

# The Political Economy of Technology Adoption: The Case of Saharan Salt Mining

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## Abstract:

Innovation is an important source of economic growth and competitive advantage. Consequently, a diverse literature in economics and management addresses a variety of questions about how to manage technological change. This paper explores the "opposite" question: 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 artisanal and small-scale mining (ASM) widespread throughout Africa. The study thus sheds light on the role of institutions in economic growth.

Key words: salt mining; artisanal small-scale mining; sub-Saharan Africa; political institutions; institutions and economic development

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## 1. Introduction

Technological innovation is an important source of economic growth and competitive advantage. Thus, a diverse literature 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, sometimes technologies are slow to be adopted, prompting explanations such as the "appropriateness" of technology in different economies (Basu and Weil, 1999; 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 extremely long term despite the existence of more advanced technology.

Our setting is salt mining in the Sahara Desert, which by most accounts has remained largely unchanged since at least the 14<sup>th</sup> century, and possibly as far back as the fifth century B.C. Salt is extracted using hand tools and, until recently, was transported by camel caravan to market towns on the edge of the desert. With the exception of the trucks that now traverse the ancient trade routes, other aspects of the salt business would be recognizable to Ibn Battuta who described the practice in 1353 and Herodotus who mentioned salt mining in *Histories*. Elsewhere, the history of salt production has been characterized by organizational and technological change, including large-scale production organized by the church in medieval Europe (Multhauf, 1978) to mergers of competing firms in 19<sup>th</sup> century America (Roy, 1997). Why is Saharan salt extracted by traditional technology when, everywhere else, technology has changed?

To answer our question, we assemble theories from economics and management and assess each theory against the details of our case, which at first blush seems exotic. But our setting, while extreme in its longevity, is part of a much broader phenomenon of persistent traditional technology generally and artisanal and small-scale mining (ASM) specifically, which involves "labour-intensive, low-tech mineral exploration and processing activities," (Hilson, 2011). A burgeoning literature asks why such back-

breaking and often illegal work as ASM persists (Perks, 2011), while we ask why it remains small-scale and low-tech.<sup>1</sup> Our research design involves original ethnographic research (Gilberthorpe, 2013) and brings diverse theories to bear on a seemingly narrow question that has much broader implications for understanding how technology, organization and economic growth interact.

We consider such diverse theories as technological “appropriateness” based on 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. We organize these theories and others 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. Each theory is examined in turn and guides the use of details obtained through anthropological research. For example, we might posit that camels are used where there are no roads, which would lead us to explore the provision of road building and maintenance. Our ethnographic research involved immersion into the culture and society of Taoudenni salt miners over a 15-month period in 2008 and an earlier month-long observation period in 2006 to provide first-hand detail.

Proceeding through candidate theories, we find that some theories apply in our case while others do not. For example, our ethnographic research shows that, contrary to earlier accounts, camels have been largely displaced by MAN-type trucks, which do not require roads.<sup>2</sup> Thus, the network effects of roads that might have hindered adoption of wheeled transport do not play a role in our case. However, other economic factors do affect technology adoption. The relative cost of camels affects truck adoption just as the cost of horses affected the rate of adoption of tractors by American farmers (Rhode and

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<sup>1</sup> The literature finds many reasons for the persistence of ASM. The low skill required makes ASM possible for most able-bodied workers. But also, earnings are more predictable than farming (Hilson, 2010; Bryceson and Jonsson, 2010) and mining work is complementary to farming’s seasonality (Kamlongera, 2011; Okoh and Hilson, 2011). In some cases, mining income is used to fund capital and human capital investments (Hilson and Garforth, 2013; Hilson and Bockstael, 2012; Maconachie, 2011).

<sup>2</sup> Large cargo trucks manufactured by MAN and Mercedes-Benz are now commonly used for transportation of goods and people throughout the Sahara (Scheele, 2012).

Olmstead, 2001). Also, product standards, which certify quality in the consumer market, may explain why miners reject labor-saving technologies that alter the form-factor of salt bars.

