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INTERTWINED: TECHNOLOGICAL CHANGE AND COERCED LABOR DEMAND IN YUCATÁN'S HENEQUEN HACIENDAS

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Abstract

At the end of the 19th century the state of Yucatán became a monocrop economy centered around the export of twine made from the henequen agave. The regions old haciendas were transformed into proto-industrial units where henequen was cultivated and processed. The new hacienda system brought about the invention and adoption of machinery used in henequen production as well as the proliferation of debt peonage, a coercive labor arrangement in which peasants become indebted to the landlord and must in turn offer their labor to him until their loans are repayed. I argue that this was the case because the introduction of machines brought along higher returns to experience, and this in turn generated greater incentives for landlords to retain (skilled) workers in their control. I then formalize this theory in a mathematical model. Finally, with data from a particular hacienda, I show that, empirically, 1) experienced operators of the machines produced higher outputs and 2) the possibility of learning-by-doing shifted demand for coerced labor.

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Data Sources: The data used for this work was kindly provided by Shannan Mattiace and Tomas Nonnenmacher and does not come from public-access databases.

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Daniel Pérez Huerta

1 Introduction

To the Mexican elites of the 19th century, the technological developments of the Industrial Age came to embody the promise of progress. Though at the national level their efforts to harness these innovations would yield mixed results, mechanization did prove an extraordinary success in one unlikely region of the country.

When the henequen rasping machine was introduced in 1856, the state of Yucatán was a backwater, with an economy dominated by cattle ranchers and fledgling sugar plantations, and suffering in the aftermath of a brutal peasant rebellion that had decimated the indigenous population. By the turn of the century the rasping machine had sparked a drastic change in Yucatán. The textile industry built on the cultivation of the henequen plant, a species of agave used to produce twine, had turned the state into Mexico's biggest exporter, and brought the steam engine and smoke stack into the old countryside haciendas.

But with this technological transformation also came a social one. At the same time the rasping machine was turning the haciendas into proto-industrial units where henequen was both cultivated and processed into twine, the old institution of debt peonage became widespread. More and more of the state's peasant population were permanently tied to the haciendas through their debts to the landlords, prohibited from leaving their service until they could repay their loans. This system of labor coercion, immortalized in outsider accounts such as John Kenneth Turner's *Barbarous Mexico* (1909), would become a crucial feature of Yucatán's economy, up until it was abolished in the wake of the Mexican Revolution.

The "henequen episode" in Yucatán offers an interesting case study in the relationship between labor institutions and technology. As production became more efficient, why did *hacendados* resort to ever more coercive practices to ensure a larger and larger supply of workers? Understanding these developments is not only valuable in the context of the Mexico's transformation into a modern economy at the dawn of the 20th century, but also fits into a much broader literature within

economic history.

In this study, I argue that the joint expansion of coercive labor arrangements and mechanization in the henequen haciendas of the late 1800's represents an apparent contradiction that stands in contrast with previous work dealing with other historical contexts. I then offer a explanation for this phenomenon: that the introduction of machines also brought along higher returns to experience, and this in turn generated greater incentives for the *hacendados* to retain (skilled) workers in their control. I then formalize this theory in a mathematical model, and prove that under certain conditions more efficient technology leads to higher tied labor demand. Finally, I take data from a particular hacienda, Itzincab Cámara, and show that, empirically 1) more experienced operators of the henequen rasping machine produced higher outputs and 2) the possibility of learning-by-doing shifted demand for tied labor, measured by the different compensations given to machine-room and field workers, in line with the predictions of the theoretical model.

2 Motivation

In the long run of history, coercive labor arrangements—broadly defined as systems where employers exert a significant degree of extra-economic control over their workers, legally or otherwise—have been the norm rather than the exception. Accordingly, within economic history a large literature has been devoted to understanding the causes, nature and impact of coercive labor institutions in a variety of locations and time periods.

A recurring subject is the role played by factor endowments, the relative abundance or scarcity of land and labor in an economy, in the formation of such institutions. The best known theory on the relationship between factor endowments and coercive regimes is the Domar hypothesis, which at its most basic holds that, under favorable political conditions, a small group of elites who each hold vast amounts of land but face stiff competition for a limited number of workers have incentives to use coercive arrangements in order to secure a sufficient supply of labor. Since Domar (1970) presented the canonical form of this argument, a series of subsequent theoretical (Acemoglu and Wolitzky 2011, Conning 2004, Bardhan 1983) and empirical (Klein, Ogilvie, and Edwards 2021, Naidu and Yuchtman 2013, Scheidel 2005) works have provided support for the relevance of labor scarcity to the establishment of coercive systems.

A related set of studies have taken the relationship between labor scarcity and labor coercion as a starting point to examine the impact of coercive institutions over subsequent economic developments. In particular, some authors, for example Hornbeck and Naidu (2014), Whatley (1987), Fleisig (1976) and Tyrefors, Pettersson-Lidbom, and Lindgren (2017)[1] have argued that, during the 19th century, societies in which these institutions prevailed faced reduced incentives to adopt the labor-saving innovations of the era. In these economies, the mechanization of agriculture and the emergence of manufacturing industries were thus stifled by the use of coerced labor.

A low supply of workers and high wages incentivize the creation and adoption of machinery designed to substitute labor (Acemoglu 2010); Allen (2009), for example, argues that the scarcity

[1] Most of this research focuses on the Southern United States before and after the abolition of slavery. Although the economic rationale behind the nexus between coerced labor and technology can be extended to other cases, the US does present some features that may have intensified this dynamic. In particular, before the 1807 ban on importing new slaves, American plantation owners had access to an elastic supply of enslaved workers. In other historical contexts, landlords faced a constrained quantity of laborers and might have suffered labor supply shortages even with the use of coercion, incentivizing mechanization. However, farms with more slaves still lagged behind in agricultural implements in the decades before (Wright 2006) the Civil War, well after losing access to the external slave market.

of labor in England and Scotland relative to the rest of Europe is what led the Industrial Revolution to start in Britain rather than in the continent. However, the availability of coercive arrangements suppresses labor costs and reduces the chances of suffering labor shortages during high-demand periods, thus lowering the potential gains from any labor-substituting technology. Mao and Wang's (2018) study into the use of financing in the antebellum United States presents a nice illustration of this argument: In states with low enslaved populations, the expansion of banking and access to finance spurred innovation (as measured by the number of registered patents), but in the Southern states newly available credit was instead used to acquire more slaves.

Note that the argument is not that forced labor institutions impede technological innovation in general. Indeed when a technology is labor-*augmenting*, like the development of better cotton seeds in the Southern US documented by Olmstead and Rhode (2008), nothing discourages its adoption in coercive economies. It is labor-substituting technologies—mechanization—, defined in Acemoglu (2010) as those that have a non-positive effect on labor's marginal productivity, that are spurred by conditions of worker scarcity and therefore might be affected by the prevalence of forced labor.

In light of this premise, the joint adoption of labor-substituting machinery and coercive labor institutions in the henequen haciendas of the late 19th century presents an economic puzzle. I argue that the apparent reversal in the relationship between tied labor and mechanization in the case of Yucatán is due, in part, to the fact that free and coerced workers are not perfect substitutes. In this sense, this work fits in a wider literature that asserts that landowners employed coercion not only because it alleviated labor supply problems but also because the different property rights over coerced labor implied distinct advantages (or disadvantages) in the production process itself.

Perhaps the most famous example of this proposition is Fogel and Engerman discussion of American slavery in *Time on the Cross* (1995 [1974]). Fogel and Engerman claim that use of slaves allowed plantation owners to employ a different production arrangement, "gang labor", which raised efficiency but was considered unpleasant and usually avoided by free laborers.[2] Fenoaltea (1984), on the other hand, puts forward that the difficulties in providing incentives for enslaved workers account for the division of free laborers into "care-intensive" and forced laborers into

[2] This theory, like much of *Time on the Cross*, has been debated at length. Toman (2005) and Field (1988a, 1988b) support Fogel and Engerman's broad claim regarding the importance of gang labor; see Hilt (2020) for an overview of the criticisms.

