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Original Article

The political economy of technology adoption: The case of Saharan salt mining

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ABSTRACT

Innovation is an important driver of economic growth and competitive advantage. A diverse literature in economics and management addresses a variety of questions about how to manage associated technological change. This paper explores the "opposite" question: Namely, what explains the absence of change? We apply existing theories of non-adoption to our case study, salt mining in the Sahara Desert, in order to generate new insights into barriers to technology adoption. We find that political organization establishes an environment for the formation of higher-order economic organizations, which in turn affect the direction and rate of technology adoption. Our setting seems exotic, but traditional methods of production persist in myriad impoverished settings, including those containing widespread artisanal and small-scale mining (ASM) activity. The study thus sheds light on the role of institutions in economic growth.

1. Introduction

Technological innovation is an important driver of economic growth and competitive advantage. There is now a diverse literature that spans contexts and levels of analysis to examine the adoption of technology. This literature includes work explaining the timing and pattern of adoption of agricultural innovations by individual farmers (Griliches, 1957), and of manufactured goods (Rogers, 2003; Gort and Klepper, 1982; Klepper, 1996). However, at times, technologies are slow to be adopted, prompting explanations such as the "appropriateness" of technology in different economies (Basu and Weil, 1998; Acemoglu and Zilibotti, 2001) and cognitive obstacles to adoption. In this paper, we extend this latter line of inquiry to investigate the persistence of traditional technologies over the long term, despite the existence of more advanced technology.

Our setting is salt mining in the Taoudenni region of the Sahara Desert, which by most accounts has remained largely unchanged since at least the 14th century, and possibly as far back as the fifth century B.C. Located in northern Mali, the Taoudenni salt mine is the largest in the Sahara, and has been described throughout history, including accounts by Ibn Battuta in 1353, and Herodotus who mentioned salt mining in *Histories*. Salt is extracted using hand tools and, until recently, was transported by camel caravan to market towns on the edge of the desert. However, elsewhere, the history of salt production has been characterized by profound organizational and technological change, including large-scale production organized by the church in medieval Europe (Multhauf, 1978) and the rise of Midwestern firms in 19th century America (Roy, 1997). Why, then, is Saharan salt extracted by traditional technology when, everywhere else, technology has changed?

One concern about such an exotic setting is whether findings are generalizable. We would argue that Saharan salt mining is but one example of persistent traditional technology. Basu and Weil (1998) observe that crops are still harvested by sickle in India, and ASM, which occurs throughout Africa, Asia, and Latin America, is defined as "labour-intensive, low-tech mineral exploration and processing activities" (Hilson, 2011). A burgeoning literature explores why this arduous and informal activity is so widespread

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(Perks, 2011). We ask why it remains predominantly artisanal and low-tech.[1]

To explore this question, we use a research design that tests candidate explanations against the facts on the ground. The theories are drawn from the economics and management literature and the factual details come from original ethnographic research (Gilberthorpe, 2013) on the economy and society of Taoudenni salt miners and the market towns of the salt trade.[2] Candidate theories include technological "appropriateness" given relative prices and worker skill, network effects of roads for wheeled transport, legal origins that could affect investment, and cognitive barriers to adapting to change. Explanations are organized into three categories: (1) theories that explain the choice of production technology, (2) theories that explain the choice of transportation technology, and (3) theories that explain "extinction", or why technologies cease to be used.

To illustrate our research design, consider a theory on the role of specialized intermediaries in technological diffusion. Rosenberg (1963) argues that intermediaries spread information and provide expertise, and are thus necessary agents of technological diffusion. But in our case, we find that worker specialization occurs, and so we can reject Rosenberg's theory that an absence of intermediaries explains persistence of traditional methods.

Applying this method, we reject quite a number of theories, and find that the most relevant literature is that which focuses on organization and hierarchy. For example, the small-scale mining operations of Taoudenni, and ASM more generally, are peculiar given the large-scale organization of salt production even historically, in medieval Europe and 19th century U.S. Several areas of research suggest that political organization is related to economic organization in complex ways. First, the history of the corporation indicates that this relationship may involve learning or unobserved heterogeneity, as corporations were originally created for political purposes, to form cities (Kuran, 2003, 2010; Lipartito, 2004), and subsequently used for commercial purposes, in this case for salt production. Second, high-quality political institutions seem to facilitate an increase in firm size. Libecap (1978) details the case of Nevada, where early mining practices closely resemble our salt mining context. California mining financiers helped to organize Nevada into a U.S. Territory, which, among other changes, transformed the legal framework from scattered, autonomously formed "mining district codes" to federal law (Clay and Wright, 2005). Large capital investments were made and, in a short period of time, ASM was replaced by some of the largest firms in the country (Hannah, 2008).

We examine additional interactions between political and economic organizations. Importantly, we find that commercial corporations do not form where political corporations have not formed: foreign mining corporations operating in sub-Saharan Africa, therefore, have not "replaced" ASM. Instead, ASM persists *alongside* foreign-owned large-scale mining operations (Dondeyne et al., 2009; Van Alstine and Afionis, 2013; Geenen, 2014). Such organizational shortcomings, both political and economic, contrast starkly with the relatively smooth functioning of markets in our setting. Product markets are reliable, with stable prices and quality standards; debt contracts are used regularly; and workers specialize, becoming, *inter alia*, blacksmiths at the mine, and mechanics who accompany trucks with tools and spare parts in tow (Scheele, 2012). Markets for technology also appear to function, as satellite phones and GPS make truck journeys safer.

Our findings, though derived from a specific, even extreme, case, move the focus away from a search for market failure and instead draw attention to the relationship between political and economic institutions and their role in catalyzing technological change and economic growth. The analysis also raises new questions for future research, such as: *Why* are some societies organized politically in a way that promotes economic organization while others are not? and *Why* is the incorporation of municipalities for political purposes a precondition for the formation of hierarchical firms?

2. Case study: the Taoudenni salt trade

Journalist Michael Benanav's 2006 account of his journey to the Taoudenni salt mines describes a 40-day trek with two experienced salt miners—cousins, who served as his guides across a stark and featureless landscape of shifting sand (Benanav, 2006). The trip begins with one cousin and a handful of camels; the other cousin is met several days later at one of the wells that dot the route across the desert. Not only are the cousins able to find each other sight unseen on either side of a large sand dune, but the navigation from one well to the next is repeated daily without the benefit of stars (they travel during the day) or GPS navigation.

While Benanav (2006) provides a valuable first-hand account, Rombe-Shulman's extensive ethnographic fieldwork provides a wealth of perspectives, including findings from 70 in-depth interviews with salt merchants, transporters, miners, and consumers. As part of a "participant observation" method common to anthropological research, Rombe-Shulman lived among her subjects in a rented house, and hired three assistants to help identify interviewees and conduct (and translate for) the in-depth interviews using a comprehensive list of open-ended questions. Together they also conducted dozens of shorter interviews. Details about the mine and mining practices are drawn from these interviews.

The mine itself is a former seabed where high quality salt is carved out of the ground in rectangular slabs using simple tools. Several layers of lower-quality salt must be gone through to reach the pure white salt for which Taoudenni is known. Historically, all of the lower grades of salt have also been extracted in slabs and traded as well, except *wara*, the top-most layer of salt, which must be removed to reach the lower, more valuable layers. Because it is so hard, *wara* is laborious and time-consuming to remove and typically involves the cooperation of other miners (Rombe-Shulman, 2013; Clauzel, 1960). However, it serves as a good building material for constructing the mine and shelter structures. Thus, the otherwise ubiquitous corrugated iron, used to make "tin roofs" throughout Africa (Edgerton, 2006, p. 41) is not used here. It is now also sold, the only type in rock form rather than slab form.

The size and shape of the slabs are consistent with early descriptions and have practical origins. Specifically, camels can carry two 35-kg slabs on each side (150 lb per side). The standard size and shape of slabs facilitate transactions, historically and presently, because salt was and continues to be a form of currency. According to lore, salt was traded for gold—and worth its weight in that precious metal—and is still sold in the same market towns as in ancient times, including Timbuktu

[1] The literature identifies many reasons for the persistence of ASM. The low skill required makes ASM possible for most able-bodied workers. Moreover, it argues that earnings are more consistent than farming (Hilson, 2010; Bryceson and Jonsson, 2010) and that mine work is complementary to agriculture, which is typically undertaken seasonally (Kamlongera, 2011; Okoh and Hilson, 2011). In some cases, mine income is used for capital and human capital investments (Hilson and Garforth, 2013; Hilson and van Bockstael, 2012; Maconachie, 2011).

[2] Rombe-Shulman's immersion into the Taoudenni salt industry began with a six-week examination of Timbuktu in mid-June to early August of 2006. A more lengthy residence began there in November 2008 and concluded in February 2010, and included time spent in the major market towns of Bamako and Mopti, as well as Bobo-Dioulasso, the second largest city in Burkina Faso, and formerly home to prominent salt trading families. Bobo-Djoulasso still serves as a trade and transportation hub for salt.