Political organization also plays an important part on several levels. Without military restrictions on truck ownership and use in Taoudenni, trucks would probably have been adopted earlier. More broadly, the ability to organize politically is associated with public institutions, like clearly defined property rights and access to courts, which support capital mobilization. Libecap (1978) details the case in Nevada, where mining interests organized the region into a U.S. Territory in order to transform the legal framework from scattered, autonomously designed “mining district codes” to federal law. The former arrangement suited early silver mining practices that resemble our salt mining context, but the latter institutional setting accommodated the large capital investments needed to access harder-to-mine ore, and mining firms quickly became the largest firms in the country (Hannah, 2008).

The historical tendency toward large size applied to salt mining as well, which makes the small, ad hoc, kinship-based operations of Saharan salt mining all the more notable. If we consider organizational innovations like the “corporation” to be technologies, too, then we see how important political organizations for economic organization. In the case of corporations, they were originally created for political purposes, to form municipalities in medieval Europe (Kuran, 2003, 2010) and 18<sup>th</sup> century U.S. (Lipartito, 2004). Later, corporations for commercial purposes mobilized both capital and labor, engaging workers as employees for the first time. Interestingly, while autonomously formed corporations replaced ASM historically, transplanted foreign firms have not replaced ASM in economies where firms do not form autonomously (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 for the final good are reliable, with stable prices and quality standards; debt contracts are used

regularly; and workers specialize, including 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.

By focusing on a narrow and tractable question of technology adoption in a specific case, we call attention to how political and institutional background conditions affect technological change and economic growth. Our set of details illustrates relationships between political representation, economic organization, technology and growth.

## **2. Case Study: Taoudenni Salt Trade**

Journalist Michael Benanav's 2003 account of his journey to the Taoudenni salt mines describes a forty-day trek with two experienced salt miners, cousins, who serve as his guides across a stark and featureless landscape of shifting sand. 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) let alone GPS navigation.

Once at the mine itself, Benanav finds 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 also, Clauzel 1960). However, it serves as a good building material for constructing the mine and shelter structures (Photo 3 shows the opening of a mine). 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, each is 30-40 kilos are consistent with early descriptions and have practical origins: camels can carry two slabs on each side. Photo 1 shows camels carrying salt slabs in a caravan. The standard size and shape of slabs facilitate transactions, historically and presently, where salt is 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 (de Villiers & Hirtle, 2002). Map 1 shows a map of 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. The purest layer of salt from Taoudenni is used by the locals in traditional medicines to improve virility, as something akin to the Viagra of West Africa. Accordingly, it claims the highest price.

While our setting seems geographically isolated, 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 (Paul 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 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 non-adoption at one extreme, to rapid adoption at the other. The resulting analysis is a unique combination of the historical and the modern.

To organize the technologies and the theories 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, but also a literature on network effects that pertains to road infrastructure. Of course, much of the analysis from the mechanization discussion applies to transportation, especially as it relates to individual-scale technology, since we posit the decision to change from camels to trucks to occur at the level of an individual camel-herder. As before, we examine economic and institutional theories.

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 rather than replaced. A different set of theories can be brought to bear on this last type of technological change that involve economic and cognitive factors.

### **3.1. Tools: Small- and Large-Scale Technology**

There are three ways to produce salt: evaporate salt water (brine), mine out of the ground as rock salt, or burn sodium-rich plants, filter the ashes, and evaporate the salt water. In the west-central Sahara, rock salt is dug out of the ground. Mining technology varies historically and geographically. In developed countries, large-scale specialized equipment is used. Photo 2 shows machinery used by Morton Salt. In our context, hand-held tools are employed. "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 physically demanding. 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 technology such as the machine pictured in Photo 2 involve a different set of economic and institutional considerations, and thus are 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 (see Photo 3) can take a month of valuable time out of a six-month season and there is no guarantee of a rich vein. Mechanizing the mining 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 may also play a role in adoption.