"effort-intensive" activities in the ancient Greek and Roman economies. Closer to the labor supply issue, Wright (2006) argues that ownership over slaves permitted American cotton planters to quickly expand into the more fertile lands in the Southwest by freely uprooting their existing workforce.

In my case, my hypothesis is that tied laborers in Yucatán differed from free workers in their (task-specific) human capital, by virtue of having worked for a longer time on the hacienda. Coerced labor and rapid technological adoption coexisted because peonage ensured that workers with experience at using the rasping machine could not leave the *hacendados*' service—that is, it allowed landowners to benefit from the effects of learning-by-doing.

Learning-by-doing, the increase in a person's skill at a given task through the accumulation of on-the-job experience, plays an important role in explaining productivity growth (Chang, Gomes, and Schorfheide 2002, Stokey 1988, Arrow 1971) and the organization and compensation of labor within firms (Shulz, Chowdhury, and Van de Voort 2013, Gathmann and Schönberg 2010, Gibbons and Waldman 2004, 1999). Theoretical studies (Jovanovic and Nyarko 1996, Parente 1994) also have considered the close link between learning-by-doing and technological innovation: Workers gradually extract the full potential of a new technology through direct experience using it, and this process must (in part) start again when the current technology is replaced. Work in economic history by David (1970) and Bessen (2012) provides evidence for this relationship in the context of rapid mechanization during the 19th century. Looking at New England's textile industry, both authors conclude that as weavers gained experience with the new power looms, this led to noticeable improvements in the mills' productivity.

I discuss the particular details of the henequen rasping machine in the following section, but, a priori, there is no reason to believe that an experienced operator could not have made better use of the device. If that was the case, *hacendados* would have had an incentive to make sure skilled workers remained in their service. As a result, the rasping, or decorticating, machine might have not only reduced overall labor demand but also changed the *type* of workers demanded.

3 Historical Context

3.1 "Oro Verde"

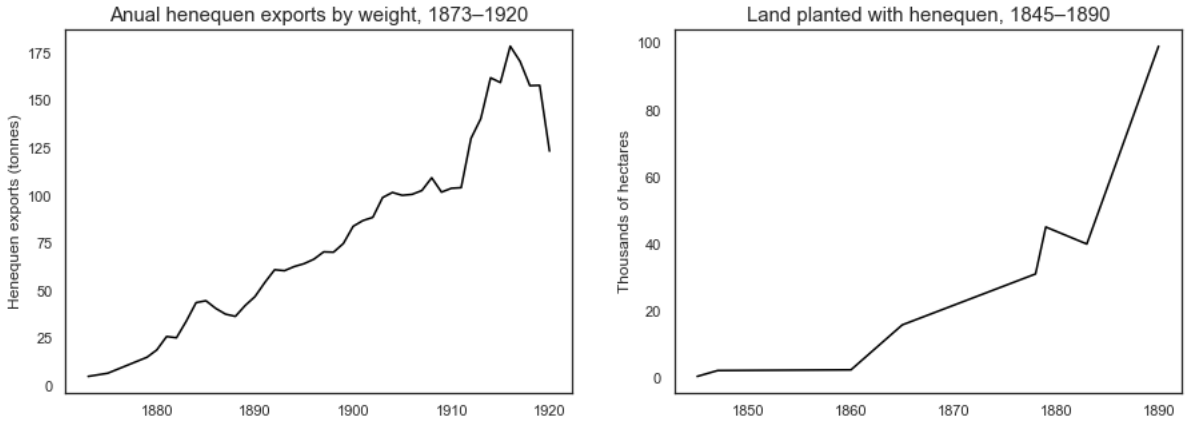
Yucatan's Maya population had used henequen fiber to produce twine since before the Conquista, and throughout the three centuries of Spanish rule henequen production would remain practically unchanged: a small scale affair geared towards domestic use and the local market. The first concrete efforts to turn the crop into a profitable enterprise would not come until after Independence (Cline 1948).

In 1830, a group of Yucatecan entrepreneurs came together to form the first partnership dedicated to the cultivation and promotion of henequen, planting 32 hectares (ha) of the crop in an old hacienda (Cámara Zavala 1936). Although this first attempt led to middling results, interest continued to increase. Support from the state government in particular would prove to be instrumental for the early development of the industry: The legislature promoted the creation and improvement of decorticating machines, funneled indigenous landholdings into the hands of the *hacendados* and legalized the use of bound labor in 1843 (González Navarro 1979).

Despite these efforts, in the beginning the new industry experienced only modest growth. Production was still constrained by technological and economic factors: The first prototypes for a decorticating machine had appeared in the 1830's but soon proved to be ineffective (Zamora Pérez 1999), and traditional methods to extract the agave fiber were labor intensive and wasted too much pulp. So by the mid 19th century henequen still played a minor role in Yucatan's economy, overshadowed by more lucrative crops like sugar cane, cotton and palo de tinte. Fiber was just starting to represent a notable share of the state's exports: In 1847 Yucatan exported 956,522 kg of manufactured twine products to Cuba and 1,133,000 kg of raw fiber to the United States (Regil and Peón 1852).

Starting in 1847, Yucatán went through a long period of peasant insurrection and brutal racial violence between the Maya population and the Hispanic ruling class, known as the Caste War. Authorities quickly reestablished control of Mérida and the surrounding towns that encompassed the henequen zone (Rugeley 2009). But in the sugar cane region in the southeast, the war dragged on for decades. Maya peasants destroyed sugar and cotton plantations, laying waste to the state's most profitable industries (Hoil Guitérrez 2016). After the initial outburst of violence subsided,

Figure 1: Growth of the henequen industry



Source: Exports from Manero (1935); land data from Cline (1948) and González Navarro (1979).

Yucatán's elites had no choice but to entrust their fortunes to henequen.

They were soon rewarded with the invention of the first successful decorticating machine, the Solís Wheel, in 1856. Four years prior the state legislature had offered a prize for a design capable of producing 20 pounds of fiber a day (Hernández Álvarez 2019). José E. Solís' machine over-delivered, with a daily output of more than 80 lbs (Mendoza 2017, Barba 1905). A string of innovations over the original design quickly followed—including the introduction of steam-powered machines in the 1860's—in a race to increase the machines' yields.

The mechanization of rasping removed the greatest technological bottleneck to the mass production of henequen fiber. At the same time, the economic environment improved significantly. Credit markets developed through import-export houses (financed themselves by US banks and manufacturers) and local notaries (Levy 2012, Joseph and Wells 1982). Between 1860–69, land planted with henequen increased from 2,600 to 16,000 ha, almost doubling to 31,200 ha by the end of the following decade (Cámara Zavala 1936).

Henequen production was soon boosted by another technological innovation, the McCormick reaping machine, which entered the US market in the early 1880's. Demand for twine, used to bind the harvested grain, skyrocketed as the machines spread across Midwestern farms. Henequen fiber was more pliable than its competitors and as a result was deemed ideal for the mechanical binder (Wells 1998). The price of fiber almost tripled, going from around 4 US cents per pound in 1876 to reaching a peak of over 11 cents in 1890 (Carstensen and Roazen-Parrillo 1992). By

1883, practically all the rural estates in the partidos of Mérida and Hunucmá, at the heart of the henequen zone, produced the crop (González Navarro 1979), and almost 60 per cent of the state's agricultural land was used for henequen (Yucatán State Government 1885).

