altitude (in metres) within the municipality constructed, respectively, from Global Land 1-km Base Elevation Project (GLOBE) and ISTAT (from Buonanno et al. 2015)

[i] Direct access to one of the postal roads (both available from Buonanno et al. 2015)

[l] Distance to rivers and ports in km (from Buonanno et al. 2015)

Table 1 (continued)

[m] Dummy equal to one for municipalities with less than 10-km distance from the five largest cities (from Buonanno et al. 2015)

[n] Inhabitants per square km (from Buonanno et al. 2015)

[o] Seismic risk from Protezione civile (2022)

[p] Altitude of city centre in metres (ISTAT)

[q] The list of the (active and non-active) mines in the sulphur-producing municipalities is available in Squarzina (1963)

of production has negative impact and is significant.[20] The full specifications in columns 7 and 8, without and with department fixed effects, respectively, show that the coefficients of the inclined shafts and of the quadratic term are significantly different from zero and exhibit a negative sign. This finding suggests that the effect of work mechanization emerges only when the impact of larger productions is properly taken into account by the quadratic specification. The last two specifications have also the highest values of the adjusted R^2 measure, among similar specifications that include (or not) department fixed effects. Finally, similarly to Buonanno et al. (2015, Table 3), we find that citrus suitability is never statistically significant and always exhibits a negative sign. Although land suitability may not fully capture the actual production of Sicilian citrus during the nineteenth century, this finding questions somehow the nexus between citrus cultivation and mafia.

Figure 2 shows the marginal effect of sulphur production computed by using the full specification in column 8 of Table 2. The figure shows that the local abundance of sulphur has an impact on mafia intensity that is consistently decreasing. Among the 40 municipalities with strictly positive production, the impact of sulphur production on mafia drops by 20% in the top quartile (i.e. 0.12), and it halves at the 90th percentile (i.e. 0.308). The marginal effect becomes even negative for the municipality with the highest level of production (Caltanissetta, with a value equal to 0.973).

The declining impact of sulphur on mafia suggests that the abundance of resources is not the whole story. If the resource curse was the only explanation, we should expect a constant, if not increasing, marginal impact of sulphur production on mafia activity. Thus, in addition to the "demand for violence" explanation based on rich resources and bad institutions proposed by Buonanno et al. (2015), our evidence provides new insights about the relevance of working conditions for the "supply" of violent individuals. In the next section, we provide additional robustness checks to our results.

[20] The comparison of the adjusted R^2 of specifications in columns 2 and 6 supports the inclusion of squared production.

Table 2 Sulphur production in 1883 and mafia intensity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sulphur production	2.354***	2.260**	2.405***	2.429**	5.726***	5.614***	6.581***	6.997***
	(0.843)	(0.875)	(0.906)	(0.988)	(1.191)	(1.537)	(1.229)	(1.600)
Sulphur production squared					− 4.792***	− 4.634***	− 5.685***	− 6.077***
					(1.305)	(1.539)	(1.330)	(1.569)
Inclined shaft			− 0.021	− 0.077			− 0.093*	− 0.154**
			(0.060)	(0.077)			(0.055)	(0.078)
Citrus suitability	− 0.025	− 0.023	− 0.024	− 0.022	− 0.025	− 0.023	− 0.024	− 0.022
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Cereal suitability	0.033***	0.022**	0.033***	0.021*	0.035***	0.023**	0.034***	0.023**
	(0.009)	(0.011)	(0.010)	(0.011)	(0.010)	(0.011)	(0.010)	(0.011)
Olive suitability	0.005	− 0.002	0.005	− 0.001	0.003	− 0.002	0.003	− 0.001
	(0.010)	(0.013)	(0.010)	(0.013)	(0.009)	(0.013)	(0.010)	(0.013)
Water scarcity	1.148***	− 0.012	1.148***	− 0.018	1.134***	− 0.006	1.132***	− 0.016
	(0.152)	(0.192)	(0.153)	(0.193)	(0.153)	(0.193)	(0.153)	(0.193)
Ruggedness	0.003***	− 0.001	0.003***	− 0.001	0.003***	− 0.001	0.003***	− 0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Different elevations	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.108	0.140	0.109	0.143	0.126	0.145	0.131	0.153
	(0.113)	(0.100)	(0.114)	(0.100)	(0.113)	(0.100)	(0.113)	(0.100)
Distance to rivers	− 0.019**	0.003	− 0.019**	0.002	− 0.020**	0.003	− 0.020**	0.001
	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)
Distance to port	− 0.002	− 0.003	− 0.002	− 0.003	− 0.001	− 0.002	− 0.001	− 0.001
	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.007)

Table 2 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Urban	0.628***	0.167	0.632***	0.177	0.653***	0.212	0.676***	0.245
	(0.187)	(0.195)	(0.189)	(0.196)	(0.183)	(0.191)	(0.185)	(0.193)
Population density	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.772**	1.040**	− 0.770**	1.060**	− 0.788**	0.934*	− 0.783**	0.941*
	(0.367)	(0.506)	(0.368)	(0.507)	(0.365)	(0.504)	(0.366)	(0.503)
Adj. R^2	0.386	0.569	0.383	0.569	0.395	0.578	0.396	0.584
Department FEs	No	Yes	No	Yes	No	Yes	No	Yes
N	282	282	282	282	282	282	282	282

The dependent variable is the measure of mafia intensity provided by Cutrera (1900). The production measure is thousands of tons of sulphur produced per square km at the municipality level, recorded in MAIC (1887). Columns 2, 4, 6 and 8 include department fixed effects. Robust standard errors in parenthesis. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$ and $^{***}p < 0.01$