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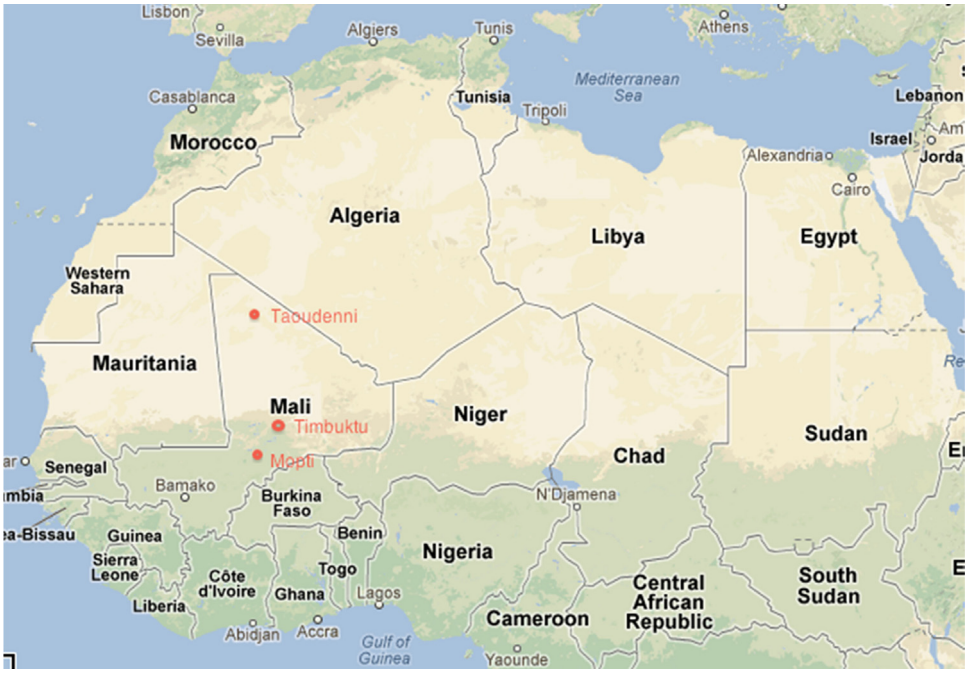

Fig. 1. The Taoudenni salt caravan. *Note*: Timbuktu is a common embarkation point for trips into the desert. Taoudenni is the location of the salt mines. Salt is transported back to Timbuktu and sold there or in Mopti, another market town south of Timbuktu. The Sahara Desert is denoted by the beige area.

(de Villiers and Hirtle, 2002). Fig. 1 shows these locations in the context of the Sahara Desert.

The different grades of salt transported from Taoudenni are just one source of variation in West African salt markets, where the subtle nuances of salt are described the way Western oenophiles describe fine wine. Far from a homogeneous commodity, different varieties of salt are used for different purposes, including culinary, medicinal, and veterinary. Throughout Mali, sea salt is cheap and plentiful, imported from Senegal and Ivory Coast; rock salt is also imported from Mauritania. But the purest layer of salt from Taoudenni is special and commands a 300% premium over ordinary salt. It is used as a condiment and sometimes to improve virility, as the Viagra of West Africa. The farther from Taoudenni the salt is sold, the more expensive it becomes: in Burkina Faso, it is a mystical commodity used for special occasions.

While our setting seems geographically isolated, some changes have occurred over time. The French colonial government paved the wells used by caravans, making them more reliable. Camel caravans have also changed. In the past, caravans were much larger, organized by a town or several neighboring towns, to make travel and mining safer against bandits (Lydon, 2009). Large caravans also included slaves, who were brought to the salt mines where they were unable to navigate the desert to escape (Lovejoy, 1986). Finally, trucks have largely displaced camels. On the one hand, camel herders argue that trucks are impractical for the desert because they break down, stranding the driver whereas the death of a camel in a caravan does not (Seligman, 2007). On the other hand, trucks are faster, taking as little as three days each way compared to 30 days by camel. This speed makes up for the higher costs incurred for fuel, repairs, and maintenance for trucks.

3. Explaining technology adoption or the persistence of traditional practices

Given the changes in mining and transportation practices described above, it would be hard to argue that the Saharan salt industry is unchanged over time. Instead, what makes this setting particularly interesting is that some practices have managed to persist across *historical time*. This allows us to investigate a wide range of adoption experiences, from failure to uptake at one extreme, to rapid adoption at the other. The following analysis is a unique combination of the historical and the modern. To organize the technologies and the reasons that might explain their adoption, we consider three modes of technological change.

First, we examine the adoption of production technology and ask why miners do not mechanize production. We consider individual-scale technology, such as jackhammers and explosives, as well as large-scale technology, such as specialized mining vehicles. Economic and institutional explanations for the non-adoption of technology are assessed.

Next, transportation technology adoption is largely a question of camels *versus* trucks. This is not a new question, so we draw upon an existing animal-replacement literature, as well as a literature on network effects as it pertains to road infrastructure. The literature on mechanization discussed in the context of individual-scale technology also applies.

Finally, we inquire about the extinction of practices. Whereas the previous two categories look at technology adoption as a replacement of traditional practice, this third category looks at how practices might be abandoned entirely rather than replaced. A different set of theories, which involve broad economic and cognitive factors, can be brought to bear on this last type of technological change.

3.1. Tools: small- and large-scale technology

There are three ways to produce salt: by evaporating salt water (brine); mining salt out of the ground as rock salt; or by burning sodium-rich plants, filtering the ashes, and evaporating the salt water. In the west-central Sahara, rock salt is extracted from the ground. Mining technology for this type of extraction varies historically and geographically. In developed countries, large-scale specialized equipment is used:

> All of the bars of salt are trimmed and polished after they are extracted using specialized tools. Most of these tools have

changed little over the last five hundred years, according to the miners; except now they use a large pickaxe to break the layer of *wara*, whereas before they would just use large rocks that they hurled at the ground. (Rombe-Shulman, 2013, p. 32)

In thinking about technological alternatives to long-held practices, we consider separately small-scale and large-scale technologies. On an individual scale are technologies that would make the miner's work faster and less demanding physically. For example, explosives have long been used in mining and construction, and jackhammers are a general-purpose technology that could be adopted, as they require no electrical infrastructure. Larger-scale technologies involve a different set of economic and institutional considerations, and are thus examined separately.

3.1.1. Individual-scale machinery

The geology of Taoudenni salt suggests that a jackhammer or explosives would be useful for extracting salt. The hard top layer of rock salt, *wara*, must be removed to get to the more valuable layers of higher-quality salt underneath. Removing this layer of rock is not only back-breaking, but it is also costly and time-consuming. Miners often ask other miners for help, paying each helper a day's food for their efforts. Constructing a mine can take a month of valuable time out of a six-month season and there is no guarantee of a rich vein. Mechanizing the process of digging could thus expedite and ease the work of miners. We examine economic obstacles to jackhammer adoption, including appropriateness of technology and information economics in product markets. Institutional impediments to adoption are also analyzed, such as a lack of intermediaries to promote new technology, which may also play a role in adoption.

One reason a technology might not be adopted is a lack of "appropriateness", which depends on relative prices and capabilities (Basu and Weil, 1998). Technologies created in developed countries are adopted most quickly by countries at a similar stage of economic development, and may be inappropriate for less developed economies. Acemoglu and Zilibotti (2001) show that skill differences can result in lower productivity in adopting countries. Allen (2009) demonstrates how relative prices can explain lack of adoption. Using the example of the spinning jenny in the 18th century, Allen estimates that a jenny cost six months' earnings for a British worker but 18 months' earnings for a French worker. Thus, the enthusiastic adoption in Britain and low adoption in France was due to different relative prices: French spinners earned far less for a month's work than British spinners.

We follow Allen and estimate the cost of a jackhammer relative to a salt miner's earnings. That is, we calculate whether a jackhammer can pay for itself in a reasonable amount of time. We begin with a used gas-powered jackhammer that can be obtained in the U.S. for about US$600 in current dollars. We do not have equipment prices for Mali, but note that this type of equipment is commonly used in construction projects in Mali's urban areas, which suggests that a market for jackhammers likely exists. Next, we base the following income calculations on Rombe-Shulman (2013, p. 34). A miner can sell the lowest grade of *wara* for US$0.30/kg. The highest-quality salt would be worth US$0.50/kg wholesale and sells at a retail premium of two to three times that of sea salt, and sometimes more. A miner averages six bars of salt per day at 30–40 kg per bar. At the conservative US$0.30 price and 30 kg size, this comes to over US$300 per six-day week. Over the course of 20 weeks, this comes to over US$6000 in a single season. Miners have costs, including food, transportation, tools, and family obligations such that they are far from wealthy. Nevertheless, our calculation shows that the price of equipment falls within the scale of a single miner's earnings. Thus, appropriateness does not explain the lack of adoption of jackhammers.