The henequen boom eventually ran its course. While Yucatán mostly avoided the turmoil of the Mexican Revolution, the new state and federal governments' policies—including the abolition of debt peonage in 1914—were not as favorable to *hacendados* as those of the Porfirian regime. More importantly, after peaking during the First World War demand for henequen entered a prolonged decline in the 1920's, driven by the replacement of combined harvesters for mechanical binders in US agriculture and the introduction of synthetic fibers (Pretel 2019). But by then the 'green gold' had transformed Yucatán, and dragged its inhabitants from self-subsistence plots to the proto-industrial complexes of the grand henequen haciendas.

3.2 Debt Peonage in Yucatán

Debt peonage, an arrangement in which peasants indebted to a landlord pledge their labor to fulfill their obligations, had been a feature of economic life in Mexico since the colonial period. Practices around peonage exhibited great regional variation, and it seems that even before the henequen boom indebted workers in Yucatán faced harsher conditions than their peers in Central Mexico, where peons enjoyed a greater freedom of movement and barganing power against the *hacendados* (F. Katz 1974). However, according to Knight (1986), Yucatecan peonage at the start of the 19th century was still "of a relatively mild kind, [...] the peon's workload was light; they owed limited labor services to the hacienda; and on many haciendas the Indiands seemd to be 'their own masters"'.

Before the 1850's the haciendas in northwestern Yucatán, what would become the epicenter of henequen cultivation, were dedicated to cattle ranching. Although some workers lived on the hacienda, labor requirements were low, and a survey by Bracamonte y Sosa (1988) finds that while in the biggest haciendas the resident laborforce reached around 90–110 men, most estates usually had little over 20–30 peons. These workers were divided into *luneros* and *asalariados*. *Luneros* provided one day of free labor to the *hacendado* once a week in exchange for a plot of land, called *milpa*; ocasionally they were called on to work for the hacienda on other days of the week and payed a wage in return. *Asalariados* had no land of their own, instead being payed a daily wage

for their labor (Cámara Zavala 1936).

The first step in the transformation of Yucatecan peonage came in 1843, when the state legislature made it illegal to hire workers who had left the hacienda without settling their debts and mandated local authorities to capture fugitive peons (F. Katz 1974). The law was repealed soon afterwards in response to the Caste War, but in 1863, when the threat of Mayan insurrection subsided and with labor demand rising in henequen haciendas, the old decree came back in force (González Navarro 1979). At the same time, Maya villages were being stripped of their communal holdings under the liberal Reform laws. The newly available land fell into the hands of *hacendados*, and so did the indigenous peasants who had just lost their livelihoods.

Economic forces and favorable political circumstances combined to drastically increase the prevalence of indebted hacienda labor. The number of peons went from 20,767 in 1880 to 26,273 five years later (Yucatán State Government 1885), growing again to 81,767 in the 1895 census (González Navarro 1956). When the revolutinary government put an end to debt peonage in 1914, governor Salvador Alvarado claimed to have freed 100,000 peasants (Knight 1986). Bonded labor not only increased on the extensive margin but intensively as well: as labor demand grew, so did the time *luneros* spent working directly for the hacienda, so much so that the word came to mean a full-time resident worker (Alston, Mattiace, and Nonnenmacher 2009, Ortiz Yam 2011). Both landlords and state authorities made greater and greater efforts to keep workers on the haciendas, going as far as recruiting the help of bounty hunters to track down escaped peons (Peniche Rivero 1999).

3.2.1 Debts and coercion

The nature and evolution of worker's debts during this period deserves close attention. *Hacendados* exploited religious and cultural norms as well as the threat of corporal punishment to keep workers tied to their land (Meyers and Carlson 2002, Bracamonte y Sosa 1988, Knight 1986) but it was debt that formed the legal justification of peonage. According to Peniche Rivero (1998), upon coming of age young workers would be pressured into marriage. In order to pay the Church's fees and settle their new family, they would need to borrow a sizeable amount—often over a year's salary—from the *hacendado*. These loans were recorded in the *nohoch* (big) account. Smaller and more frequent loans, like wage advances and food from the hacienda store, went into the *chichan*,

or small, account. Worker's rarely made any payments toward their debts, and accounting records don't register accrued interests, suggesting these were not seen as actual loans.

Were these debts truly the base of a coercive labor system, or were they just another incentive for workers? A wave of revisionist works (see Cross 1979, Bauer 1979, Bazant 1974) cast doubt on the "forced" nature of Mexican peonage. Surveying the haciendas of central Mexico and the Bajío, this studies argued that workers enjoyed some degree of mobility and that their debts were "a perk, rather than a bond" (Knight 1986: 46). These, however, are not mutually exclusive functions, and in Yucatán, unlike in central Mexico, debts seem to have played both roles. Even if most workers were not, as some accounts at the time claimed, *de facto* slaves (Turner 1984 [1910]), coercion was an important factor in the henequen economy.

Though there was plenty of variation across haciendas, peonage usually did involve some degree of mutual agreement—must notably, at the moment the parties entered the arrangement. Peasants often resisted the expansion of henequen haciendas, and some of the young workers fled the estates before reaching the age when they could legally take on debt (Peniche Rivero 1998). But many willingly became peons, knowing they might never leave. Haciendas offered relatively high living standards, specially as the privatization of communal lands removed peasants outside options, and peonage provided other benefits, like exemption form military service (Ortiz Yam 2011). Moreover, workers themselves asked for higher loans, which they saw as part of the *hacendados*' responsibilities (Gill 1991).

Debt was then an incentive and, at least for some peons, the bond it created between them and the hacienda was of a more social than legal nature, strengthened by the association of big loans to life milestones like marriage and baptisms. Indeed, Alston, Mattiace, and Nonnenmacher (2009) suggest that debts were used because they, unlike a salaries, created a sense of reciprocity and social obligation that solved monitoring problems inside the hacienda.

In this respect, Yucatecan peonage was similar to its equivalents in the rest of Mexico. The crucial difference, however, was that in Yucatán debt also allowed for the use of naked coercion when positive incentives were not enough. State laws made it illegal for indebted laborers to leave their masters' estates, and made local authorities responsible for searching for any deserters. They also granted legal authority to the hacienda overseers, and prohibited the aiding of fugitives. Court records of trials against workers show that these laws not only existed in the books (Nickel

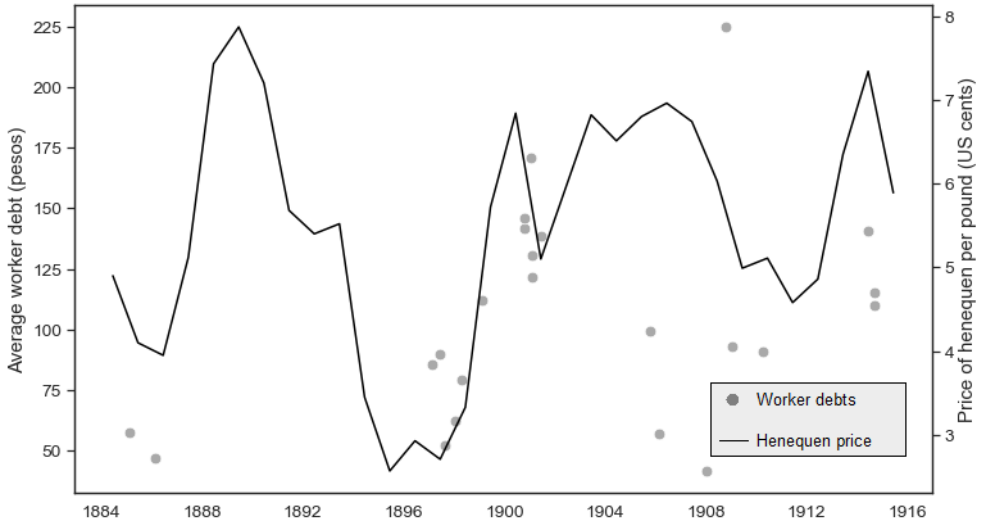
1997). *Hacendados* hired bounty hunters and advertised rewards for the capture of wanted peons in newspapers and magazines (González Navarro 1979). It was also possible to, in essence, buy and sell peons through the transfer of debt records between landlords (Bellingeri 1988).