The appropriateness of technology, according to Basu and Weil (1998), depends on relative prices and capabilities. Technologies created in developed countries are most likely to be adopted by countries that are developmentally close, 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) focuses on relative prices in the case of the spinning jenny, which was adopted enthusiastically in 18<sup>th</sup> century Britain. There, a jenny cost half a year's earnings while in France, the same jenny cost a year and a half's earnings. The low adoption in France was thus due to what French spinners could earn for a day's work.

We apply Allen's basic approach to assess whether a jackhammer could 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 \$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 salt, *wara*, for \$0.30/kg. The highest-quality salt would be worth \$.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 to 40 kg per bar. At the conservative \$0.30 price and 30 kg size, this comes to over \$300 per 6-day week. Over the course of 20 weeks, this comes to over \$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 cannot explain the lack of adoption of jackhammers.

An institutional explanation posits that intermediation is needed to promote adoption. Rosenberg (1963) shows 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. Also, modern conveniences like satellite phones and GPS have been adopted by the salt mining industry, especially merchants and transporters. 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 likely, explanation for the continued use of traditional tools is suggested by the economics of information. Taoudenni's best salt arrives at the market in rectangular bars, a form factor since time immemorial that had a practical purpose when transport was performed exclusively by camels. However, now that camel transport is no longer the dominant means of transport, why not change the form factor? One explanation is that the product standard conveys information about the product. Given the sophistication of salt consumers and the cultural meaning of this particular type of salt, a high premium is paid for a guarantee of quality, which this costly, hard-to-imitate "packaging" provides.

The salt bars pictured in Photo 1 are "finished", either by miners or by individuals at the mine who perform this function for a fee of one bar for every four bars finished. This finishing work involves trimming the salt bar to the standard size and shape, and fortifying the fragile raw salt with an acidic saltwater found in the mines, which turns the salt "hard like iron" and thus makes it transportable (Rombe-Shulman, 2013 p. 31). Customers purchase salt that has been cut from a large slab into smaller pieces in the

marketplace, then pulverize it themselves. A jackhammer and, for that matter, explosives as well as the Italian brining technology, would pulverize the salt, saving consumers the trouble, but also make 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.

*Summary:* In analyzing three theories for the non-adoption of small-scale technology, we find that product standards likely serve a quality certification function that cannot be overcome by individual miners, who then must continue traditional practices.

Appropriateness with regard to relative prices and skill is most likely not an issue, nor is the availability of technology intermediaries.

### **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, a large seller could overcome such obstacles. In general, firms use a variety of sales strategies, such as branding and advertising, to communicate quality and achieve a price premium, and in 19<sup>th</sup> century Michigan, salt firms consolidated to do just that (Roy, 1997). Thus, our analysis of small-scale technology leads us to a second question, about large-scale enterprise and the adoption of larger-scale technology. Several theories address questions of scale. First, an economic analysis of market size might show that Saharan salt mining falls below the minimum efficient scale of a large-scale technology. However, institutional explanations could also apply to questions of capital investment in large-scale technology and large-scale organization.

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. Therefore, for the purposes of our analysis, 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, 1967). As with appropriateness, discussed above, higher wages (relative prices) played a role in encouraging adoption. But this was a case in which minimum efficient scale was important, as farm size increased in response to greater demand for wheat.

The question for our case is thus whether the West African market for salt is too small to support large-scale equipment? While data are scant, Lovejoy estimates salt production of 1500 metric tons in 1972 in Fachi and a similar amount in nearby Bilma. These two salines produced the bulk of salt for central Sudan, in modern Niger and Northern Nigeria, which is east of the trading region that includes Taoudenni. However, these figures provide a conservative estimate of the level of demand, given that the population of our focal trading region has quadrupled since the 1970s. If we include other types of salt produced in the region, such as "trona", whose production is estimated by Bouquet (as cited by Lovejoy) 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 in the tens of thousands of metric tons.

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 a thousand times larger than the West African market. However, demand of over 20,000 metric tons is still sufficient to accommodate larger scale technology. A 5000-year-old salt mine in Turkey produces 500 tons of salt each year but is operated by a firm employing 16 workers and has used "machines and underground blasting" since the 1970s (Catholic Online, 2013).