A second possible explanation for non-adoption is institutional. Rosenberg (1963) posits that intermediation is needed to promote adoption, showing how the machine tool industry emerged when toolmakers from manufacturing firms struck out on their own and specialized in adapting their tools for an ever-diversifying customer base of manufacturers. Might jackhammers be adopted if intermediaries provided sales and service to miners? Evidence suggests not. First, miners are exposed to jackhammers because they travel to cities where they are used in construction. In addition, specialization in tools is observed. Taoudenni has a blacksmith whose sole purpose is to make and maintain tools for miners and is paid a flat fee in salt slabs by miners each season. Similarly, Scheele (2012, p. 100) describes truck mechanics who travel on truck journeys to repair flat tires and other breakdowns. Finally, we have anecdotal evidence that an Italian firm came to Taoudenni to market a brining technology that uses water to extract salt. Miners rejected this technology but the anecdote suggests the existence of technology marketers.

A third, and credible, explanation for the continued use of traditional tools is information signaling, in which sellers invest in a costly "signal" to convey high quality and thus high price. Customers recognize premium-quality Taoudenni salt by its unique form factor, the identical rectangular bars that are ideally sized to be transported, two on each side of a camel. This form factor has existed for time immemorial for practical reasons, but persists even though truck transport is now dominant because it conveys information about product quality. Given the sophistication of salt consumers and the cultural meaning of this particular type of salt, a high premium is paid for guaranteed quality, which this costly, hard-to-imitate, "packaging" provides.

To get a sense for how costly this packaging is, we note two sources of cost. First, the salt bar is trimmed to the standard size and shape, and the fragile raw salt is fortified with an acidic saltwater found in the mines, which turns the salt "hard like iron" and makes it transportable (Rombe-Shulman, 2013, p. 31). Miners either "finish" their own salt bars or pay individuals at the mine who specialize in finishing. Specialists charge one bar of salt for every four bars finished. A second source of cost is borne by the customer, who purchases salt from the slab at the marketplace. After a smaller piece is cut from a large slab, it is then pulverized. A jackhammer and, for that matter, explosives as well as the Italian brining technology, would pulverize the salt, saving consumers the trouble, but also making the salt unrecognizable as a premium product. Communicating the quality of a product that deviates from the standard would be difficult for an individual miner.

Of the three explanations for the non-adoption of small-scale technology, we find that signaling and product standards likely serve a quality certification function. We posit that it is more profitable for miners to adhere to these standards and charge a premium than to use lower-cost methods but charge a lower price. Hence traditional practices persist. Meanwhile, "appropriateness" with regard to relative prices and skill is most likely not an explanation, nor is the availability of technology intermediaries.[3]

3.1.2. Large-scale machinery

While an individual miner might find it difficult to change existing product standards that convey information about quality to the marketplace, in principle, there are ways to overcome such obstacles. For example, in 19th century Michigan, salt firms consolidated to advertise and communicate the quality of their

[3] We also find no evidence of collective action in agreeing upon traditional technology. That is, we could find no cases in which a miner was threatened for wanting to use a different tool, for example. The adoption of the pickaxe is suggestive that miners are not opposed to new technologies as long as they allow them to perform the necessary tasks.

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product (Roy, 1997). Large size or collective action would be necessary for a systemic change, however. Thus, our analysis turns to large-scale enterprise and the adoption of large-scale technology. Several theories address questions of scale, including market size considerations and institutional explanations.

Note that we consider separately the adoption of organizational innovation, namely the large-scale firm or corporation. While large firms (as measured by employees or sales) are associated with large-scale technology, the two are not inextricably linked historically. For the purposes of our analysis, therefore, we consider large-scale technology and large-scale organization separately throughout.

3.1.2.1. Market size. In a classic case of technology adoption in American farming, the mechanical reaper gained widespread use decades after its invention, only after economic conditions became suitable (David, 1971). As with appropriateness, discussed above, higher wages (relative prices) played a role in encouraging reaper adoption, but scale was also important in this case. Farm size had also increased in response to greater demand for wheat, and eventually reached the large scale at which reapers were most efficient.

The question for our case is whether the West African market for salt is too small to support large-scale equipment? Unfortunately, data are scant, especially for this region. Lovejoy (1986) provides estimates of salt production from the late 1960s and early 1970s, but the population of the region has more than doubled since then (and estimates of the region's population are also unreliable). Nevertheless, we present Lovejoy's estimates to provide an order of magnitude of production. In the salt-producing region east of Taoudenni's trading region, the two main salines (Fachi and Bilma) each produced about 1500 metric tons in 1972. These two salines supply the bulk of salt for central Sudan, in modern Niger and Northern Nigeria. If we include other types of salt produced in the region, such as "trona", the production of which is estimated by Bouquet (as cited by Lovejoy, 1986) at 10,000 metric tons in 1967, and European salt imported at a rate of another 10,000 metric tons in 1906, the total volume of salt produced in the region is several tens of thousands of metric tons.[4] As conservative and outdated as this estimate is, demand of over 20,000 metric tons is still sufficient to accommodate larger scale technology. A 5000-year-old salt mine in Turkey is operated by a firm that employs 16 workers and produces 500 tons of salt each year, featuring, since the 1970s, "machines and underground blasting" (Catholic Online, 2013). Thus, market size considerations do not fully explain why larger-scale equipment and organization are not used in Saharan salt mining. Mines producing much less salt than Taoudenni organize production using employees and machines.

3.1.2.2. Institutions: legal origins. An institutional problem might explain the absence of large-scale technology and organization. The literature begins with an exploration of what drives the quality of government. La Porta et al. (1999) find that geography, legal origins, and religion all play a role. Acemoglu et al. (2001) focus on governmental institutions that affect economic growth, especially property rights and the rule of law. They find that economic institutions and performance today are driven by settlers' ability to establish good institutions, which was determined in turn by European mortality rates in the colonies. Cross-country regressions by Rodrik et al. (2004) further support the primacy of institutions, even explaining away some of the geography findings in La Porta et al. (1999).

Banerjee et al. (2002) connect these higher-level institutions to technology adoption: when sharecroppers in India are granted new legal rights to their tenancy, they adopt new Green Revolution seeds, which increase productivity. Kuran (2003, 2010) connects legal institutions to the adoption of organizational innovation, pointing out that the Islamic legal system did not recognize fictitious persons, preventing the formation of corporations. Instead, partnerships were used, but these were dissolved upon the death of any single partner, and could involve costly and uncertain renegotiation. Thus, large partnerships were discouraged at a time when corporations were emerging in medieval Europe for municipal and religious purposes, putting Muslim entrepreneurs at a disadvantage to Europeans. Kuran (2003) believes that the resulting business enterprises, usually temporary *ad hoc*, two-man partnerships, probably prevented the political influence to change legal doctrine. A third hindrance to achieving scale was Islamic inheritance law, which divides estates across all surviving family members. Kuran (2003) contrasts this with the European practice of primogeniture, in which the eldest son inherits an estate intact.[5]

All of these seem to apply to our present salt mining setting, complete with small, temporary partnerships. But do legal institutions explain the lack of technology adoption or organizational innovation? The evidence suggests they do not. First, commercial courts were established in the 19th century, and while Europeans enjoy a century-long head start, Islamic law has long ceased to hinder incorporation. More importantly, throughout the period of Islamic economic decline, the rule of law was respected, with Islamic courts even preferred by non-Muslims, who were permitted to choose from among Muslim, Christian and Jewish courts (Kuran, 2003). Thus, the link between law and weak institutions discussed by the literature above does not apply here. It is possible that courts are accessible mainly in the urban settings Kuran (2003) describes, whereas on the outskirts of the Sahara, recourse to adjudication is costly. Even so, poor legal access might actually encourage incorporation. Laeven and Woodruff (2007) show that incorporated firms are less vulnerable to weak legal protections than sole proprietorships, and that even in Mexico's legal environment, the majority of mining firms are incorporated.

While Islamic law might have posed a problem for economic organization early in its history, it does not present a real impediment to corporations today. Moreover, historically, this region enjoyed respect for the law and high quality of courts, which are inconsistent with weak institutions resulting from legal origins.

3.1.2.3. Institutions: political organization and property rights. Islamic legal origins do not explain technology and organizational adoption. Banerjee et al. (2002) provide a different explanation. In their study, areas with village-level governments had significantly higher productivity after controlling for new seed adoption and property rights. This suggests a role for political organization, which we will now examine for technology adoption and organizational innovation.