Ultimately, debt provided a way for *hacendados* to ensure workers would not leave their control, whether this happened because loans created a strong social bond between peasant and master that a wage could not, or because it legally tied workers to the plantation when said bonds failed. Debt was conceived as an expensive but effective investment in retaining workers (Nickel 1996), either through coaxing or coercion; data on the impact of the abolition of debt peonage on worker turnover rates suggest that this was indeed its role, and that once it was prohibited, it could not easily be replaced with other margins of compensation (Mattiace and Nonnenmacher 2014).

Accordingly, contemporary commentators claimed that peons became more and more indebted as the henequen boom took over haciendas and demand for resident workers increased. The available data, however, paints a somewhat contradictory picture. Historical studies show that the average workers' debts did rise over this period (Knight 1986), but so did their wages. Looking at the cattle haciendas of the 1840's, Bracamonte y Sosa (1988) finds that *asalariados* earned a yearly wage of 12–15 pesos. Information on workers' debts is scarcer, but for two mid-sized haciendas he records an average debt of around 20–22 pesos, or 133.3 to 183.3 per cent of the peons' annual salary. Sixty years later, with the henequen economy in full swing, Peniche Rivero (1999) finds that workers were payed between 180 and 338 pesos a year, depending on their productivity and the specific tasks they performed; for the same period Nickel (1996) reports a mean peon debt of 133.4 pesos, or 74.1–39.4 percent of annual salary.

Hence at first glance the data points to a reduction in the burden of debt, but further analysis complicates this conclusion. Nickel's data on debt shows great variation both within and between haciendas. Among de 1,541 workers he samples, over one third had more than 200 pesos in debt, and a few reached levels over 600 pesos. It is possible that even if the mean amount of debt was lower, a greater proportion of peasants than before faced extreme debts. Moreover, as Bellingeri (1988) shows, debt levels also changed throughout the henequen boom, seemingly tracking the price of the crop.

Figure 2: Average worker debt versus henequen prices, 1885–1914



Source: Debt data from Bellingeri (1988); price series from Carstensen and Roazen-Parrillo (1983, 1992)

Second, loans and wages were not the only margins of compensation for the peons. These also included, e.g., land provided to the *luneros*. Some authors (Wells and Joseph 1996, Baerlein 1914) argue that as the number of resident laborers increased and more land was allocated to henequen the *milpas* became smaller, forcing workers to obtain their food through the hacienda store and thus to incur more short-term debts. Finally, because laws and technology (the introduction of railroads and the telegraph made it easier to track down escaped peons) changed during this period, it might be that lower levels of debt were just as if not more effective at keeping workers inside the hacienda than at the start of the century.

3.2.2 Peons and the Rasping Machine

A general lack of laborers influenced Yucatán's labor institutions. In contemporary accounts, landlords make it clear that *hacendados* they consider the lack of available workers a serious problem. In a message to the Finance Ministry from 1878 three henequen barons complained that they "had jobs to spare and lacked arms" (de Regil Peón, Dondé, and García 1880: 257) and that cultivation had reached "all the extension allowed by the working population at hand" (264). The Caste War had eradicated a large share of the state's population, which dropped from 422,403 residents in 1846, a year before the conflict, to 117,223 a decade later and stood at just 282,934 by 1877

(González Navarro 1979). Along with the Maya peasants that fell as casualties of the conflict, many fled to the eastern state of Quintanta Roo and others still were taken captive and sold to Cuba (González Navarro 1968).

The decorticating machine, however, was supposed to solve the labor scarcity problem; instead, after its invention labor demand (at least as judged by the number of resident workers in the haciendas) greatly increased.

The rasping, or decorticating, machine greatly decreased labor requirements in the fiber extraction stage, considered by *hacendados* the biggest obstacle to the expansion of the henequen industry (Cámara Zavala 1936). With traditional tools, the Mayan *tonkos* and *pakché*, one laborer could rasp around 35 leaves in an hour. By contrast, a crew of three workers using early rasping wheel models could process 800 to 1,000 leaves in the same period of time, close to a ten-fold increase on a per-worker basis. Towards the end of the 19th century, faster machines, operated by teams of six to eight men, reached rates of 1,500 leaves per worker/hour (Barba 1905).

At first decorticating machines spread slowly. Esteban Solís had introduced the first working machine in 1856, but in 1863 he pleaded with the state government to extend his patent for another ten years, claiming that the slow growth of henequen crops (which do not produce fiber for seven years after being planted) only allowed him to sell 64 units (Hernández Álvarez 2019). But once the plants in the first henequen fields reached maturity, adoption accelerated: a statistical report from the state government shows that in 1876 there were at least 600 rasping wheels in Yucatán, of which 400 made use of steam engines (Cline 1948). In 1883 there were just over a thousand machines (García Quintanilla 1979) and in 1891, 1,300 steam-powered rasping wheels in the state (Pretel 2019).

Constant efforts to refine and improve over the original design resulted in more efficient machines. Zamora Pérez (1999) finds 26 patents registered between 1854 and 1889 related to henequen decorticating machines, and 46 concerning fiber extraction implements in general. A significant share of these stemmed from local Yucatecan inventors (Cámara Zavala 1936), an exception in the history of technology in 19th century Mexico (see Beatty 2015). The introduction of rasping machines spurred further technological modernization inside the haciendas: Platforms and elevators transported the leaves that would be fed into the machine, mechanical presses were used to make the dried fiber into bales. As the chain of production was distributed among different parts of the

estate, Decauville narrow-gauge railways where installed to connect the interior of the hacienda.

The mechanization of rasping also changed the organization of hacienda labor. Work was broadly divided into field- and machine room tasks. Inside the latter, *elevadores* operated the elevators that fed leaves to the machine; *bagaceros* dealt with bagazo, waste generated as a byproduct of the rasping process; *fogoneros* kept the steam engines going, using timber as fuel; young peons hung the obtained fiber out to dry; *prensadores* pressed the fiber into bales. The actual operators of the decorticating wheels were the raspers, who used the machine to extract the fiber from the leaves. The whole process was supervised by a foreman who was in charge of the peons in the machine room.

All of these tasks demanded some degree of skill, but rasping in particular rewarded expertise as novice machine operators could reduce the leaves' yields and waste valuable fiber (Zamora Pérez 1999), and even suffer serious injuries—not an uncommon occurrence, according to a report to the state governor (Rejón and Ybarra 1885). Later, more complex machines solved some of the safety issues but also required more specialized knowledge to even function (Hernández Álvarez 2019). However, it was virtually impossible to acquire any experience with these tools outside of an henequen hacienda. There was of course no formal technical education available to peasants. So while working in the field bore some resemblance to traditional agricultural labor, the proto-industrial setting of the machine room represented something completely new to the majority of peons. I argue that this fact had two significant implications for labor arrangements in henequen haciendas: (1) skill was acquired through task-specific, "on-the-job" experience, that is, learning-by-doing and hence (2) skilled labor was scarce outside the hacienda walls.

Evidence form the partido of Mérida suggests that haciendas with more decorticating machines, or with more complex machines, had marginally larger resident workforces, as reported in Table 1. Without more detailed data, however, the link between technology and debt peonage in Yucatán is merely tentative. To properly examine the dynamics I have discussed in this section, I now proceed to a more in-depth theoretical and empirical analysis of the henequen haciendas.