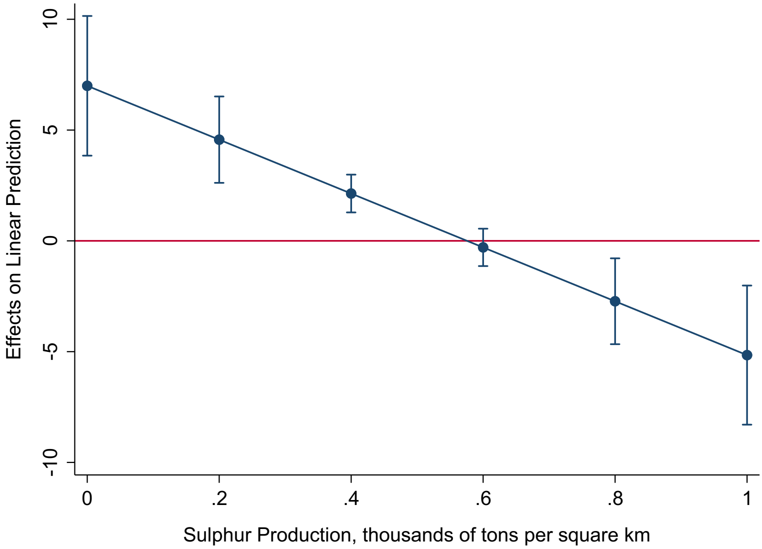

Fig. 2 Marginal effects of sulphur production in 1883 on mafia intensity. *Note*: Marginal effects of sulphur production based on the estimates of column 8, Table 2

4.2 Robustness checks

To test the robustness of our results, we first exploit the alternative measure of local sulphur production (per square km) provided by Parodi (1873), also used by Acemoglu et al. (2020). As shown in Table 6 and Fig. 3 in the Appendix, the main results are unchanged.[21]

A main concern is that our results are driven by a few municipalities. To this purpose, we replicate the analysis using a M-estimator (Huber 1973). As shown in Table 3, our main findings are unaffected, thus confirming that the quadratic OLS specification is not driven by outliers.[22] Our conclusions are further confirmed when we re-estimate our basic OLS specification excluding the top producing municipality, Caltanissetta, as shown in the Appendix in Table 8.

Further, as noticed by Buonanno et al. (2015, p. F194), the presence of mafia in one municipality can create spillover effects in the neighbouring municipalities. To tackle such an issue, we test for spatial spillover by estimating a spatial

[21] Following Buonanno et al. (2015), one might also presume that, in contrast with production in tons, the number of sulphur mines is generally stable being determined by exogenous geological features. As a consequence, from an empirical point of view, the number of mines should be preferred to limit endogeneity issues. For this reason, we use the number of mines per square km (and its square) as an instrument for the sulphur production per square km (and its square). As shown in Table 7 in the Appendix, our results are still there.

[22] We use the command robreg in STATA developed by Jann (2021).

Table 3 Estimates robust to outliers: M-estimator

	Production				Production			
	MAIC, 1887				Parodi, 1873			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sulphur production	2.4512***	2.7130**	6.9934***	7.6162*	3.6585**	5.0634	10.5231***	11.0494***
	(0.9265)	(1.3078)	(1.1552)	(4.0444)	(1.5146)	(5.3006)	(1.9173)	(3.7632)
Sulphur production squared			− 6.1232***	− 6.5930*			-13.3703***	–13.6084***
			(1.2391)	(3.6855)			(2.8959)	(5.1706)
Inclined shafts	− 0.0272	− 0.1536**	− 0.1076**	− 0.2248***	− 0.0143	− 0.1398*	− 0.0866*	− 0.1990***
	(0.0585)	(0.0656)	(0.0500)	(0.0828)	(0.0579)	(0.0745)	(0.0488)	(0.0642)
Citrus suitability	− 0.0215	− 0.0259	− 0.0206	− 0.0278	− 0.0229	− 0.0286	− 0.0225	− 0.0288
	(0.0165)	(0.0194)	(0.0166)	(0.0210)	(0.0167)	(0.0202)	(0.0166)	(0.0205)
Cereal suitability	0.0333***	0.0154	0.0345***	0.0190	0.0339***	0.0186	0.0354***	0.0195
	(0.0096)	(0.0105)	(0.0098)	(0.0127)	(0.0095)	(0.0124)	(0.0096)	(0.0119)
Olive suitability	0.0043	0.0117	0.0023	0.0093	0.0044	0.0090	0.0024	0.0088
	(0.0099)	(0.0136)	(0.0102)	(0.0183)	(0.0099)	(0.0187)	(0.0098)	(0.0200)
Ruggedness	0.0029***	− 0.0013*	0.0030***	− 0.0014*	0.0030***	− 0.0014*	0.0030***	− 0.0014
	(0.0008)	(0.0007)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Different elevations	0.0004***	0.0006***	0.0004***	0.0006***	0.0004***	0.0006***	0.0004***	0.0006***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0001)	(0.0002)
Distance to rivers	− 0.0187**	− 0.0031	− 0.0196**	− 0.0026	− 0.0180**	− 0.0000	− 0.0189**	0.0012
	(0.0085)	(0.0073)	(0.0083)	(0.0090)	(0.0083)	(0.0082)	(0.0081)	(0.0082)
Distance to port	− 0.0016	− 0.0051	− 0.0009	− 0.0040	− 0.0019	− 0.0063	− 0.0013	− 0.0060
	(0.0037)	(0.0071)	(0.0036)	(0.0086)	(0.0037)	(0.0084)	(0.0036)	(0.0087)
Population density	0.0014***	0.0013**	0.0013***	0.0012*	0.0014***	0.0013**	0.0013***	0.0012*
	(0.0004)	(0.0006)	(0.0005)	(0.0007)	(0.0004)	(0.0006)	(0.0004)	(0.0007)