The California Gold Rush provides an excellent setting in which to study the connection between political organization and technology adoption. As in our Saharan salt mining setting, the "open access" system initially prevailed in California, in which people claimed an informal, temporary property right to mine

[4] To put this figure into perspective, tens of millions of metric tons are produced in the US by a few large, multinational firms, including Cargill, Inc. and Morton Salt, Inc. The US market, where road de-icing is the largest use (Salt Institute, 2014), is 1000 times larger than the West African market.

[5] Note that Kuran (2003) blames specific rules for the commercial decline of Islam rather than the idea that Muslims are culturally opposed to commercial gain. Quite the contrary, "In the early Islamic centuries the Middle East was teeming with money changes, moneylenders, and pawnbrokers, along with 'merchant bankers'."

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public land (Clay and Wright, 2005). The U.S. Government had the explicit right to charge a royalty on ore since 1807 and had done so in Indiana's lead mines and elsewhere, but eventually, by the 1830s, "authorities in Washington lacked enforcement power, even over their own agents, who abetted evasion. . .almost surely with side payments for personal profit" (Clay and Wright, 2012). In place of formal property rights, mining district codes emerged autonomously, in a manner, suggested by Demsetz (1967), which coordinated property claims among miners that was particularly well-suited to the Gold Rush.[6] Early production technology evolved from panning water for gold, which individuals could undertake alone, to a system of troughs and apparatuses that required three to six people, usually temporary *ad hoc* partnerships like those in the Sahara today.

But it is here where the similarity ends, as the two situations quickly diverged. Libecap (1978) lays out the sequence of events for Nevada, which followed California as a site of mineral exploitation. Once surface ore had been exhausted, more capital-intensive processes were needed. This created demand for more secure property rights and formal institutions, and eventually resulted in the formation of Nevada's Territorial Government in March 1861. A similar process occurred a decade earlier in California, which gained statehood in 1851. In fact, it was Californians who were interested in organizing Nevada as a Territory in order to invest in technology for Nevada mining. Within decades after statehood and the California Land Act of 1851, which also strengthened property rights (Clay, 1999), half of US mining firms employed over 1000 workers (Hannah, 2008).[7] At the same time, public investment in technology took off. In 1867, the federal government invested in a War Department Survey of the West that identified the location of gold and silver deposits, and methods and equipment for digging and treating ore. The US Geological Survey was started just a decade later, while at the same time, universities began a flurry of mining research and training programs (Clay and Wright, 2012).

With political organization and technology adoption, the former clearly preceded the latter, at least in Western gold and silver mining. And, while it is unclear what statehood provided investors, a survey by Fisher et al. (2009) suggests property rights and security are constant worries among ASM workers. A majority of claim-holders were concerned about eviction despite owning a legal property right, and health and property were at risk for the vast majority of respondents. Moreover, not just any political organization generates positive outcomes. The ASM experience shows that where local political organization is weak, indigenous populations fail to benefit from mineral exploitation by foreign firms (Van Alstine et al., 2014; Kamlongera, 2013) especially in the presence of corrupt national governments (Van Alstine and Afionis, 2013). However, Triscritti (2013) presents a counterfactual in Peru, where sometimes violent local organization and weak national government eventually led to greater cooperation and benefits for the local population from the large mining company. Moreover, Maconachie and Hilson (2011) show how locally-managed property rights led to the organization of cooperatives, associations, and "economic interest groups".

Political organization also laid the groundwork for organizational innovations, at least in the case of the corporation. In the US, corporations were the organizational form for cities in the late 18th and early 19th centuries, and were only later used to organize commercial activity. According to Lipartito (2004), "one-half to two-thirds of early corporate charters went to start towns," while those for business organized "public works such as bridges, roads, and canals." Kuran (2003) describes a similar situation in Europe, where corporations were formed for religious and community purposes. Indeed, large salt works were organized by the medieval church, and featured a system of evaporation troughs, fuel for heating the brine, and workers to stir brine (Multhauf, 1978). A counterfactual case in contemporary Ghana, where ASM groups have poor access to capital and thus trouble eking out a living, one license-holder hired a Chinese firm to exploit his claim. The Chinese firm brought capital equipment and workers, built a security fence and processing facility, and succeeded wildly by mobilizing labor and capital in a way that miners themselves could not do (Hilson, 2012).

Historically, once commercial corporations emerged, they grew. In the case of cotton spinning in Japan, private corporations were more competitive and efficient at implementing technology than their government-owned predecessors (Braguinsky and Hounshell, 2014). Some firms grew large enough to interact with the law to further firm growth, especially in the U.S. McCurdy (1978) recounts the case of the I. M. Singer & Company, a sewing machine manufacturer, whose salesmen were taxed as out-of-state peddlers, and Chicago beef manufacturers, who faced state-level inspections. Singer successfully sued to eliminate local taxation of goods manufactured out of state, and meatpackers successfully sued to eliminate pre-butchering inspections by state-level authorities.

Anti-trust law has had its own unexpected influence on firm size. Roy (1997) describes the salt industry in the Great Lakes region in the decades before and after the Civil War. Salt companies such as the Saginaw Salt Manufacturing Company and the Central Ohio Salt Company organized dozens of salt producers into a single "pool" that standardized product quality and prices. Note that this very type of organization could bring about change in product quality standards in our Saharan setting. When courts refused to enforce pooling contracts because the multilateral arrangements restrained trade, salt producers merged into a single large firm. Djelic (1998) argues that the first case involving the Sherman Act had the counter-intuitive effect of *promoting* horizontal consolidation in industries.[8] By dismissing the case against E.C. Knight, a sugar holding company that controlled 90% of US production, the US Supreme Court signaled to firms and the Justice Department that *production* monopolies were legal as long as they were not trading monopolies that crossed state lines. The resulting corporate behemoths were viewed with alarm in Europe, where family ownership and smaller firm size continue to dominate industrial organization.

While the connection between large firms and large-scale technology is drawn from examples from silver mining, to boiling salt water in the Middle Ages, to building bridges in 19th century America, all of these occurred without a key feature of modern firms: the employment relation. Instead, this organizational innovation came into widespread use in the U.S. only in the early 20th century. According to Rosenberg and Birdzell (1986), "As late as 1892, so substantial a plant as Carnegie's Homestead Works

[6] Clay and Wright (2012) describe how miners autonomously organized and signed onto "codes", or lists of rules. An example of a rule that suits miners' situation is "claim jumping". Certain actions signaled ownership of a claim, such as leaving tools at a mining site. But abandoned sites could be taken over or "jumped" by another miner. While this suggests property rights were insecure, miners preferred this rule, "visualizing themselves as claim jumpers as easily as claim protectors." Moreover, claim jumping allowed for intensive, efficient exploitation of the mineral-rich area.

[7] We do not have good information about what technology was adopted by California and Nevada mining firms, only that small-scale technology described above was no longer sufficient. Also, we cannot say what investors feared under the open access regime, only that political organization, especially in Nevada, was needed. California was already a state when gold was discovered.

[8] *US vs E.C. Knight*, 1895. The sugar holding company comprised four formerly independent sugar refiners. The court argued that the Sherman Act did not apply because all of the firm's production took place in one state (Pennsylvania). After the dismissal, the government instead focused its attention on inter-firm coordination (Djelic, 1998).

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avoided the problems of organizing and managing the work of its manufacturing employees." Carnegie instead used contract laborers (*i.e.*, workers hired on a spot market). Thus, the scale achieved by the firms discussed above occurred without "employees". Did organizational innovation and the employment relation play any role in large-scale technology adoption or was it unnecessary, as early examples discussed above might suggest?

The literature on the theory of the firm provides some discussion of the employment relation in large firms. The early literature focuses on sheer size, as the emergence of large corporations was stunning and unprecedented. Thus, Berle and Means (1932) discuss supply-side factors, such as financial markets that aggregate the capital required to create large corporations, while Chandler (1977) focuses on demand-side factors, especially operational complexity (of railroads), that necessitate hierarchy and large size. In addition, Schumpeter (1942) observed that large firms are particularly adept at generating innovation. Later, attention turned to employment. Alchian and Demsetz (1972) claimed that indivisibilities in work tasks, such as when two people load a truck, explain why companies need employees, and Williamson (1975) argued that the idiosyncratic nature of modern jobs combine with uncertainty and opportunism to create the need for employees.[9] Taken together, this literature suggests that firms combine employees within a hierarchy to perform complex, idiosyncratic, and innovative tasks in an uncertain environment. Firms created to perform under such circumstances might well adopt technology more intensively than firms without employees. Our salt mining context and ASM provide a useful counterfactual.