Table 1: Determinants of hacienda population

	Hacienda resident workforce	
	(1)	(2)
Rasping wheels	46.068^{***}	45.400^{**}
	(8.010)	(16.847)
Rasping wheels^2	-1.908^{***}	-3.886^{*}
	(0.575)	(2.057)
Planted Area		77.710^{*}
		(27.664)
Cattle		0.130^{*}
		(0.074)
Intercept	14.949	-28.294
	(16.914)	(26.550)
R^2	0.479	0.736
Obvs.	58	31
Note:	*p< 0.1, **p< 0.05, ***p< 0.01	
Source:	Castillo Peraza (1886)	

4 Model

I formally lay out the relation between tied labor and technology through a theoretical model. The model is a modified version of the one proposed by Bardhan (1983), extended to consider two production periods[3] and hence the possibility of learning through experience. More recent treatments of the subject (Naidu and Yuchtman 2013, Acemoglu and Wolitzky 2011, von Lilienfeld-Toal and Mookherjee 2010) focus on what might be termed the "intensive margin" of coercion, the investment of the landlord into retaining any single worker. Bardhan (1983)'s model, and by extension my own, deal with the "extensive margin" of coercion, the amount of tied workers the landlord uses with respect to their total labor demand. However, compensation and worker's outside options still play a role in the model—as I discuss later, I use this variables to evaluate the model's predictions on the data.

The environment is as follows: A risk-neutral landlord produces an agricultural good in two periods $t = \{1, 2\}$, using only labor as an input (land and capital are fixed). In both periods the landlord's output Y_t is uncertain: it takes a value of y with probability α or a value of 0 with probability $1 - \alpha$. This uncertainty in production could represent meteorological factors out of the landlord's control, or exogenous fluctuations in demand for the good in foreign markets. Labor requirements are related to output through the function $L_t = zY_t$. The parameter z represents the available production technology—the introduction of a labor-saving innovation leads to a decrease in z and thus to labor requirements L_t.

To satisfy their labor demand, the landlord has access to two labor markets: a tied market and a spot market. The tied labor market is open at the start of the first period, before the value for Y_1 is realized. At this point, the landlord may hire L^T tied workers and offer them the payment schedule (w_1^T, w_2^T). Peasants who agree to the contract remain with the Landlord through both production periods. When L^T is not enough to fulfill labor requirements zY_t, the landlord must turn to the spot market and hire the remaining workers at a spot wage w_t.

Workers are hired from a mass of risk-neutral peasants of size N. Peasants can choose to

[3] Another change to the original model is the omission of what Bardhan (1983) calls the "lean period", right after peasants enter into tied contracts but before production begins, during which the landlord must pay the tied workers' wages without having a use for their labor. The reason for this is twofold: Tying the peasants over two productive periods introduces trade-offs similar to those created by the lean period, and because henequen cultivation was labor-intensive year-round, a model with no lean period more closely represents the dynamics of the *haciendas*.

work for the landlord or to remain out of the labor market altogether and work in self-subsistence agriculture. If they choose the latter, each peasant i earns the outside option x_{it}. Workers are assigned their outside option at the start of each period t according to the distribution $f(x)$ with support on the interval $[0, \bar{x}]$. For any peasant i, their outside option in the second period x_{i2} is independent from the outside option they were assigned in the first period x_{i1}. Peasants evaluate payments through the utility function $u(x)$, with $u'(x) > 0$ and $u''(x) < 0$. The landlord and the peasants share the same discount factor $\delta < 1$.

4.1 No learning

In what follows I consider the interior solution where the equilibrium quantity of tied labor is $0 < L^T < zy$; a brief discussion of the edge case $L^T = zy$ is given in Appendix A.1.

Let w_t^l and w_t^p denote the spot wages expectations of the landlord and the peasants, respectively. At the start of $t = 1$, peasants are assigned their outside options x_{i1} and the landlord determines their demand for tied labor L^T. The landlord wishes to maximize their expected earnings:

$$\max_{L^T}(1+\delta)\alpha y - (w_1^T + \delta w_2^T)L^T - \alpha(w_1^l + \delta w_2^l)(zy - L^T) \tag{1}$$

Each additional unit of tied labor grants the landlord expected savings of $\alpha(w_1^l + \delta w_2^l)$ at a price $w_1^T + \delta w_2^T$. Furthermore, it is easy to show that for any level of (discounted) spending $W^T = w_1^T + \delta w_2^T$, peasants' utility over the two periods is maximized by setting $w_1^T = w_2^T = w^T$. So the landlord will hire additional tied labor until marginal cost equals marginal benefits; that is:

$$(1+\delta)w^T = \alpha(w_1^l + \delta w_2^l) \tag{2}$$

For their part, peasants are assigned their outside option for the period at the start of $t = 1$ and evaluate whether to accept a tied labor contract given w^T. Suppose there is a worker with an outside option $x_{1t} = \hat{x} \leq \bar{x}$ such that they are indifferent between entering a tied contract and remaining

free. This implies that $\hat{x}$ satisfies

$$(1+\delta)u(w^T) = (1-\alpha)u(\hat{x}) + \alpha u(w_1^p) + \delta\left[(1-\alpha)\int_0^{\hat{x}} f(x_2)u(x_2)dx_2 + \alpha\left(F(w_2)u(w_2^p) + \int_{w_2^p}^{\bar{x}} f(x_2)u(x_2)dx_2\right)\right] \quad (3)$$

Condition (3) assumes that $\hat{x} < w_1^p$, which is consistent with the resulting equilibrium as long as $L^T < zy$. Finally, demand for tied workers must equal supply for the market to clear, so $\hat{x}$ must be such that

$$NF(\hat{x}) = L^T \quad (4)$$

Spot wages are determined once the value for Y_t is realized. In the first period, all peasants with an outside option $x_{i1} \leq \hat{x}$ are already working for the landlord. When $Y_1 = y$, the spot wage w_1 must go above $\hat{x}$ to fulfill the labor requirement zy; in particular

$$NF(w_1) = zy$$

So

$$w_1 = \begin{cases} 0 & \text{if } Y_1 = 0 \\ F^{-1}\left(\frac{zy}{N}\right) & \text{if } Y_1 = y \end{cases}$$

On the other hand, at $t = 2$ peasants that remained free in the previous period have been assigned a new outside option from the distribution $f(x)$: additional workers can be hired from the start of the distribution. If $Y_2 = y$, the landlord needs to hire $zy - L^T$ laborers from the spot market, which has a size $N - L^T$:

$$(N - L^T)F(w_2) = zy - L^T$$

And

$$w_2 = \begin{cases} 0 & \text{if } Y_2 = 0 \\ F^{-1}\left(\frac{zy-L^T}{N-L^T}\right) & \text{if } Y_2 = y \end{cases}$$

In a rational expectations equilibrium, $w_t^l = w_t^p = w_t$. Accordingly, the equilibrium wages can be plugged into equations (2) and (3), which along with the market-clearing condition can be used to derive the equilibrium values of L^T, w^T and $\hat{x}$.