Table 3 (continued)

	Production				Production			
	MAIC, 1887				Parodi, 1873			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water scarcity	1.1828***	− 0.0394	1.1697***	− 0.0672	1.1864***	− 0.0493	1.1711***	− 0.0686
	(0.1521)	(0.1772)	(0.1567)	(0.1835)	(0.1525)	(0.1752)	(0.1521)	(0.1758)
Postal roads	0.1045	0.0809	0.1259	0.1139	0.1110	0.1021	0.1322	0.1053
	(0.1179)	(0.0914)	(0.1194)	(0.1109)	(0.1178)	(0.1008)	(0.1161)	(0.0980)
Urban	0.6283***	0.1445	0.6747***	0.1867	0.5827***	0.0353	0.6145***	0.0640
	(0.1924)	(0.2202)	(0.1864)	(0.2020)	(0.1947)	(0.2615)	(0.1915)	(0.2000)
Constant	− 0.8672**	1.6230***	− 0.9005**	1.4871**	− 0.8589**	1.7032***	− 0.8756**	1.6304***
	(0.3680)	(0.4885)	(0.3695)	(0.5853)	(0.3704)	(0.5152)	(0.3674)	(0.5311)
Department FEs	No	Yes	No	Yes	No	Yes	No	Yes
N	282	282	282	282	282	282	282	282

Estimates obtained from the M-estimator. The dependent variable is the measure of mafia intensity provided by Cutrera (1900). The production measure is thousands of tons of sulphur produced per square km at the municipality level. In columns 1–4, we use the production measures from MAIC (1887); in columns 5–8, we use the production measures from Parodi (1873). Significance levels: $*p < 0.10$, $**p < 0.05$ and $***p < 0.01$

Table 4 Spatial estimates, GS2SLS estimator

	Non-standardized contiguity matrix						Row standardized contiguity matrix					
	Sulphur production from MAIC, 1887			Sulphur production from Parodi, 1873			Sulphur production from MAIC, 1887			Sulphur production from Parodi, 1873		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sulphur	6.934***	6.987***	6.949***	11.150***	11.132***	11.160***	6.648***	6.972***	6.405***	10.263***	11.124***	10.141***
	(1.478)	(1.476)	(1.478)	(2.039)	(2.035)	(2.039)	(1.477)	(1.476)	(1.446)	(2.069)	(2.035)	(2.027)
Sulphur squared	− 5.986***	− 6.117***	− 6.025***	-13.828***	-13.857***	-13.843***	− 6.003***	− 6.114***	− 5.776***	-13.233***	-13.849***	-13.416***
	(1.808)	(1.787)	(1.798)	(3.545)	(3.509)	(3.543)	(1.799)	(1.782)	(1.794)	(3.557)	(3.501)	(3.594)
Inclined shaft	− 0.164**	− 0.160**	− 0.165**	− 0.157**	− 0.146**	− 0.157**	− 0.150**	− 0.161**	− 0.131**	− 0.138**	− 0.147**	− 0.121*
	(0.067)	(0.066)	(0.067)	(0.064)	(0.064)	(0.064)	(0.066)	(0.066)	(0.065)	(0.064)	(0.064)	(0.063)
Citrus suitability	− 0.019	− 0.021	− 0.020	− 0.021	− 0.023	− 0.021	− 0.018	− 0.020	− 0.018	− 0.020	− 0.022	− 0.020
	(0.015)	(0.015)	(0.015)	(0.014)	(0.015)	(0.014)	(0.014)	(0.015)	(0.013)	(0.014)	(0.015)	(0.013)
Cereal suitability	0.022**	0.020**	0.021**	0.023**	0.022**	0.023**	0.016	0.020**	0.018*	0.017*	0.022**	0.019**
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.009)	(0.010)	(0.010)	(0.009)
Olive suitability	− 0.002	0.002	− 0.000	− 0.003	− 0.000	− 0.003	0.004	0.001	0.001	0.004	− 0.001	− 0.000
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.009)	(0.010)	(0.010)	(0.009)
Water scarcity	− 0.030	− 0.020	− 0.031	− 0.047	− 0.031	− 0.047	− 0.058	− 0.024	− 0.033	− 0.074	− 0.033	− 0.034
	(0.175)	(0.173)	(0.174)	(0.173)	(0.172)	(0.173)	(0.174)	(0.172)	(0.171)	(0.173)	(0.171)	(0.167)
Ruggedness	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001	− 0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Different elevations	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.139	0.154*	0.142	0.153*	0.169*	0.153*	0.162*	0.151	0.156*	0.175*	0.167*	0.165*
	(0.093)	(0.092)	(0.093)	(0.092)	(0.092)	(0.092)	(0.092)	(0.093)	(0.088)	(0.092)	(0.092)	(0.085)
Distance to rivers	0.002	0.000	0.001	0.005	0.003	0.005	0.000	0.000	0.002	0.003	0.003	0.005
	(0.009)	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)	(0.008)	(0.009)	(0.009)	(0.007)

Table 4 (continued)