*Summary:* 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, Johnson and Robinson (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 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 contrasts this with the European practice of primogeniture, in which the eldest son inherits an estate intact.<sup>3</sup>

All of this seems to describe 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 19<sup>th</sup> century, and while Europeans enjoy a centuries-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 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.

*Summary:* The Islamic legal history of the region does not present a real impediment to corporations today. Moreover, the respect for the law and quality of courts historically are inconsistent with the connection between legal origins and weak institutions.

### 3.1.2.3 Institutions: Political Organization

While Islamic legal origins do not explain technology and organizational adoption, Banerjee et al (2002) suggest a different mechanism for institutional factors. In their study, areas with village-level governments had significantly higher productivity after

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<sup>3</sup> 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'."

controlling for new seed adoption and property rights. This suggests a role for political organization, whose role we 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, an the “open access” system initially prevailed in California, in which people claimed an informal, temporary property right to mine public land (Clay and Wright, 2003). 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.<sup>4</sup> 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 here 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

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<sup>4</sup> 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.

the California Land Act of 1851, which also strengthened property rights (Clay, 1999), half of US mining firms employed over 1000 workers (Hannah, 2008).<sup>5</sup> 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. Also, 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 18<sup>th</sup> and early 19<sup>th</sup> centuries, and were only later used to organize commercial activity. According to Lipartito (2004), "one-half to two-thirds of early

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<sup>5</sup> 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.



corporate charters went to start towns," while those for business organized "public works such as bridges, roads, and canals." Kuran 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 involved 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 miners 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 large. 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 Singer sewing machine company, 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-butchered inspections by state-level authorities.

Anti-trust law worked its own unexpected influence on firm size. Roy (1997; Ch. 7) describes the salt industry in the Great Lakes region in the decades before and after the Civil War. Salt companies like 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 .<sup>6</sup> 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.

Throughout our discussion, the connection between firm size and technology has been assumed. Larger firms use larger-scale technology, whether in mining, boiling salt water in the Middle Ages, or building bridges in 19<sup>th</sup> century America. But a key feature of modern corporations, the employment relation, did not come into widespread use in the U.S. until the early 20<sup>th</sup> century. Thus, according to Rosenberg and Birdzell (1986), the scale achieved by the firms discussed above occurred without the organizational innovation of “employees”. "As late as 1892, so substantial a plant as Carnegie's Homestead Works avoided the problems of organizing and managing the work of its manufacturing employees," by instead using contract laborers, i.e., workers hired on a spot market. Thus, the adoption of employees, an organizational innovation, is distinct from the adoption of large-scale technology.

The theory of the firm examines several factors driving firm size, including technology and organizational adoption. The theory begins with a focus on size, as the emergence of large corporations was remarkable and unprecedented. Berle and Means (1932) credit financial markets with aggregating the capital required to create large corporations. Chandler (1977) argues that operational complexity (of railroads) necessitated multi-level managerial structure and large size. And Schumpeter (1942) famously connects large firms with innovation. Alchian and Demsetz (1972) are the first to explore the employment relation specifically, arguing that indivisibilities in work tasks, such as when two people load a truck, explain why companies need employees. Williamson (1975, ch.

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<sup>6</sup> *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; Ch. 1).

4) credits the idiosyncratic nature of modern jobs combined with bounded rationality and opportunism with the existence of employees.<sup>7</sup> Perhaps our salt mining setting lacks employees because the work of salt miners do is neither idiosyncratic nor uncertain.

However, the labor market in our setting does not conform to the assumptions of the theory of the firm. Slavery was outlawed in 1908 but it persists informally to this day (Hall, 2011).<sup>8</sup> Perks (2011) and Maconachie and Hilson (2011) describe debt bondage and slavery as part of a poverty trap for ASM miners. 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 exploring the connection between slavery and technology use. This literature is consistent with 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

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<sup>7</sup> Williamson argues that the employment relation arises in circumstances where firms face idiosyncrasies and uncertainty in their operating environment. Under these circumstances, the use of an external spot market for labor is costly compared with 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.