In particular, the labor market in our setting does not conform to the assumptions of the theory of the firm. Slavery was outlawed in 1908 but persists informally to this day (Hall, 2011).[10] Perks (2011) and Maconachie and Hilson (2011) describe debt bondage and slavery as part of a poverty trap for ASM operators, and Rombe-Shulman (2013) interviewed a miner from a former slave caste who was abducted by his family's former masters. This family had been contracted to transport the miner to Taoudenni and back, but on his way home, held the miner for a year against his will and forced him to work. The miner was unable to leave or contact his family because he had no means of communicating, traveling or navigating the route home. The abductors felt entitled to enslave the miner, who had no legal recourse because courts were too far away and costly. This situation resembles that described in Solomon Northup's autobiography of illegal kidnap and enslavement (Northup, 2014, orig. 1953) rather than the legal institutions of the antebellum South or pre-1908 Mali. Nevertheless, if slavery is a regular practice, it could affect the incentives for adopting the modern employment relation. A large literature, beyond the scope of this paper, already exists which explores the connection between slavery and technology use. The findings in this literature are consistent with the dynamics of historical Saharan salt mining operations, which were much bigger than the present day and used large numbers of slaves and traditional tools (Lovejoy, 1986).

The presence of slavery may say something about political organization. Wright (2003) argues that abolition itself is a novel institutional innovation, one for which political action was central.[11] Politics also supported slavery, which Southerners understood. They feared immigration "because a growing class of nonslaveholders, especially outsiders with non-Southern backgrounds might create a political threat to slavery in the South," (Wright, 1978, p. 125). With abolition, the political connection is clearly portrayed in two contrasting case studies, Kentucky and Illinois (Wright, 2003). Kentucky had low rates of slave ownership, but slave owners were disproportionately represented at their statehood convention and defeated the antislavery amendment to the state constitution. By contrast, Illinois had crop conditions associated with slave states and thus high numbers of slaves, but slave owners were unable to amend the constitution to permit slavery.

Large corporations, slavery, and abolition: none could exist without political action. Corporations were originally created to serve a political need, to organize towns and public works. Only later would corporations come to be associated with large-scale commercial enterprise, but once they did, they facilitated investment, as in the case of the California Gold Rush, and the employment relation. What we do not know is the exact mechanism that statehood conferred for investors who then purchased mining equipment in California and Nevada. We also do not know if abolition hinders the adoption of the employment relation.

3.2. Transportation

Like the traditional tools currently used by Saharan salt miners, camels have plied the desert routes for millennia. So our question about the replacement of camels with new technology is similar to our analysis of technological adoption of tools, with the addition of a few areas of theory that relate to camels and transportation. That said, our fieldwork shows that trucks are largely replacing camels, contrary to popular accounts like that of Benanav (2006). The question of adoption, therefore, is one of timing, and the discussion of such factors as appropriateness, relative prices, and intermediaries, can be dispensed with. In the following, we focus on the additional theories associated with transportation issues, and the role that politics play in the timing of adoption.

3.2.1. Technological competition

The question of technological persistence is somewhat more nuanced when applied to camels than to wooden tools. After all, camels are genetically adapted to survive and thrive in desert conditions. Might they be better than motor vehicles? This is the logic behind a theory of "dominant design" in which many different product models compete during a period of innovative ferment and an optimal design emerges (Anderson and Tushman, 1990). Like the camel's adaptation to the desert, products as varied as glass, cement, and computers settle upon a robust standard set of product features after numerous variations are tested in the market. The enclosed steel body in automobiles was established after an initial period of design ferment and is a particularly long-lived standard for a reason.

However, analysis by historian Bulliet (1990) explains why trucks are replacing even genetically ideal camels. The author describes the competition between camels and wheeled vehicles over time, especially horse-drawn carts with wooden wheels in the desert, but also attempts to use the camel in Europe. But whatever

[9] Williamson (1975) argued that the employment relation arises in circumstances in which firms face idiosyncrasies and uncertainty in their operating environment. Under these circumstances, the use of an external spot market for labor is costly compared to an internal labor market. Features of the internal labor market include (1) wages attached to job functions (rather than individuals, thus minimizing wage bargaining costs), (2) internal arbitration mechanisms that are lower-cost than litigation but still fair, thus promoting worker investments in idiosyncratic skills, and (3) internal promotion, which improves worker cooperativeness.

[10] Anecdotally, slavery is still commonplace. de Villiers and Hirtle (2002) note that "Most upper-caste Tuareg. . .still had slaves to take care of flocks and herds and to perform various domestic tasks in the 1960s. A cynic in Timbuktu said in 1998, 'Yes, they freed the slaves in 1968, but not all of them have been told yet'".

[11] Wright argues that "With the aid of hindsight, we may view the northern abolition of slavery as an institutional innovation that channeled developmental energies into these new paths," such as "investments in transportation and other forms of market structure" that promoted economic development.

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the camel's natural advantages may be, Bulliet shows that they are no match for motorized vehicles.

Given the advantages of trucks over camels, we look to the literature to explain the timing of the current decline in camels. Markets are one explanation for a protracted replacement period. An economic analysis of the displacement of horses by tractors on American farms finds that adoption was slowed by the influx of horses onto the market as tractor buyers sold their horses (Olmstead and Rhode, 2001). This new supply of horses drove down horse prices, making tractors less attractive, and explained the slow pace of tractor adoption.

Competition can also slow the rate of replacement. Saxonhouse and Wright (2010) describe two cotton spinning technologies which divide the global marketplace until a complementary innovation for drawing out fibers before spinning finally tips the balance in favor of one of the technologies. Christensen (1992a, 1992b, 1997) tells the story for disk drive technology, where entrants innovate in niche markets but eventually overtake the main market dominated by incumbents. The eventual success of an entrant can take time, much like the tractor case. Snow (2008) examines a technology's "last gasp", explaining how new technology spurs innovation in the old technology. New technologies can also open up a new niche for the old technology, thus slowing the incumbent's demise (Adner and Snow, 2010), or increase demand as a complement to old technology. Edgerton (2006) shows, among many other examples, how railroad use increased demand for horse-drawn wagons to move cargo locally from rail stations.

In the cases covered by the literature, old technologies can be incredibly long-lived, as with the dominant design of the automobile and the still-useful old technologies cataloged by Edgerton. But new technologies displace old technologies when demand conditions change, often because of continued or complementary innovation. Thus, large disk drives are displaced by smaller disk drives as customer preferences evolve, and tractors sell more as adaptations make them useable on a greater variety of terrains.

In our case, those involved in the Saharan salt business have found truck transport to be attractive, just as Bulliet would predict. Trucks are faster than camels—a round trip takes six to 10 days compared with 30 days by camel. Moreover, large commercial vehicles produced by MAN trucks and a new Mercedes-Benz costs about US$50,000 each and does not require roads. While fuel is costly compared to forage, climate change has reduced the availability of forage. Thus, camels have declined in population for this reason as well. Complementary technologies have further aided truck adoption. Satellite phones and GPS technology have made journeys safer, although the danger of being stranded in the desert is still quite real. Finally, truck drivers do not travel alone. As with caravans, a small team travels together, including one member responsible for performing minor truck repairs (Scheele, 2012).[12]

The camel as a "dominant design" helps explain why camels have persisted in their desert niche into modern times. But because camels have been replaced rapidly by a superior technology (and its complements), other theories, explaining slow adoption, do not apply.

3.2.2. Network externalities

The absence of roads might seem to be an obstacle to the displacement of camels by vehicles, but as we have already discussed, trucks do not always require roads. Nevertheless, the literature on networks effects is interesting for what we do not observe. Katz and Shapiro (1986, 1994) characterize network externalities as arising when the greater the adoption of a technology the greater the investments in complementary goods.[13] With very few vehicle owners, complementary investments such as roads, emergency services, fueling stations, might not get built. Skills can also be complementary, as discussed by Acemoglu and Zilibotti (2001) as well as Saxonhouse and Wright (2010). David (1985) illustrates the connection between skills and technology adoption in the case of a superior typewriter keyboard that failed to be adopted because a large installed-base of typists was already trained to use the old keyboard design. Costly retraining would have to take place in order for the new keyboard to be adopted. Finally, in the case of jackhammers, presented above, trucks might be needed to transport them, if they prove unwieldy for camel transport.