	Non-standardized contiguity matrix						Row standardized contiguity matrix					
	Sulphur production from MAIC, 1887			Sulphur production from Parodi, 1873			Sulphur production from MAIC, 1887			Sulphur production from Parodi, 1873		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Distance to port	− 0.001	− 0.002	− 0.002	− 0.003	− 0.004	− 0.003	− 0.003	− 0.002	− 0.002	− 0.005	− 0.003	− 0.003
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)
Urban	0.257	0.281	0.262	0.163	0.184	0.162	0.234	0.292	0.196	0.148	0.189	0.118
	(0.193)	(0.202)	(0.199)	(0.192)	(0.197)	(0.192)	(0.193)	(0.206)	(0.171)	(0.192)	(0.199)	(0.161)
Population density	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.199	− 0.219	− 0.225	− 0.125	− 0.119	− 0.123	− 0.623	− 0.234	− 0.612	− 0.576	− 0.125	− 0.557
	(0.455)	(0.472)	(0.465)	(0.449)	(0.459)	(0.450)	(0.481)	(0.479)	(0.432)	(0.478)	(0.463)	(0.410)
λ	0.012		0.010	0.013		0.013	0.351***		0.447***	0.371***		0.491***
	(0.010)		(0.010)	(0.010)		(0.010)	(0.125)		(0.118)	(0.126)		(0.116)
ρ		0.036	0.021		0.021	0.002		0.158	− 0.259*		0.093	− 0.363**
		(0.022)	(0.026)		(0.022)	(0.025)		(0.103)	(0.152)		(0.103)	(0.151)
N. obs	280	280	280	280	280	280	280	280	280	280	280	280

The table contains the results from a spatial autoregressive models estimated using the generalized spatial least squares estimator developed by Kelejian and Prucha (1998). Estimates in columns 1–6 are computed using a non-standardized contiguity matrix. Estimates in columns 7–12 are computed using a row standardized contiguity matrix. The coefficient λ represents the effect of neighbour values of the dependent variables, i.e. the SAR component of spatial autoregressive model. The ρ coefficient represents the autoregressive parameter of the spatial lag of the error terms. Columns 1, 4, 7 and 10 include only the (SAR) spatial lag of the dependent variable. Columns 2, 5, 8 and 11 estimate a spatial error term model. Columns 3, 6, 9 and 12 estimate a SARAR model that simultaneously includes the spatial autoregressive term of the dependent variable and consider a spatial autoregressive error term. All estimations include department fixed effect. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$ and $^{***}p < 0.01$

autoregressive model, i.e. by using spatial lag autoregressive terms, and by allowing for spatially correlated error terms. As in Buonanno et al., we employ the generalized spatial two-stage least squares (GS2SLS) estimator developed by Kelejian and Prucha (1998). In Table 4, we consider: (i) the effect of spatial lag autoregressive terms (i.e. the impact of neighbours' levels of mafia) in columns 1, 4, 7 and 10; (ii) the presence of spatially autocorrelated error terms in columns 2, 5, 8 and 11 and, finally, (iii) both the presence of spatial lag autoregressive terms and spatially autocorrelated error terms in columns 3, 6, 9 and 12. The estimates obtained, by using both the measure of sulphur production from MAIC (1887) and from Parodi (1873), do not alter our main findings.

Also, when we investigate the relation between mechanization—as measured by the adoption of inclined shafts—and local criminal activity, one may legitimately ask in which direction causation is running. Although we suggest that more mechanization reduced local propensity to crime, there remains the possibility that causation runs the opposite way, i.e. that low levels of local criminal activity encouraged entrepreneurs to invest more. To tackle this issue, we instrument local mechanization by exploiting the altitude of the municipality. This choice is strongly supported by the observation that mountainous areas were particularly favourable to the adoption of the inclined shaft. According to the technical report of Cagni (1903) on sulphur extraction, the excavation technique largely depended on the features of local terrains. In particular, he argued that in "mountainous terrains, which include inclined strata, the implementation of horizontal galleries or inclined shafts is to be preferred" (p. 72).

Still, the use of "altitude" as (the sole) instrument would not be likely to satisfy the "exclusion restriction", as noted by Buonanno et al. (2015). Indeed, one might presume that municipal "altitude" directly affected the local activity of mafia. Due to the insufficient number of policemen who patrolled the region, remote municipalities were likely to be more exposed to brigandage and the need for private protection. Thus, to reinforce our findings, we exploit an additional source of exogenous variation in the first stage regression: We instrument inclined shaft also with an index of seismic risk at the municipal level. This index, available from the Italian *Protezione Civile* 2022 (Italian Civic Protection System), rates the seismic risk of each Italian municipality with a scale ranging from 1 (maximum risk) to 4 (very low risk). Since we noticed that (i) the adoption of the inclined shaft allowed for the implementation of the cut-and-fill method, and (ii) the cut-and-fill method reduced the likelihood of collapses in sulphur mines, we presume that inclined shafts were particularly suitable in areas that were more exposed to seismic risks.

Table 5 shows the results for both measures of sulphur production (per square km). Columns 1-2 (MAIC, 1887) and 3-4 (Parodi, 1873) report the results we obtain by instrumenting inclined shafts with both altitude and seismic risk as instruments. Our results are confirmed. The F statistics of the first stage coefficients of the instrumental variables are above the conventional threshold of 10.[23]

[23] The inclusion of department fixed effects, which captures much of the variability of the instruments, is mainly responsible for the reduction of the value of the F statistics and the reduced significance level of the coefficient of the seismic index. Indeed, it is not uncommon that the inclusion of geographic fixed effects reduces the first-stage F statistics: see e.g. Acemoglu et al (2020, p. 557).