For ease of notation, let $G(x) \equiv F^{-1}(x)$ and $U(w) \equiv \int_0^w f(x)u(x)dx$. Using the fact that $\hat{x} = F^{-1}(L^T/N)$ (from eq. (4)) and $w^T = \frac{\alpha(w_1+\delta w_2)}{1+\delta}$ (from eq. (2)), equation (3) becomes

$$(1+\delta)u\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right) = (1-\alpha)u\left(G\left(\frac{L^T}{N}\right)\right) + \alpha u(w_1) + \delta\left[(1-\alpha)U(\bar{x}) + \alpha(F(w_2)u(w_2) + U(\bar{x}) - U(w_2))\right] \tag{5}$$

Before giving an definite form for $F(\cdot)$ and $u(\cdot)$, (5) can be totally differentiated with respect to z to carry out a comparative statics analysis of the optimal demand for tied labor L^{T*}. This yields

$$\frac{\partial L^{T*}}{\partial z} = \frac{\alpha w_{1z}\left(u'\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right) - u'(w_1)\right) + \delta\alpha w_{2z}\left(u'\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right) - F(w_2)u'(w_2)\right)}{(1-\alpha)u'\left(G\left(\frac{L^{T*}}{N}\right)\right)g\left(\frac{L^{T*}}{N}\right)\frac{1}{N} + \delta\alpha w_{2L}\left(F(w_2)u'(w_2) - u'\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right)\right)} \tag{6}$$

Spot wages are increasing in z and $w_{2L} < 0$. Since $u'(x)$ is strictly decreasing, it is easy to show that $u'\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right) \geq u'(w_1)$. Therefore a sufficient condition for (6) to be non-negative is that

$$u'\left(\frac{\alpha(w_1+\delta w_2)}{1+\delta}\right) \geq F(w_2)u'(w_2)$$

Suppose $u(x) = \ln(1+x)$ and that $F(x)$ can be described by a continuous uniform distribution $\mathcal{U}(0,\bar{x})$. The previous inequality becomes

$$\frac{1}{1+\frac{\alpha(w_1+\delta w_2)}{1+\delta}} \geq \frac{w_2}{\bar{x}}\frac{1}{1+w_2}$$

and with some simple algebraic manipulation one can arrive to

$$\frac{\alpha(w_1+\delta w_2) - (1+\delta)\bar{x}}{(1+\delta)} \leq \frac{\bar{x}}{w_2} - 1$$

Because $\bar{x}$ is higher than both spot wages, this inequality always holds and $\partial L^{T*}/\partial z \geq 0$, meaning improvements in labor-saving technology lead to a lower demand for tied workers, in line with the literature. Repeating this procedure for the total number of peasants yields $\partial L^{T*}/\partial N \leq 0$, thus a higher number of available workers relaxes the landlord's demand for tied labor.

4.2 Learning-by-doing and technology

So far, the model has extended the conclusions of Bardhan (1983) to a scenario in which there are two productive periods—albeit for a discreet, rather than continuous distribution of the output variable Y_t. Now I introduce a mechanism that can reverse the results of the model by allowing for learning-by-doing. In particular, output in output in the "good" scenario where $Y_t \neq 0$ is now

$$Y_t = y + S_t \varepsilon(z)$$

where $\varepsilon(z)$ is positive and decreasing function of z, and S_t is the share of laborers that have previously worked with the current technology.

In the model, more efficient technologies also offer higher rewards to skill. Historically this was not always the case: as L. F. Katz and Margo (2014) note, the early stages of industrialization involved the substitution of uneducated factory workers for highly skilled artisans. However, authors like Bessen (2012) provide evidence of this relationship holding for other experiences of mechanization, as more complex machines replaced earlier models, and it is a common assumption in theoretical treatments of learning-by-doing (Karp and Lee 2001). More importantly, it seems to apply to the development of the henequen decorticating machines, specially before the mid-1880's (Zamora Pérez 1999).

As no production has occurred before the start of the first period, there are no "skilled" laborers in the market and naturally S_1 is simply zero. The potential to exploit the workers' previous experience comes in $t = 2$: In the second period—with probability α—there are zy peasants who worked with the landlord at $t = 1$; out of those, L^T have a tying contract and will remain at the landlord's service, but the rest will only be available to the landlord if their new outside options x_2 are smaller than the second period spot wage w_2. Therefore S_2 goes up with the number of tied peasants:

$$S_2 = \frac{1}{zy}[L^T + (zy - L^T)s_2]$$

Here, s_2 represents the proportion of free peasants hired by the landlord at $t = 2$ that also worked for them at $t = 1$.

Since outside options are assigned at random, s_2 and therefore S_2 as a whole are random

variables. When the landlord makes their decision, they need to take into account the distribution of s_2; suppose it is described by the PDF $h(s_2)$:

$$E[Y_2] = \alpha(y + \varepsilon(z)E[S_2]) = \alpha\left(y + \alpha\varepsilon(z)\int_0^1 h(s_2)\frac{1}{zy}(L^T + (zy - L^T)s_2)ds_2\right) \tag{7}$$

Notice that the linear effect of the proportion of experienced workers over $\varepsilon(z)$ means the landlord need only consider the expected value of s_2 when making their decision, which affords the model some mathematical simplicity at the cost of allowing for a more general relationship between S_2 and $\varepsilon(z)$. If there are $zy - L^T$ experienced free peasants and $N - zy$ peasants who did not work for the landlord at $t = 1$, the expected value of s_2 is

$$E[s_2] = \frac{zy - L^T}{(N - zy) + (zy - L^T)} = \frac{zy - L^T}{N - L^T}$$

and so (7) reduces to:

$$E[Y_2] = \alpha y + \alpha^2\left[L^T + \frac{(zy - L^T)^2}{N - L^T}\right]\varepsilon(z)$$

In an scenario where better technology increases the rewards to learning, the landlords problem becomes

$$\max_{L^T}(1 + \delta)\alpha y + \delta\alpha^2 S_2(L^T)\varepsilon(z) - (1 + \delta)w^T L^T - \alpha(w_1^l + \delta w_2^l)(zy - L^T)$$

Their FOC is then:

$$(1 + \delta)w^T = \alpha[w_1^l + \delta\alpha w_2^l + \delta\alpha S_{2L^T}(L^T)\varepsilon(z)] \tag{8}$$

An additional unit of L^T benefits the landlord not only by saving them the potential expenditure $\alpha(w_1^l + w_2^l)$, but also through the increase in the expected share of experienced laborers $S_{2L^T}(L^T) > 0$.

Because individual peasants don't directly share in the extra output $S_t\varepsilon(z)$, the rest of the model is solved as in the scenario with no potential for learning. The workers' decision to enter a tied contract is still determined at the margin by (3)—that also implies the market clearing condition is the same as in (5). Similarly, labor requirements are not affected by experience so spot wages in equilibrium are given by $w_1 = G\left(\frac{zy}{N}\right)$ and $w_2 = G\left(\frac{zy - L^T}{N - L^T}\right)$ when $Y_t = y + S_t\varepsilon(z)$, and are $w_1 = w_2 = 0$ otherwise.

The reaction of the demand for tied labor to a change in technology is modified by the introduction of the extra term $S_t\varepsilon(z)$. Once again, I use the total derivative of

$$(1+\delta)u\left(\frac{\alpha(w_1+\delta w_2+\delta\alpha S_{2L^T}\varepsilon(z))}{1+\delta}\right)=(1-\alpha)u\left(G\left(\frac{L^T}{N}\right)\right)+\alpha u(w_1)$$
$$+\delta\left[(1-\alpha)U(\bar{x})+\alpha(F(w_2)u(w_2)+U(\bar{x})-U(w_2))\right]$$

with respect to z to obtain an expression for the relationship between optimal tied labor demand and the technology level:

$$\frac{\partial L^{T*}}{\partial z}=\frac{\alpha w_{1z}(u'(w^T)-u'(w_1))+\delta\alpha w_{2z}(u'(w^T)-F(w_2)u'(w_2))+\delta\alpha^2u'(w^T)(\varepsilon'(z)S_{2L^T}+\varepsilon(z)S_{2L^Tz})}{(1-\alpha)u'\left(G\left(\frac{L^{T*}}{N}\right)\right)g\left(\frac{L^{T*}}{N}\right)\frac{1}{N}+\delta\alpha\left[w_{2L^T}(F(w_2)u'(w_2)-u'(w^T))-\alpha u'(w^T)\varepsilon(z)S_{2L^TL^T}\right]} \tag{9}$$

where w^T is the tied workers' payment implied by the FOC in (8).