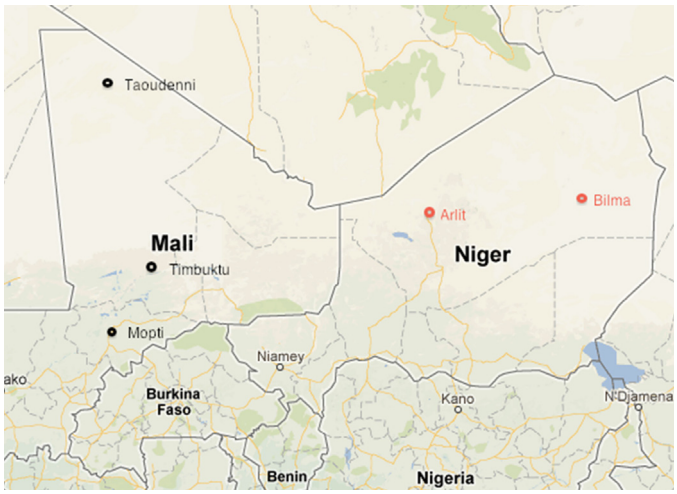

Fig. 2. Map of Arlit, Niger. *Note*: Arlit, Niger is the location of a uranium mine, located in the Sahara Desert, which is denoted by the pale beige color. It is serviced by a road, which runs due south from Arlit. For reference, locations associated with the salt caravan in Mali—Taoudenni, Timbuktu and Mopti—are denoted in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Network effects can be overcome by public or private investment or innovation. For example, the long-dominant personal computer now faces a challenge from innovative new products, including tablets and smart phones (Worthen and Sherr, 2012). More often, governments take action to make complementary investments. The French colonial government paved the wells now used by camel caravans, making them more reliable. In the US, federal road-building made automobiles more useful; and in the present day, a public agency in California is paying for car battery recharging stations to promote adoption of electric cars (Baker, 2009). Foreign state-owned firms are already involved in mineral extraction in sub-Saharan Africa, including French state-owned firm Areva, which mines uranium in Arlit, Niger (see Fig. 2), and Chinese state-owned firms that mine a variety of metals throughout the region (Barta et al., 2008); these firms have built and maintained roads, even in politically-insecure and environmentally-hostile places.

The invention of MAN-type trucks has facilitate truck adoption in the Sahara, much as the development of tablets and smartphones has challenged the *status quo* dominance of the personal computer. These trucks, by not requiring roads, allow camel-herders to adopt vehicles and break free of network effects.

[12] The dangers of traveling by truck in the Sahara should not be underestimated. The New York Times reported recently on the deaths of 92 people, half of them children, when their two trucks broke down just miles from a well (New York Times, 2013).

[13] This occurred with Windows-based personal computers, the increasing popularity of which spurred outside software developers to create useful new programs that made computers even more valuable.

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3.2.3. Politics

That government action can encourage adoption has been seen in several examples discussed above. The French Government promoted the spinning jenny in the 18th century, paved wells in the Sahara in the 1950s, and built and maintain a road through the desert to their uranium mine in Arlit, Niger in the present day. Political actions can also impede the adoption of technology. In our case, government restrictions likely prevented the earlier adoption of trucks by the salt mining industry. Until 1988, a military prison housing political prisoners was maintained in Taoudenni (McDougall, 1990, p. 253), so truck use in the area was restricted by the military. Following the prison's closure, a coup in 1991 launched a civil war in Mali that lasted until 1996, during which the government again restricted the ownership and use of trucks to military uses in order to control the mobility and economy of lighter-skinned Tuareg and Arab Northern Malians, whom they viewed as traditional slave-holders and potential rebels (Lecocq, 2010). After the war, the Malian Government could no longer maintain its ban on civilian trucks, and trucks began the classic s-shaped curve of technology adoption. Adoption started out relatively slowly—our observation in 2003 still found extensive camel use—but by 2006, camels were quickly becoming scarce.

3.3. Extinction

In our analysis of technology adoption, it is easy to overlook the remarkable fact that a particular traditional technology has persisted for millennia. For example, the ability to navigate the desert, including a mental map of wells, is passed down from father to son, with boys making their first trip at about 11 years of age.[14] Given the life-and-death tacit knowledge involved in navigating the desert and the costly product standards that must be adhered to, any number of interruptions could have caused the trade to go extinct. Thus, while the discussion has addressed the possibility that workers replace old practices with new practices, there might instead be a disappearance of the practice itself. Interviews suggest that even with hard-won tacit knowledge, salt mining is a difficult profession, and young people would rather find other ways to make a living, if given the chance.

Two strands of the management literature suggest paths that could lead to extinction, both focused on cognition and knowledge. First, cognitive impediments prevent firms from understanding and reacting to changes in their competitive environment causing the firm to go out of business. Second, new business opportunities arise making existing activities unattractive to younger generations of workers. The incumbent activities are abandoned and the skills, which contain much tacit knowledge, are forgotten.

The first mode of extinction, which is similar in spirit to the technology competition literature discussed above, is the inability to adapt to changes—with fatal consequences. Henderson and Clark's (1990) seminal article on architectural innovations describes a paradigm shift in the semiconductor equipment industry, in which new techniques disrupt incumbents whose success using old techniques prevent them from succeeding with new techniques. In this scenario, incumbent firms fail because managers are wedded to a technology that they are expert in and that has served them well in the past, whereas change requires that managers acquire a completely different set of knowledge and expertise. Thus, this literature focuses on cognitive impediments to technology adoption.

Cognition can combine with a firm's internal systems to prevent adoption, too. Tripsas and Gavetti (2000) describe how Polaroid's senior management was convinced of its "razor and blade" business model, which they had pursued in the past (razors being subsidized by profits from selling blades). Despite developing advanced technology for digitization, a faulty business model helped bring about Polaroid's failure. Similarly, Sull (1999) details Firestone's response to the radial tire, invented by French rival Michelin. By adhering to old budgeting processes and refusing to close factories, Firestone nearly went out of business and eventually replaced its management in order to adapt. Cole (1998) makes a similar argument in explaining why American automakers failed to adopt "lean" manufacturing techniques, introduced by Japanese competitors. Cognitively, American managers did not view Japanese firms as a legitimate source of new knowledge; organizationally, departments lacked linkages for collaboration on quality problems. Moreover, Siggelkow (2001) describes apparel-maker Liz Claiborne's inability to respond to changes in workplace dress codes. Here, too, executives had to be changed in order for the firm to replace complex complementary practices that were fine-tuned for the old environment.

In our case, either type of cognitive problem might affect technology adoption, especially for trucks. Clearly, different skills are required of trucking and camel herding. Moreover, organizational changes are needed to convert to trucking. While travel by camel or truck involves small groups, with the latter, members of the group must specialize in various areas, including driving, navigating and mechanical maintenance. This organizational change might be too disruptive to overcome. Indeed, our research finds that a group of prominent camel herders met with the Interior Minister in 2001 to discuss tensions between camel owners and truckers and to enact policies that would protect camels. This effort failed, and camel owners have since moved into truck ownership, often selling their camels and pooling family money to purchase a truck.

The second mode of extinction, in which miners simply abandon their trade for other opportunities, can be observed historically and in the literature. Cattani et al. (2013) describe the loss of tacit knowledge for making Cremonese violins. After his death, Antonio Stradivarius passed down his workshop to his sons, the younger of which turned to textile trading after the elder son passed away. Saxonhouse and Wright (2010) also discuss how mule-spinning died out as young workers chose not to invest in training for a doomed technology. Hotz (2009) discusses the efforts made at the Getty Museum in California to preserve panel painting knowledge from its last living practitioners, and points out other areas in which tacit knowledge and skills rest with a few retired—and dying—practitioners, including nuclear warhead refurbishment and manned lunar space flight.[15] Given these examples, we note that unlike creative destruction, which yields new and better methods or goods, this second mode of extinction can result in the loss of valuable knowledge and skills.

In our setting, extinction could occur in two ways. First, entrants with new technology might drive out existing miners.[16]

[14] Other important cultural and religious practices are kept alive in the same way. An extensive system of apprenticeships have kept alive the centuries-old skills needed to perform the annual re-application of mud to the Mosque of Djenne, a world heritage site (Apotsos, 2009). Without this transfer of tacit knowledge, practices would fail to persist.

[15] According to Hotz, "the Government Accountability Office reported that the U.S. National Nuclear Security Administration no longer remembers how to make a classified component crucial to refurbishing nuclear warheads. Few records of the process were kept, and almost everyone involved in its production 30 years ago has retired or died. Similarly, half of NASA's work force is now eligible for retirement, according to one estimate. Reams of data they gathered in decades of space flight have been discarded for lack of storage space or archived in electronic file formats for computers no longer in use."

[16] A failed 2008 venture by French artisan producer, Salt of Azalai, suggests that there might be some interest among foreign producers in Taoudenni salt. However rather than introduce new technology, Salt of Azalai produced specialty salt for export to France using the same traditional methods to process (pound) the salt, hiring women to do the pounding. The enterprise quickly went out of business, possibly because of the global economic crisis.

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Evidence from ASM elsewhere suggests that individual miners coexist with large multinational firms: the sector's operators mine alluvial deposits, while large firms use capital-intensive methods to exploit deeper ores (Dondeyne et al., 2009; Geenen, 2014). Second, young people might abandon the practice. Our interviews suggest they have a preference for moving to cities and finding work other than mining. Moreover, jobs in oil exploration and drilling in Taoudenni have already drawn some salt miners to the oil industry. If enough salt miners were occupied elsewhere, the knowledge and skills that have been actively transferred across time could die within a generation.