Table 5 IV regressions

	Production MAIC, 1887		Production Parodi, 1873	
	(1)	(2)	(3)	(4)
Sulphur production	7.0516***	7.3633***	10.9221***	12.1633***
	(1.2360)	(1.4906)	(2.2328)	(2.2464)
Sulphur production squared	− 6.1758***	− 6.4586***	-13.9241***	-15.3671***
	(1.3516)	(1.4840)	(3.4298)	(3.3018)
Inclined shaft	− 0.1437***	− 0.1950***	− 0.1573***	− 0.2244***
	(0.0438)	(0.0678)	(0.0585)	(0.0842)
Citrus suitability	− 0.0233	− 0.0211	− 0.0250	− 0.0226
	(0.0166)	(0.0156)	(0.0167)	(0.0155)
Cereal suitabiity	0.0339***	0.0224**	0.0345***	0.0233**
	(0.0094)	(0.0099)	(0.0093)	(0.0099)
Olive suitability	0.0034	− 0.0014	0.0038	− 0.0018
	(0.0093)	(0.0118)	(0.0093)	(0.0120)
Water scarcity	1.1308***	− 0.0183	1.1348***	− 0.0365
	(0.1486)	(0.1797)	(0.1486)	(0.1797)
Ruggedness	0.0028***	− 0.0012	0.0029***	− 0.0012
	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Different elevations	0.0004***	0.0006***	0.0004***	0.0006***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Postal roads	0.1333	0.1552*	0.1449	0.1735*
	(0.1100)	(0.0927)	(0.1092)	(0.0914)
Distance to rivers	− 0.0206***	0.0006	− 0.0198**	0.0029
	(0.0079)	(0.0079)	(0.0078)	(0.0080)
Distance to port	− 0.0009	− 0.0011	− 0.0015	− 0.0031
	(0.0035)	(0.0065)	(0.0035)	(0.0064)
Urban	0.6895***	0.2536	0.6342***	0.1647
	(0.1802)	(0.1802)	(0.1844)	(0.1839)
Population density	0.0013***	0.0011***	0.0013***	0.0011***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Constant	− 0.7797**	− 0.1770	− 0.7702**	− 0.0948
	(0.3570)	(0.4962)	(0.3581)	(0.4973)
Department FEs	No	Yes	No	Yes
Instruments	First stage regression			
Altitude	0.0064***	0.0076***	0.0061***	0.0075***
	(0.0014)	(0.0025)	(0.0014)	(0.0022)
Seismicity index	0.8198*	0.7393	1.2573**	1.0489
	(0.4371)	(0.5178)	(0.5115)	(0.9508)
First stage F statistic	[24.0547]	[12.4508]	[29.9297]	[12.6276]
Adj R^2	0.3946	0.5838	0.3962	0.5923
N. obs	282	282	282	282

The estimates are obtained by using as instrumental variable the predicted number of inclined shaft computed from a first stage Poisson regression (Wooldridge 2010). F statistic on instrumental variables coefficients in square brackets. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$ and $^{***}p < 0.01$. $^{**}p < 0.05$ and $^{***}p < 0.01$

Finally, Table 9 in the Appendix reproduces the results of Tables 2 and 6 by using as main regressors the absolute levels of sulphur production (i.e. quantities not divided by the area of the municipality) from MAIC (1887), from Parodi (1873) and the number of mines as in Buonanno et al. (2015).

To sum up, after surviving a battery of robustness checks, our evidence shows that the impact of sulphur on mafia's presence is largely attenuated in municipalities that (i) were relatively richer in sulphur and (ii) underwent more intensive mechanization. Thus, while, on the one side, we confirm the nexus between resources, weak institutions and mafia; on the other side, our results suggest that when local resources were abundant enough to stimulate investment in organization and mechanization at the workplace, the thrust to criminal attitudes was weaker.

5 Discussion and conclusions

Some recent explanations for the origins of Sicilian mafia focus on the demand for private protection which, due to the combination of abundant resources and weak institutions, was delegated to gangsters. In this paper, we argue that the demand for violent individuals is not the full story. For what concerns the nexus between sulphur and mafia, other factors affected the local "supply" of violent individuals.

In the sulphur industry, the availability of resources went together—in most cases—with miserable working conditions. Similarly to Buonanno et al. (2015), we find that Sicilian sulphur mines favoured the diffusion of mafia activities in municipalities that were on the small–medium scale of production. However, in municipalities that exhibited larger ore extraction, sulphur had a much smaller impact on mafia. Our explanation emphasizes the duality of the Sicilian mining industry in the second half of the nineteenth century. On the one side, there was a vast majority of small mines characterized by inadequate and chaotic cultivation techniques. Such mines were a sort of no man's land where disorder and confrontation were the norm, an ideal breeding environment for the supply of violent individuals. On the other side, the resource-richest locations offered room for the development of a few large mines, often controlled by foreign investors. Larger mines hired competent technical personnel, offered first-aid medical assistance and had a scale sufficient to implement mechanization, such as inclined shafts for transportation and updated devices for air circulation and dewatering. Possibly, the organization of labour in such mines provided a novel set of implicit and explicit rules which disciplined the workforce and improved safety. At the same time, progressive mechanization alleviated working conditions by reducing fatigue, contributing to safer and healthier jobs and, finally, excluding children from ore transportation. In this perspective, the varied quality of local working conditions in the sulphur industry either fueled or dampened the culture of violence.

Differences in workplace conditions still seem to be crucial in the mining industry of developing countries. Recent research by Salas et al. (2015) has concentrated on the relation among miners' working conditions, workplace violence and psychological distress in some Latin American countries. The authors emphasize that psychological distress and exposure to violence are disproportionally large in the Bolivian and Chilean mines they consider. There, miners are exposed to precarious employment, "rare use of safety equipment" and "low life expectancy". By contrast, they find no evidence of abnormal distress and violence among Peruvian miners, "who were employed in a relatively large industrial mine offering formal contract" and "occupational health services" (p.472–473).