Even though for any given w_1 and w_2 the payment for tied workers is higher when learning-by-doing is possible, as long as the interior solution condition $L^T \leq zy$ holds it is still the case that $u'(w^T) > u'(w_1)$ and—for the function forms used in the previous section—$u'(w^T) > F(w_2)u(w_2)$. So for (9) to be negative, meaning that an improvement in labor-substituting technology generates a rise in tied labor demand, the terms related to $S_{L^T}\varepsilon(z)$ have to be large enough to offset the incentives to secure a smaller supply of labor in the face of more efficient technology. To ensure an interior solution $w_{2L^T}+\alpha\varepsilon(z)S_{2L^TL^T}$ must be negative (see Appendix A.1); while this does not necessarily make the denominator in (9) positive, in what follows I focus on the equation's numerator.

Notice an increase in z affects the experience-related benefits of hiring additional tied laborers, that is, $\alpha S_{2L^T}\varepsilon(z)$, in two ways: First, it directly reduces the rewards to skill through the decline in $\varepsilon(z)$. Second, higher labor requirements mean that for any level of tied labor $L^T < zy$ there are now more peasants that worked for the landlord at $t=1$, so hiring from the free population is likely to result in a higher ratio of skilled workers. That means $\frac{\partial^2 S_2\varepsilon(z)}{\partial L^T\partial z}=\varepsilon'(z)S_{2L^T}+\varepsilon(z)S_{2L^Tz}$ in the numerator of eq. (9) is strictly negative, opening the possibility for the whole term to be negative as well.

To analyze a particular case, let

$$\varepsilon(z) = \frac{\bar{\varepsilon} y}{z^{\theta}}$$

The benefits of learning-by-doing are expressed as a proportion of the original output y through the parameter $\bar{\varepsilon}$, while $\theta > 0$ determines how this benefit changes with upgrades to the production technology. For the function forms of $u(\cdot)$ and $f(\cdot)$ used in the previous section, a sufficient condition for the numerator in eq. (9) to be negative is that

$$\bar{\varepsilon} \geq \frac{z^{2+\theta} y \bar{x} (N - L^T)^2 \left[\frac{1}{N} + \delta \frac{1}{N - L^T}\right]}{\delta \alpha (N - zy)[\theta(N - zy) + (N + zy)]} \tag{10}$$

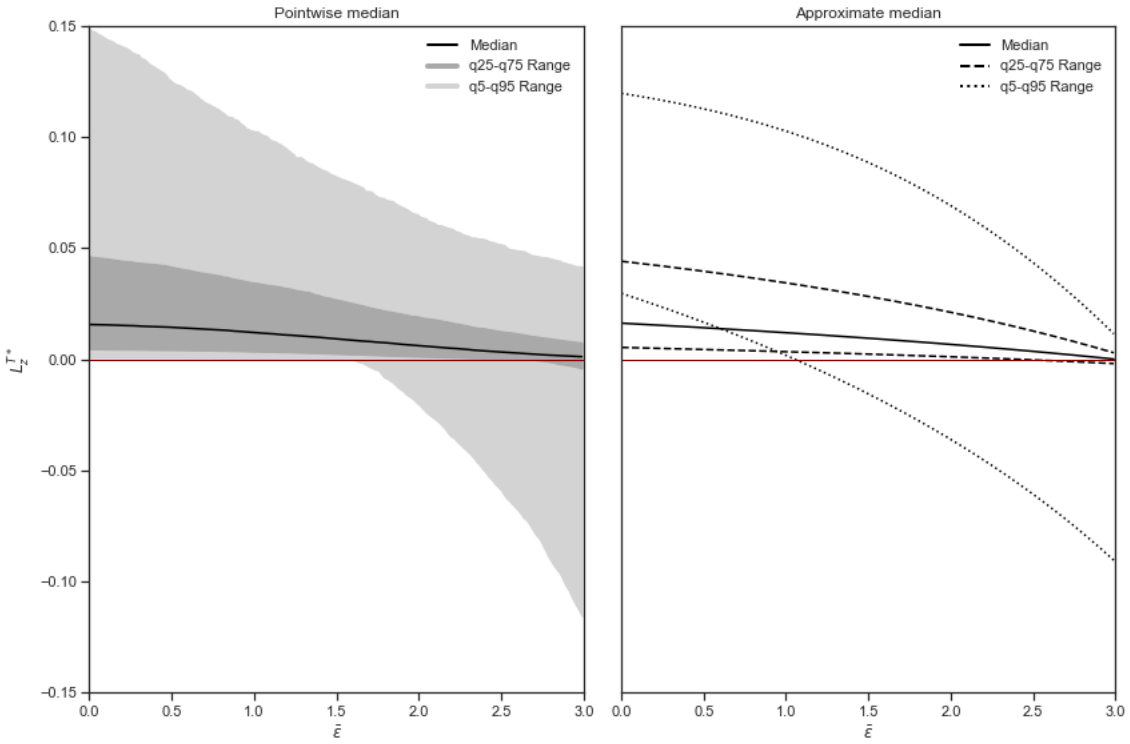
It is easily proven that (10) is harder to fulfill for lower values of δ and α, as the rewards to experience are both less likely to materialize and more heavily discounted. With a bit more work one can also show that the right-hand side of the inequality is decreasing in N, since a higher number of total workers leads to lower spot wages, reducing the incentive to secure tied laborers and allowing the skill-hoarding incentive to dominate in the event of a rise in z.

While (10) opens the door to negative values of $\frac{\partial L^{T*}}{\partial z}$, to further examine the feasibility of a positive relationship between tied labor and technological innovation in equilibrium, and due to the relative complexity of evaluating the derivative at the optimal L^{T*}, I resort to a computational solution. I start by drawing a random set of parameters $\{N, z, y, \bar{x}, \alpha, \delta, \theta\}$ (their respective distributions are selected to ensure that I arrive at an interior solution later on). Then I compute the optimal L^{*T} from (8) for the selected set of parameters and a given value of $\bar{\varepsilon}$. Finally, $\bar{\varepsilon}$ and the resulting L^{T*} are used as inputs to obtain the equilibrium value of (9).

I repeated this procedure multiple times, drawing a different set of parameters each run, and plotted $\frac{\partial L^{T*}}{\partial z}$ as a function of $\bar{\varepsilon}$. Figure 4 reports the results of this exercise: The left-hand graph shows the 5th, 25th, 50th, 75th and 95th quantiles from among all iterations at each point $\bar{\varepsilon}$, so every quantile may be made up from points obtained using different parameters. The right hand graph instead shows the actual functions $L_z^{T*}(\bar{\varepsilon})$ that most closely approximate said pointwise quantiles (selected by minimizing the sum of squared errors.)

As the figure shows, in equilibrium tied labor can increase in response to the introduction of labor-saving technology if this is accompanied by a high-enough reward to experience. It may seem $\bar{\varepsilon}$ must be considerably large to generate this effect, as even close to the 95th percentile the

Figure 3: Simulation results



Source: Data generated by the author through computational simulation of the model, with the fundamental parameters picked at random (see Section 4.2). Results from 5,000 draws of the parameter set.

derivative only turns negative once $\bar{\varepsilon} > 1$. However, because $\varepsilon(z) = \bar{\varepsilon}y/z^{\theta}$, a value of $\bar{\varepsilon} = 3$ translates to a crew full of experienced laborers producing only 15 percent extra output, assuming z and θ take their median vaules (Table 5 in Appendix A.2). Figure 5 in the appendix also confirms that this relationship is more likely to take hold with larger peasant populations and better probabilities of high production α.