In short, preferences for jobs outside of salt mining are the likeliest avenue for extinction. The rapid adoption of trucks makes us skeptical that miners have a cognitive impediment to livelihood-threatening technology. Moreover, large-scale technology is often compatible with ASM.

4. Discussion and conclusion

Our case study examines a single traditional industry and the adoption possibilities of several different technologies. The setting is a harsh, unforgiving Sahara Desert, whose long history allows us to consider a variety of institutional and organizational counterfactuals. We find economic explanations for the non-adoption of small-scale production technologies and for the timing of truck adoption. For example, the use of product standards to convey quality prevents the adoption of technologies that would pulverize premium salt, but appropriateness and ignorance of technology are not factors. The adoption of trucks exhibits similar patterns. Camels are certainly well adapted to their task, which may explain why they filled this particular niche for so long. But once political restrictions were lifted, transition to trucks was rapid.

Often, the explanations that do not explain adoption are as interesting as those that do. We observe individuals acquiring skill and specializing, both in tool making and truck maintenance. Old camel-herding knowledge is cast aside for faster trucks and complementary technologies like GPS navigation and satellite phones. Markets, overall, seem to function quite well. In addition to the markets for technology, miners also borrow to finance their expeditions as debt contracts are written and honored, product markets are reliable, and demand is stable.

Going beyond economic explanations, we continue to peel the onion and ask why larger-scale technology is not used, and find that political institutions are essential to the adoption of large-scale technology and organizational innovation. The California Gold Rush demonstrates this connection well, as autonomous mining district codes were replaced, at miners' request, by the formal property rights that permitted investment in new technology. Because large-scale technology adoption could occur without higher-level organization, we consider the adoption of the employment relation, an organizational innovation, separately. Here again, political organization is historically linked with economic organization, as corporations, which adopted the employment relation extensively, were created originally to organize towns. Consistent with this, our study of various bodies of literature shows that where political organization does not exist, firms do not arise.

This is true throughout the Sahara, where commercial activities lack hierarchical organization, not only in salt mining, but also in other trades. This is precisely what we would expect if something as broad as "political organization" were needed for technology adoption. So, while Taoudenni is officially in Mali, life there resembles the rest of the Sahara much more than the large urban centers of found in the southwestern part of the country, including its capital Bamako. Scheele (2012) describes a merchant trade in the northern Sahara region in Algeria where makeshift shelters, informal cooperation among dealers, and small-scale business arrangements, all resemble arrangements in salt mining. de Villiers and Hirtle (2002) and Seligman (2007) describe traditional salt production practices in other parts of the Sahara, which produces gray salt cones *via* brine evaporation. Here, too, a standardized product is made involving small kinship groups and slaves.

Our analysis raises questions for future work. First, the relationship between political organization and economic organization begs the question of differences in the ability to organize politically. What explains heterogeneity in political organizing? Banerjee and Iyer (2005) suggest there might be differences in attitudes toward collective action. Where do differences in attitude come from?

Second, our findings suggest that large firms are important for economic growth, consistent with other recent research (Guner et al., 2008; Hsieh and Klenow, 2012). But historically, governments were involved. Medieval churches and principalities in Europe organized salt works (Multhauf, 1978), and into the 20th century, governments often owned their country's largest manufacturers. Hannah (2008) shows that of "giant manufacturing plants" at the turn of the previous century, the government owned 9% in Germany, 15% in France, 53% in Japan, but less than 2% in the US. Future research could explore the heterogeneous role of governments in creating and operating large firms. In our study, technology adoption was a key variable, so another question for future research would be whether government ownership affects technology adoption by large firms.

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References

Acemoglu, D., Johnson, S., Robinson, J., 2001. The colonial origins of comparative development: an empirical investigation. Am. Econ. Rev. 91 (5), 1369–1401.
Acemoglu, D., Zilibotti, F., 2001. Productivity differences. Q. J. Econ. 116 (2), 563–606.
Adner, R., Snow, D., 2010. Old technology responses to new technology threats: demand heterogeneity and technology retreats. Ind. Corp. Change 19 (5), 1655–1675.
Alchian, A., Demsetz, H., 1972. Production, information costs, and economic organization. Am. Econ. Rev. 62 (5), 777–795.
Allen, R.C., 2009. The industrial revolution in miniature: the spinning jenny in Britain, France, and India. J. Econ. Hist. 69 (4), 901–927.
Anderson, P., Tushman, M., 1990. Technological discontinuities and dominant designs: a cyclical model of technological change. Adm. Sci. Q. 35 (4), 604–633.
Apotsos, M., 2009. Interview, 12/8.
Baker, D.R., September 23, 2009. Charging-station network built along 101. San Francisco Chronicle.
Banerjee, A., Iyer, L., 2005. History, institutions, and economic performance: the legacy of colonial land tenure systems in India. Am. Econ. Rev. 95 (4), 1190–1213.
Banerjee, A., Gertler, P., Ghatak, M., 2002. Empowerment and efficiency: tenancy reform in West Bengal. J. Polit. Econ. 110 (2), 239–280.
Barta, P., Matthews, R.G., Batson, A., November 17, 2008. Giant mines scramble to cut output. Wall Street J..
Basu, S., Weil, D.N., 1998. Appropriate technology and growth. Q. J. Econ. 113 (4), 1025–1054.
Braguinsky, S., Hounshell, D., 2014. Spinning Tales About Japanese Cotton Spinning: Saxonhouse (1974) Then and Now. Working Paper.
Benanav, M., 2006. Men of Salt: Crossing the Sahara on the Caravan of White Gold. The Lyons Press, Guilford, CT.
Berle, A.A., Means, G., 1932. The Modern Corporation and Private Property. Transaction Publishers, New Brunswick, NJ Originally published in 1932 by Harcourt, Brace, and World, Inc.