Appendix

In this Appendix, we further assess the robustness of our findings by:

(i) Using the measure of sulphur production provided in Parodi (1873);
(ii) instrumenting the municipal measures of sulphur production (per square km) with the number of mines (per square km);
(iii) excluding the municipality of Caltanissetta as an outlier potentially driving the quadratic relation;

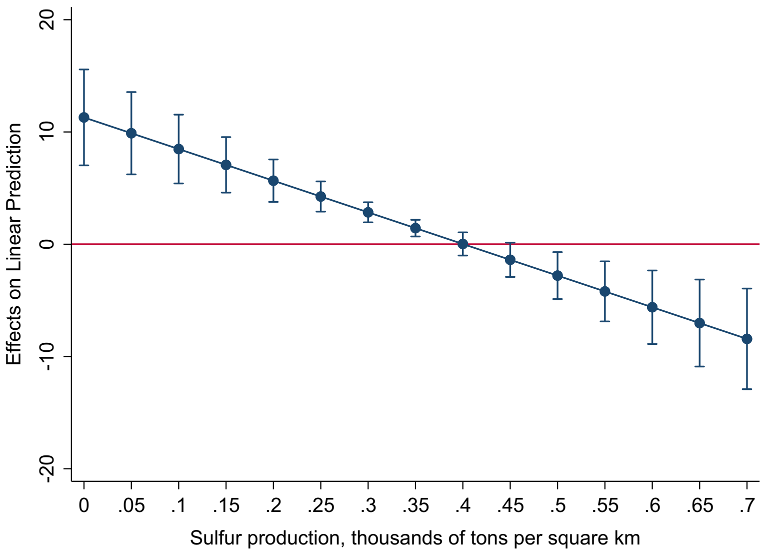

Fig. 3 Marginal effects of sulphur production in 1868–70: Parodi (1873). *Note*: Marginal effects of sulphur production based on the estimates of column 8, Table 6

(iv) using the non-normalized local measures of sulphur abundance, as measured by: (a) number of mines from Buonanno et al. (2015; (b) quantity from MAIC (1887) and (c) quantity from Parodi (1873);

Parodi's (1873) *production data.* In Table 6, we report the OLS estimates using the production of sulphur from Parodi (1873) per square km as the regressor of interest. The OLS estimates show a pattern similar to the one displayed in Table 2. The full specifications in columns 7 and 8, without and with department fixed effects, respectively, exhibit the highest level of adjusted R^2. Figure 3 confirms that the positive impact of sulphur production on mafia declines and becomes insignificant in the municipalities where production is relatively large.

Instrumenting sulphur production (per square km) with number of mines (per square km). As emphasized by Jaimes and Gerlagh (2020), the endogeneity of the measures of resource abundance is a thorny and, most often, an irremediable[24] issue: see also Torvik (2009, p. 245). Historical evidence, such as the case of interwar Ruhr coal mining discussed in Jopp (2017, pp. 951–3), also suggests that the number of mines can be quite volatile and largely related to market conditions. Moreover, as already mentioned, the number of Sicilian mines was largely affected by local fragmentation of land. However, since local production is a flow, one might still argue that the total number of (active and non-active) mines exploited by Buonanno et al. (2015) is closer to the notion of stock of available resources. For this reason, we instrument local quantities by the total number of local mines, so to control for endogeneity issues. Table 7 reports the estimates obtained by instrumenting sulphur production per square km (from MAIC, 1887, and Parodi, 1873) and its square with the number of mines per square km, and its square. The main results are unaffected.

Excluding the municipality of Caltanissetta. In principle, the significance of the quadratic production term could be driven by Caltanissetta alone, since it was the municipality with the highest production of sulphur. However, our results continue to hold even when we exclude this municipality from the sample, as shown by the estimates reported in Table 8.

Using non-normalized measures of sulphur production. In Table 9, we replicate our results using, in columns 1–2, the absolute number of mines per municipality as in Buonanno et al. (2015); in columns 3–4, the absolute levels of sulphur production from MAIC (1887); in columns 5–6, the absolute levels of sulphur production from Parodi (1873). The coefficients of squared sulphur production and inclined shafts are negative and significant as in the main specification.

[24] A noticeable exception is constituted by Ferniehough and O'Rourke (2021), who investigate the impact of the coalfield proximity on city growth. To circumvent endogeneity issues (the location of coalfields was endogenous to the effort to find them), they instrument proximity to coalfield with proximity to rock strata from the Carboniferous era.

Table 6 Sulphur and mafia intensity. Sulphur production in 1868–70: Parodi (1873)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sulphur production	3.571**	3.772**	3.613**	3.974**	9.066***	9.681***	10.013***	11.296***
	(1.419)	(1.602)	(1.484)	(1.740)	(1.917)	(2.067)	(2.001)	(2.169)
Sulphur production squared					– 11.204***	– 11.711***	– 12.592***	– 14.090***
					(2.926)	(2.992)	(3.049)	(3.130)
Inclined shafts			– 0.013	– 0.071			– 0.080	– 0.146**
			(0.058)	(0.074)			(0.051)	(0.072)
Citrus suitability	– 0.026	– 0.024	– 0.026	– 0.023	– 0.026	– 0.025	– 0.026	– 0.023
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Cereal suitability	0.034***	0.023**	0.034***	0.022**	0.036***	0.024**	0.035***	0.024**
	(0.009)	(0.011)	(0.009)	(0.011)	(0.009)	(0.011)	(0.010)	(0.011)
Olive suitability	0.005	– 0.002	0.005	– 0.002	0.003	– 0.002	0.003	– 0.002
	(0.010)	(0.013)	(0.010)	(0.013)	(0.009)	(0.013)	(0.010)	(0.013)
Water scarcity	1.150***	– 0.022	1.150***	– 0.028	1.136***	– 0.019	1.135***	– 0.030
	(0.153)	(0.192)	(0.153)	(0.193)	(0.153)	(0.193)	(0.153)	(0.193)
Ruggedness	0.003***	– 0.001	0.003***	– 0.001	0.003***	– 0.001	0.003***	– 0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Different altitudes	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.118	0.152	0.118	0.155	0.137	0.161	0.141	0.169*
	(0.114)	(0.100)	(0.114)	(0.100)	(0.113)	(0.099)	(0.113)	(0.098)
Distance to rivers	– 0.019**	0.004	– 0.019**	0.003	– 0.019**	0.005	– 0.020**	0.004
	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)
Distance to port	– 0.002	– 0.003	– 0.002	– 0.003	– 0.002	– 0.003	– 0.002	– 0.003
	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.007)