<sup>8</sup> Anecdotally, slavery is still commonplace. De Villiers and Hirtle note, "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.'"

action was central.<sup>9</sup> 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 allow slavery.

*Summary:* 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 California Gold Rush, and the employment relation. What we do not know is the exact mechanism that statehood conferred for investors who then bought 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 in use by Saharan salt miners, camels have plied the desert routes for millennia. Our question about technology adoption vis-à-vis camels is therefore similar to our analysis of technology adoption of tools, and all of the discussion above applies here as well. However, there are two differences with respect to camels. First, camels are well adapted, perhaps ideally so, for transporting humans and cargo through the desert. So the possibility exists that camels are efficient in a way that does not apply to traditional tools. Second, our fieldwork shows that, contrary to popular accounts like Benanav’s, trucks have in fact largely replaced camels. Therefore the

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<sup>9</sup> Wright argues, "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.

question has to do with the timing of adoption rather than the lack of adoption. Several economic explanations are suggested by the literature, including a literature on the competition between two technologies, especially replacement of draft animals, and network externalities. In addition, our fieldwork shows that politics play an important role in the timing of adoption.

### **3.2.1. Technology Competition**

Camels are genetically adapted to survive and thrive in desert conditions. Consequently, the question of camels' optimality is not new. Historian Bulliet (1990) 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 the camel's natural advantages, Bulliet shows that they are no match for motorized vehicles. 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.

A management literature looks at the competition not between animals and machines, but between different technologies. While this may seem far afield from our interest in replacing animals, the sheer number of examples in this literature offers insight into conditions for a technology's success. The theory of "dominant design" describes situations in which many different product models compete during a period of innovative ferment and an optimal design emerges (Anderson and Tushman, 1990). 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 is a particularly long-lived standard, and was established after an initial period of design ferment.

The case of two competing technologies is also common. 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, 1992 b, 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 spur 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 for 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, we find that camel populations and use have declined, in part because climate change has decreased the availability of forage, and because those involved in the Saharan salt business have found truck transport to be attractive. Large commercial vehicles produced by MAN trucks and Mercedes-Benz cost about \$50,000 each and do not require roads. Fuel is costly compared to forage and the danger of being stranded in the desert exists, unlike with a camel caravan, where the death of a single camel is not life threatening. However, truck travel is faster—a round trip takes six to ten days compared with thirty days by camel—and other technologies including satellite phones and GPS technology make journeys safer. 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).<sup>10</sup>

*Summary:* Theories of technology competition help explain why camels persisted in their desert niche into modern times. While largely displaced by trucks now, certain conditions contributed to this change, including climate change, the invention of trucks large enough to traverse the desert without roads, and complementary technologies like GPS and satellite phones, which make truck travel safer.

### **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.<sup>11</sup> With very few vehicle owners, complementary investments such as roads, emergency services, fueling stations, might not get built. Skills can also be complementary, as already 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.

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 tablet computers and smart phones (Worthen and Sherr, 2012).

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<sup>10</sup> 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).

<sup>11</sup> This occurred with Windows-based personal computers, whose increasing popularity spurred outside software developers to create useful new programs that made computers even more valuable.

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 Africa, including French state-owned firm Areva mines uranium in Arlit, Niger, and Chinese state-owned firms mine a variety of metals throughout Africa (Barta, Matthews and Batson, 2008); these firms have built and maintained roads, even in politically insecure and environmentally hostile places.

*Summary:* The invention of MAN-type trucks has allowed truck adoption in the Sahara, much as the development of tablets and smart-phones 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.

### **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 18<sup>th</sup> 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 hinder 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 1990:253), 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.

*Summary:* Politics played a role in limiting access to trucks and thus delaying the adoption process. Once political obstacles were removed, a familiar pattern of adoption began.

### **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 eleven years of age.<sup>12</sup> 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 hard way to make a living and young people would rather find other ways to make a living, if given the chance.

Two strands of 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.

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<sup>12</sup> 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 (Michele Apotsos, 2009). Without this transfer of tacit knowledge, practices would fail to persist.