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Bryceson, D.F., Jonsson, J.B., 2010. Gold digging careers in rural East Africa: small-scale miners' livelihood choices. World Dev. 38 (3), 379–392.
Bulliet, R., 1990. The Camel and the Wheel. Columbia University Press, New York, NY.
Catholic Online, 2013. 5000-Year-Old Salt Mines Built by Prehistoric Men Still in Use Today. http://www.catholic.org/international/international_story.php?id=53215.
Cattani, G., Dunbar, R., Shapira, S., 2013. Value creation and knowledge loss: the case of Cremonese stringed instruments. Organ. Sci. 24 (3), 813–830.
Chandler, A., 1977. The Visible Hand: The Managerial Revolution in American Business. Harvard University Press, Cambridge, MA.
Christensen, C.M., 1992a. Exploring the limits of the technology S-curve. Part I: Component technologies. Prod. Oper. Manage. 1 (4), 334–357.
Christensen, C.M., 1992b. Exploring the limits of the technology S-curve. Part II: Architectural technologies. Prod. Oper. Manage. 1 (4), 358–366.
Christensen, C.M., 1997. The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. HBS Press, Boston, MA.
Clauzel, J., 1960. L'exploitation des salines de Taoudenni. Institut de Recherches Sahariennes de l'Universite d'Alger.
Clay, K., 1999. Property rights and institutions: congress and the California Land Act of 1851. J. Econ. Hist. 59 (1), 122–142.
Clay, K., Wright, G., 2005. Order without law? Property rights during the California gold rush. Explor. Econ. Hist. 42 (2), 155–183.
Clay, K., Wright, G., 2012. Gold rush legacy: American minerals and the knowledge economy. In: Cole, D.H., Ostrom, E. (Eds.), Property in Land and Other Resources. Lincoln Institute, Cambridge, MA.
Cole, R.E., 1998. Learning from the quality movement: what did and didn't happen and why? Calif. Manage. Rev. 41 (1), 43–73.
David, P., 1971. The landscape and the machine: technical interrelatedness, land tenure, and the mechanization of the corn harvest in Victorian Britain. In: McCloskey, D.N. (Ed.), Essays on a Mature Economy: Britain After 1940. Methuen, London (Chapter 8).
David, P., 1985. Clio and the economics of QWERTY. Am. Econ. Rev. 75 (2), 332–337.
Demsetz, H., 1967. Toward a theory of property rights. Am. Econ. Rev. 57 (2), 347–359.
de Villiers, M., Hirtle, S., 2002. Sahara: A Natural History. Walker & Co..
Djelic, M.L., 1998. Exporting the American Model: The Postwar Transformation of European Business. Oxford University Press.
Dondeyne, S., Ndunguru, E., Rafael, P., Bannerman, J., 2009. Artisanal mining in central Mozambique: policy and environmental issues of concern. Resour. Policy 34, 45–50.
Edgerton, D., 2006. The Shock of the Old: Technology and Global History Since 1900. Oxford University Press, New York.
Fisher, E., Mwaipopo, R., Mutagwaba, W., Nyange, D., Yaron, G., 2009. 'The ladder that sends us to wealth': artisanal mining and poverty reduction in Tanzania. Resour. Policy 34, 32–38.
Geenen, S., 2014. Dispossession, displacement and resistance: artisanal miners in a gold concession in South-Kivu, Democratic Republic of Congo. Resour. Policy 40, 90–99.
Gilberthorpe, E., 2013. Community development in Ok Tedi, Papua New Guinea: the role of anthropology in the extractive industries. Community Dev. J. 48 (3), 466–483.
Gort, M., Klepper, S., 1982. Time paths in the diffusion of product innovations. Econ. J. 92, 630–653.
Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econometrica 25 (4), 501–522.
Guner, N., Ventura, G., Yi, X., 2008. Macroeconomic implications of size-dependent policies. Rev. Econ. Dyn. 11 (4), 721–744.
Hall, B., 2011. A History of Race in Muslim West Africa, 1600–1960. Cambridge University Press, New York.
Hannah, L., 2008. Logistics, market size, and giant plants in the early twentieth century: a global view. J. Econ. Hist. 68 (1), 46–79.
Henderson, R., Clark, K.B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Adm. Sci. Q. 35 (1), 9–30.
Hilson, G., 2010. 'Once a miner, always a miner': poverty and livelihood diversification in Akwatia, Ghana. J. Rural Stud. 26, 296–307.
Hilson, G., 2011. Artisanal mining, smallholder farming and livelihood diversification in rural Sub-Saharan Africa: an introduction. J. Int. Dev. 23, 1031–1041.
Hilson, G., 2012. Poverty traps in small-scale mining communities: the case of sub-Saharan Africa. Can. J. Dev. Stud. 33 (2), 180–197.
Hilson, G., Garforth, C., 2013. 'Everyone now is concentrating on the mining': drivers and implications of rural economic transition in the eastern region of Ghana. J. Dev. Stud. 49 (3), 348–364.
Hsieh, C.T., Klenow, P.J., 2012. The Life Cycle of Plants in India and Mexico. NBER Working Paper, 18133.
Hotz, R.L., July 31, 2009. As art ages, so do the skills to preserve tt: hard-won expertise is easily lost to time, posing a challenge to conservators who maintain the world's masterworks. Wall Street J..
Kamlongera, P.J., 2011. Making the poor 'poorer' or alleviating poverty? Artisanal mining livelihoods in rural Malawi. J. Int. Dev. 23, 1128–1139.
Kamlongera, P.J., 2013. The mining boom in Malawi: implications for community development. Community Dev. J. 48 (3), 377–390.
Katz, M.L., Shapiro, C., 1986. Technology adoption in the presence of network externalities. J. Polit. Econ. 94 (4), 822–884.
Katz, M.L., Shapiro, C., 1994. Systems competition and network effects. J. Econ. Perspect. 8 (2), 93–115.
Klepper, S., 1996. Entry, exit, growth, and innovation over the produce life cycle. Am. Econ. Rev. 86 (3), 562–583.
Kuran, T., 2003. The Islamic commercial crisis: institutional roots of economic underdevelopment in the Middle East. J. Econ. Hist. 63 (2), 414–446.
Kuran, T., 2010. The Long Divergence: How Islamic Law Held Back the Middle East. Princeton University Press.
La Porta, R., Lopez-de-Silanes, F., Shleifer, A., Vishny, R., 1999. The quality of government. J. Law Econ. Organ. 15 (1), 222–279.
Laeven, L., Woodruff, C., 2007. The quality of the legal system, firm ownership, and firm size. Rev. Econ. Stat. 89 (4), 601–614.
Lecocq, J.S., 2010. Disputed Desert: Decolonization, Competing Nationalisms and Tuareg Rebellions in Northern Mali. Brill, Boston.
Libecap, G.D., 1978. Economic variables and the development of the law: the case of western mineral rights. J. Econ. Hist. 38 (2), 338–362.
Lipartito, K., 2004. The Utopian Corporation. In: Lipartito, K., Sicilia, D.B. (Eds.), Constructing Corporate America: History, Politics, Culture. Oxford University Press, NY.
Lovejoy, P.E., 1986. Salt of the Desert Sun: A History of Salt Production and Trade in the Central Sudan. Cambridge University Press.
Lydon, G., 2009. On Trans-Saharan Trails: Islamic Law, Trade Networks, and Cross-cultural Exchange in Nineteenth Century Western Africa. Cambridge University Press, New York.
Maconachie, R., 2011. Re-agrarianising livelihoods in post-conflict Sierra Leone? Mineral wealth and rural change in artisanal and small-scale mining communities. J. Int. Dev. 23, 1054–1067.
Maconachie, R., Hilson, G., 2011. Safeguarding livelihoods or exacerbating poverty? Artisanal mining and formalization in West Africa. Nat. Resour. Forum 35, 293–303.
McCurdy, C., 1978. American law and the marketing structure of the large corporation, 1987–1890. J. Econ. Hist. 38 (3), 631–649.
McDougall, E.A., 1990. Salts of the Western Sahara: myths, mysteries, and historical significance. Int. J. Afr. Hist. Stud. 23 (2), 231–257.
Multhauf, R.P., 1978. Neptune's Gift. Johns Hopkins.
New York Times, October 31, 2013. Bodies of 92 migrants found in Sahara Desert.
Northup, S., 2014. 12 Years a Slave, Graymalkin Media Originally published 1853.
Olmstead, A.L., Rhode, P.W., 2001. Reshaping the landscape: the impact and diffusion of the tractor in American agriculture, 1910–1960. J. Econ. Hist. 61 (3), 663–698.
Okoh, G., Hilson, G., 2011. Poverty and livelihood diversification: exploring the linkages between smallholder farming and artisanal mining in rural Ghana. J. Int. Dev. 23, 1100–1114.
Perks, R., 2011. 'Can I go?'—Exiting the artisanal mining sector in the Democratic Republic of Congo. J. Int. Dev. 23, 1115–1127.
Rodrik, D., Arvind, S., Trebbi, F., 2004. Institutions rule: the primacy of institutions over geography and integration in economic development. J. Econ. Growth 9, 131–165.
Rogers, E., 2003. Diffusion of Innovations. Free Press, New York.
Rombe-Shulman, S., 2013. (Re)Constructions of Servitude: The Work and the Meaning of Extracting Salt in Taoudenni. Working Paper.
Rosenberg, N., 1963. Technological change in the machine tool industry, 1940–1910. J. Econ. Hist. 23 (4), 414–443.
Rosenberg, N., Birdzell Jr., L.E., 1986. How the West Grew Rich: The Economic Transformation of the Industrial World. Basic Books, Inc., New York.
Roy, W.G., 1997. Socializing Capital. Princeton University Press.
Salt Institute, 2014. http://www.saltinstitute.org/salt-101/.
Scheele, J., 2012. Smugglers and Saints of the Sahara: Regional Connectivity in the Twentieth Century. Cambridge University Press, New York.
Saxonhouse, G.R., Wright, G., 2010. National leadership and competing technological paradigms: the globalization of cotton spinning, 1878–1933. J. Econ. Hist. 70 (3), 535–566.
Schumpeter, J., 1942. Capitalism, Socialism, and Democracy. Harper, New York, NY.
Seligman, T., 2007. Interview 8/29.
Siggelkow, N., 2001. Change in the presence of fit: the rise, the fall, and the renaissance of Liz Claiborne. Acad. Manage. J. 44 (4), 838–857.
Snow, D.C., 2008. Extraordinary Efficiency Growth in Response to New Technology Entry: The Carburetor's "Last Gasp". Harvard Business School Working Paper #1668643.
Sull, D.N., 1999. The dynamics of standing still: firestone tire & rubber and the radial revolution. Bus. Hist. Rev. 73 (3), 430–464.
Tripsas, M., Gavetti, G., 2000. Capabilities, cognition, and inertia: evidence from digital imaging. Strateg. Manage. J. 21, 1147–1161.
Triscritti, F., 2013. Mining, development and corporate-community conflicts in Peru. Community Dev. J. 48 (3), 437–450.
Van Alstine, J., Afionis, S., 2013. Community and company capacity: the challenge of resource-led development in Zambia's 'New Copperbelt'. Community Dev. J. 48 (3), 360–376.
Van Alstine, J., Manyindo, J., Smith, L., Dixon, J., Ruhanga, I.A., 2014. Resource governance dynamics: the challenge of 'new oil' in Uganda. Resour. Policy 40, 48–58.
Williamson, O., 1975. Markets and Hierarchies. The Free Press.
Worthen, B., Sherr, I., October 11, 2012. PC sales show steep decline. Wall Street J..
Wright, G., 1978. The Political Economy of the Cotton South. Norton, New York.
Wright, G., 2003. Slavery and American Economic Development (Walter Lynwood Fleming Lectures in Southern History). Louisiana State University Press.

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