Table 6 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Urban	0.587***	0.108	0.589***	0.115	0.602***	0.135	0.619***	0.154
	(0.190)	(0.198)	(0.192)	(0.198)	(0.188)	(0.196)	(0.189)	(0.196)
Population density	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.764**	1.088**	− 0.762**	1.110**	− 0.782**	0.998**	− 0.776**	1.025**
	(0.368)	(0.504)	(0.369)	(0.505)	(0.366)	(0.501)	(0.367)	(0.500)
Department FEs	No	Yes	No	Yes	No	Yes	No	Yes
Adj R^{ε}	0.385	0.573	0.383	0.573	0.398	0.589	0.398	0.594
N. obs	282	282	282	282	282	282	282	282

The dependent variable is the measure of mafia intensity provided by Cutrera (1900). The production measure represents thousands of tons of sulphur per square km produced at the municipality level, recorded in Parodi (1873). Columns 2, 4, 6 and 8 include department fixed effects. Robust standard errors in parenthesis. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$ and $^{***}p < 0.01$

Table 7 Instrumenting sulphur production with number of mines

	MAIC, 1887				Parodi, 1873			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sulphur production	5.821***	6.362***	6.941***	8.078***	8.942***	9.793***	10.288***	11.935***
	(1.881)	(1.642)	(2.071)	(1.758)	(2.767)	(2.031)	(3.067)	(2.336)
Sulphur production squared	− 4.179	− 4.758**	− 5.550**	− 6.833***	− 9.831*	− 11.186***	− 12.249**	− 14.990***
	(2.705)	(2.282)	(2.790)	(2.116)	(5.486)	(3.925)	(5.821)	(4.007)
Inclined shafts			− 0.104*	− 0.177**			− 0.086	− 0.153**
			(0.055)	(0.071)			(0.053)	(0.071)
Citrus suitability	− 0.025	− 0.024	− 0.024	− 0.022	− 0.027	− 0.025	− 0.026	− 0.024
	(0.017)	(0.016)	(0.017)	(0.015)	(0.017)	(0.016)	(0.017)	(0.015)
Cereals suitability	0.036***	0.024**	0.035***	0.023**	0.037***	0.025**	0.036***	0.024**
	(0.009)	(0.010)	(0.009)	(0.010)	(0.009)	(0.010)	(0.009)	(0.010)
Olive suitability	0.003	− 0.002	0.003	− 0.001	0.003	− 0.002	0.003	− 0.002
	(0.009)	(0.012)	(0.009)	(0.012)	(0.009)	(0.012)	(0.009)	(0.012)
Water scarcity	1.128***	− 0.009	1.126***	− 0.019	1.133***	− 0.021	1.132***	− 0.032
	(0.149)	(0.180)	(0.149)	(0.180)	(0.149)	(0.180)	(0.149)	(0.180)
Ruggedness	0.003***	− 0.001	0.003***	− 0.001	0.003***	− 0.001	0.003***	− 0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Different altitudes	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.135	0.155*	0.139	0.162*	0.144	0.165*	0.148	0.172*
	(0.110)	(0.094)	(0.110)	(0.094)	(0.109)	(0.093)	(0.109)	(0.092)
Distance to rivers	− 0.020**	0.003	− 0.021***	0.001	− 0.019**	0.005	− 0.020**	0.004
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Distance to port	− 0.001	− 0.002	− 0.001	− 0.001	− 0.002	− 0.003	− 0.002	− 0.003
	(0.003)	(0.007)	(0.003)	(0.007)	(0.003)	(0.006)	(0.003)	(0.006)

Table 7 (continued)

	MAIC, 1887				Parodi, 1873			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Urban	0.628***	0.192	0.660***	0.240	0.579***	0.121	0.602***	0.151
	(0.180)	(0.183)	(0.181)	(0.182)	(0.185)	(0.186)	(0.185)	(0.185)
Population density	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.787**	1.338**	− 0.782**	1.318**	− 0.779**	1.421***	− 0.774**	1.418***
	(0.356)	(0.537)	(0.356)	(0.541)	(0.357)	(0.539)	(0.357)	(0.541)
Department FEs	No	Yes	No	Yes	No	Yes	No	Yes
Adj R^2	0.393	0.576	0.395	0.583	0.397	0.588	0.398	0.594
Cragg Donald Wald F	[150.148]	[146.173]	[140.102]	[138.950]	[146.370]	[148.465]	[136.869]	[139.742]
N. obs	282	282	282	282	282	282	282	282

The estimates are obtained instrumenting the sulphur production per square km (and its squared value) with the number of mines per square (and its squared value). Columns 1, 2, 3 and 4 utilize sulphur production from MAIC, 1887. Columns 5, 6, 7 and 8 utilize production from Parodi 1873. Cragg Donald Wald F statistic in squared brackets. Robust standard errors in parenthesis. Significance levels: $*p < 0.10$, $**p < 0.05$ and $***p < 0.01$