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 (where razors are 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. And Siggelkow (2001) describes apparel-maker Liz Claiborne's inability to respond to changes in workplace dress codes. Here, too, executives had to be replaced in order for the firm to replace complex complementary practices that were fine-tuned for the old environment.

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 (forthcoming) 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 of 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.<sup>13</sup> Given these examples, we note that unlike creative destruction, which results in new and better methods or goods, this second mode of extinction can result in the loss of valuable knowledge and skills.

In our setting, existing miners might be unable to adapt and compete should an entrant bring new technology to the industry, perhaps a multinational firm already expert in salt mining.<sup>14</sup> However, such entrants have failed to drive out ASM elsewhere because their capital-intensive methods make deeper ores more economical to exploit than the alluvial deposits exploited by ASM (Dondeyne et al, 2009; Geenen, 2014). Instead, our interviews suggest that young people would like to move to cities and find other work than mining. 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.

*Summary:* Salt miners have shown such adaptability to new transportation technology that we are skeptical that cognitive impediments would bring about their extinction. Moreover, the cognitive issues described in the literature are imbedded in firms, an

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<sup>13</sup> 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."

<sup>14</sup> A failed 2008 venture by French artisan producer, Salt of Azalai, suggests 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 shortly went out of business, possibly because of the global economic crisis.

organizational innovation not present in our setting. Instead, extinction via abandonment for other economic opportunities seems a real possibility in the future.

#### **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.

In some sense, 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 in 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.

Not content to consider strictly 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 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.

In the Sahara, commercial activities lack the large-scale technology and employment relation characteristic of modern corporations. This is true not just for salt mining, but for other trades, as well, which is precisely what we would expect if something as broad as “political institutions” are 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 southwestern Mali, including its capital Bamako. Scheele describes a merchant trade in the northern Sahara region in Algeria whose makeshift shelters, informal cooperation among dealers, and small-scale business arrangements, all resemble arrangements in salt mining. De Villiers and Hirtle (2002) and the Seligman (2007) describe traditional salt production practices in other parts of the Sahara, which produces grey salt cones via brine evaporation. Here, too, a standardized product is made using baskets for evaporation and involve small kinship groups and slaves.

Desert salt mining is not unique in its use of traditional practices. Basu and Weil (1999) mention harvesting crops with a sickle in India, but many developing countries employ traditional practices in a number of industries, and ASM is widespread throughout Africa, Latin America, and Asia. Our findings are consistent with the literature on ASM, which also shows a consistent weakness of local political organization and absence of higher-order economic organization. And while our question about technology adoption initially seems narrow, it quickly turns our attention to investment and firm size, which recent research has identified as having a connection to economic growth (Guner, Ventura, and Yi, 2008; Hsieh and Klenow, 2012).

The analysis raises questions for future work. First, if organizing to demand institutional change was important for creating institutions that promoted firm size, what explains the differences in collective action even among democratic countries? Banerjee and Iyer (2005) study the legacy of three different land tenure systems in India and find individual

ownership to be associated with the highest levels of public infrastructure investment and lowest levels of inequality. But property rights alone cannot explain this because land tenure systems were changed in the 1950s. Instead, they suggest that farmers in the individual ownership regime came to view collective action differently than those who had been assigned to a landlord system, which granted de facto title to landlords and thus misaligned incentives between elites and farmers.

Second, if large firms can be created by governments, why do some governments create large firms while others do not? Medieval churches and principalities in Europe organized salt works (Multhauf, 1978), and into the 20<sup>th</sup> century, governments often own 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. Understanding the reason for and the relative merits of different modes of intervention could be helpful in understanding state-owned firms in large developing countries like China.

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Map 1: Locations related to 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.

Map 2: Detail showing Arlit and Bilma, 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 are denoted by yellow lines. For reference, locations associated with the salt caravan in Mali—Taoudenni, Timbuktu and Mopti—are denoted in black.



Photo 1: Camels carrying salt slabs



Source: National Geographic, 2003

Photo 2: A U.S. salt mine



Source: Morton Salt, 2013

Photo 3: A Taoudenni salt miner



Source: National Geographic, 2003