Table 8 Sulphur and mafia: excluding Caltanissetta from the sample

	Production		Production	
	MAIC, 1887		Parodi, 1873	
	(1)	(2)	(3)	(4)
Sulphur production	6.584***	7.183***	10.188***	11.986***
	(1.224)	(1.638)	(1.999)	(2.210)
Sulphur production squared	− 5.670***	− 6.234***	− 12.818***	− 15.043***
	(1.324)	(1.597)	(3.048)	(3.189)
Inclined shafts	− 0.108*	− 0.198**	− 0.104**	− 0.203***
	(0.056)	(0.077)	(0.046)	(0.054)
Citrus suitability	− 0.024	− 0.023	− 0.026	− 0.026
	(0.017)	(0.017)	(0.017)	(0.016)
Cereal suitability	0.035***	0.022**	0.036***	0.024**
	(0.010)	(0.011)	(0.010)	(0.011)
Olive suitability	0.003	0.001	0.004	0.001
	(0.010)	(0.013)	(0.010)	(0.013)
Water scarcity	1.131***	− 0.013	1.133***	− 0.028
	(0.153)	(0.193)	(0.153)	(0.193)
Ruggedness	0.003***	− 0.001	0.003***	− 0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Different elevations	0.000***	0.001***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.127	0.141	0.137	0.156
	(0.113)	(0.100)	(0.113)	(0.098)
Distance to rivers	− 0.020**	0.002	− 0.020**	0.005
	(0.008)	(0.009)	(0.008)	(0.009)
Distance to port	− 0.001	− 0.002	− 0.002	− 0.005
	(0.004)	(0.007)	(0.004)	(0.007)
Urban	0.678***	0.232	0.620***	0.135
	(0.185)	(0.192)	(0.189)	(0.196)
Population density	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.782**	0.947*	− 0.775**	1.033**
	(0.366)	(0.500)	(0.367)	(0.496)
Department FEs	No	Yes	No	Yes
Adj R^2	0.396	0.589	0.400	0.603
N	281	281	281	281

Columns 2 and 4 include department fixed effects. The municipality of Caltanissetta is excluded from the sample. The production measure in columns 1 and 2 represents thousands of tons of sulphur produced per square km at the municipality level, recorded in MAIC (1887). The production measure in columns 3 and 4 represents thousands of tons of sulphur per square km produced at the municipality level, recorded in Parodi (1873). Robust standard errors in parenthesis. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$ and $^{***}p < 0.01$

Table 9 Using absolute measures of sulphur production

	Number of mines		Sulphur production from MAIC, 1887		Sulphur production from Parodi, 1873	
	(1)	(2)	(3)	(4)	(5)	(6)
Sulphur	0.087***	0.089***	0.118***	0.102***	0.264***	0.261***
	(0.018)	(0.021)	(0.025)	(0.031)	(0.066)	(0.070)
Sulphur squared	− 0.001***	− 0.001**	− 0.002***	− 0.002*	− 0.010***	− 0.009**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.003)	(0.003)
Inclined shaft	− 0.149***	− 0.206***	− 0.190***	− 0.244***	− 0.245***	− 0.316***
	(0.054)	(0.065)	(0.069)	(0.088)	(0.072)	(0.076)
Citrus suitability	− 0.026	− 0.024	− 0.022	− 0.019	− 0.023	− 0.020
	(0.017)	(0.016)	(0.017)	(0.017)	(0.018)	(0.017)
Cereal suitability	0.037***	0.027**	0.034***	0.022**	0.035***	0.023**
	(0.010)	(0.011)	(0.010)	(0.011)	(0.010)	(0.011)
Olive suitability	0.001	− 0.004	0.003	− 0.003	0.001	− 0.004
	(0.009)	(0.013)	(0.010)	(0.013)	(0.010)	(0.013)
Water scarcity	1.124***	− 0.011	1.148***	− 0.005	1.148***	− 0.006
	(0.154)	(0.194)	(0.154)	(0.195)	(0.155)	(0.194)
Ruggedness	0.003***	− 0.001	0.003***	− 0.001	0.003***	− 0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Different altitudes	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Postal roads	0.121	0.119	0.105	0.116	0.120	0.133
	(0.111)	(0.096)	(0.114)	(0.099)	(0.113)	(0.099)
Distance to rivers	− 0.020**	0.004	− 0.019**	0.002	− 0.019**	0.004
	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)
Distance to port	− 0.002	− 0.003	− 0.002	− 0.001	− 0.002	− 0.003
	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.007)
Urban	0.573***	0.185	0.651***	0.234	0.624***	0.171
	(0.186)	(0.187)	(0.184)	(0.192)	(0.185)	(0.192)
Population density	0.002***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	− 0.763**	1.010**	− 0.778**	0.991*	− 0.775**	1.019**
	(0.367)	(0.503)	(0.368)	(0.507)	(0.367)	(0.499)
Department FES	No	Yes	No	Yes	No	Yes
Adj. R^2	0.403	0.586	0.390	0.570	0.400	0.589
N	282	282	282	282	282	282

The estimates are obtained using absolute measures of sulphur production (i.e. non-normalized by the surface). Columns 1 and 2 use the number of mines from Buonanno et al. (2015); columns 3 and 4 use sulphur production from MAIC (1887) and columns 5 and 6 use sulphur production from Parodi (1873). Robust standard errors in parenthesis. Significance levels: $*p < 0.10$, $**p < 0.05$ and $***p < 0.01$

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