5 Case study

I test out the empirical validity of the model through a case study of a particular henequen hacienda. Specifically, I am interested in two questions: were haciendas operating in an environment where learning played a role over output and labor decisions, as described in the extension of the model in section 4.2; and if that was the case, did the demand for workers that acquired said experience—which I measure through compensation for reasons explained below—differ from demand for unskilled labor. Among other things, which I discuss further in section 5.3, the model predicts that, under certain conditions and all else being equal, technological improvement and learning-by-doing should lead to higher *tied* labor demand (relative to total labor demand) and in turn to higher tied compensation.

Focusing on a single hacienda naturally raises doubts as to whether any findings constitute a genuine wider phenomenon, or are rather idiosyncrasies of the selected subject. Despite these concerns I opt for a case study for two reasons. First, the limits on existing and surviving data: as with any historical research, data availability represents an important constraint to studying the henequen boom. In the case of Yucatán's haciendas, records are even scarcer since the region's humid climate hinders preservation of paper records, and because many surviving documents remain in family collections rather than public archives. The second reason is that, given the available data, my hypothesis is better analyzed by looking at the detailed working of the hacienda, instead of more surface-level information.

5.1 Itzincab Cámara

The hacienda Itzincab Cámara is located in what is today the municipality of Tecoh—at the time the partido of Acanceh—some 30 km southeast of the state capital Mérida and right in the center of the henequen zone (see Figure 6). Itzincab had been established long before the henequen boom, appearing in records dating as far back as 1764. During the 18th and 19th centuries the hacienda produced maize and cattle, growing to a considerable size before gradually switching to henequen cultivation around the 1850s. In 1898 Itzincab was bought by Camilo G. Cámara, who would develop the hacienda into a full henequen enterprise (Paredes Guerrero 1997). Cámara came from a wealthy family of landowners, who by the 1890s already were important players in the monocrop

economy.

Under the Cámaras, Itzincab reached a total extension of 3,900 hectares, of which 1,320 ha (33.8 percent) were used for growing henequen. The vast hacienda complex included—besides the henequen fileds—the main house, the hacienda store, a chapel, the workers' residences, an orchard, the machine room, a space where henequen fiber was dried and packaged, and later a schoolhouse, plus a Decauville narrow-gauge railway that connected the different buildings. According to Paredes Guerrero (1997), Itzincab's layout and structure were typical for haciendas that had started out as cattle producers in the 18th and early 19th centuries and transitioned to henequen around the late 1800's. A 1910 appraisal put the hacienda's value at $750,100, about 3,600 times Mexico's per capita GDP at the time (INEGI 2015). This number included the land and buildings, the stock of henequen, as well as the resident workers, who were to remain on the property even if the hacienda changed hands.

At its peak in 1909, there were 96 tied laborers (*luneros*) in Itzincab; this resident workforce was supplemented with salaried workers and *muchachos*, young peasants, usually the sons of *luneros*. The Cámaras also briefly employed Korean immigrants and Yaqui captives[4]—though both groups did not last long at Itzincab, due to their tendency to escape the hacienda. Hence the 1910 census records a male population of 186 for Itzincab: relatively high, placing it in the 94th percentile for henequen haciendas. Nonetheless, relative to its size Itzincab had around 0.07 workers per cultivated ha, close to the average of 0.08 workers for haciendas in the core of the henequen zone (Castillo Peraza 1886).

Thus, as far as we can tell Itzincab's features seem generally in line with those of the larger Yucatán haciendas. However, an aspect which might have set Itzincab apart was its owners: the Cámara family possessed more managerial know-how than most *hacendados*, so they may have made better use of their resourcers, including laborers. They were also politically and financially well connected and thus had better access to physical and human capital.

[4] The Yaquis are an indigenous group from the northern state of Sonora. During the Porfiriato, Yaqui communities were routinely provoked and then subjugated in order to seize their lands. The displaced Yaquis became *de facto* slaves, sold to landowners in Yucatán and Oaxaca. While *hacendados* had in theory more control over Yaquis, they still preferred the native Yucatecan population, as they were considered more "docile" and thus better workers.

5.1.1 Data and sources

The bulk of my data comes from *semanarios*, weekly ledgers that include workers' daily tasks and wages. In addition to their duties, the *semanarios* place workers under different classifications based on their legal status and specialization. They also register the hacienda's output: number of henequen leaves harvested and rasped each day, and how may kilos of fiber were produced. The *semanarios* also keep track of smaller loans taken by the hacienda's laborers.

I selected Itzincab as the subject of my case study basend on the quantity and coverage of the available archival information. Although *semanarios* were standard practice in henequen haciendas by the turn of the 20th century, most archives only conserve *semanarios* from a handful of weeks. To study the role of learning and experience, wide-ranging data is needed. In turn, Itzincab's archive is one of the few hacienda collections covering a large stretch of time. The surviving Itzincab *semanarios* span from 1898—when it was acquired by the Cámaras—to 1921. Although some years in between are missing, the existing records still allow me to reconstruct a long-run history of the hacienda's operations.

The Itzincab archives also include other records. Besides the *semanarios*, a separate document dating from 1910 records the peasants' age and accumulated debts. There are also receipts from the hacienda store and records of payments made to outside workers, however these mostly professional services, such as doctor's appointments. Where possible, I complement this data with information from sources outside the hacienda, mainly state and local government reports.

5.2 Learning-by-doing and henequen rasping

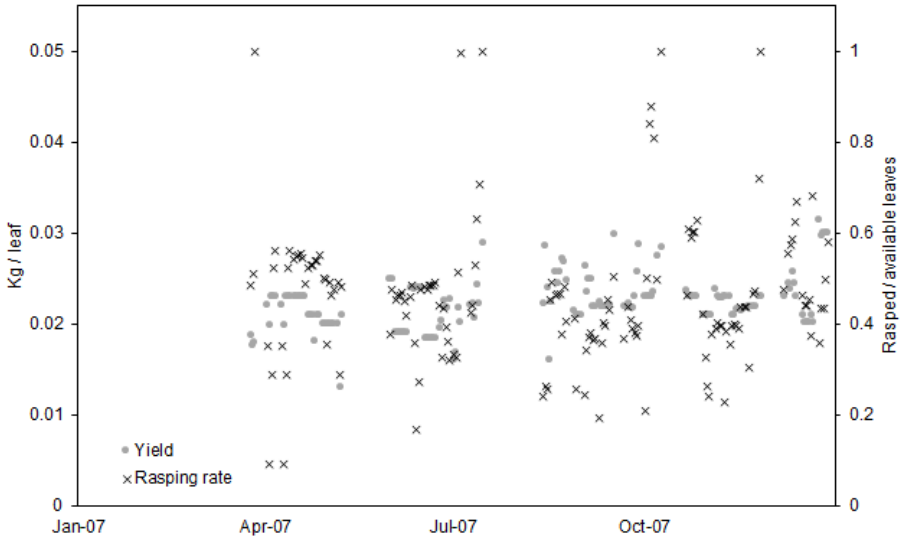
Workers in Itzincab performed a wide variety of tasks throughout the year. Besides the machine room duties described in section 3.2.2, laborers operated the rail carts, worked in the orchard, looked after goats, maintained the compelx's buildings, gathered wood for the steam engine, and planted and harvested henequen. The division of labor within the hacienda remained relatively stable: in a sample of 22 randomly selected weeks, workers on average perform their most common job in 63.02 percent of recorded entries.

Specialization was higher among machine-room workers, lending support to the hypothesis that working with the decorticating wheel commanded higher skill premiums than traditional agri-

cultural tasks. When a laborer's top task was in the machine room, they performed said job on average 74.43 percent of the time, versus 59.02 percent for field workers (p-value < 0.001, $N = 281$). Some caution is warranted when looking at these numbers, as this degree of specialization might only have been possible thanks to Itzincab's large workforce and thus not common practice across haciendas; in any case, greater division of labor could have been a further incentive for landlords to secure larger supplies of workers.

So far I have assumed that henequen rasping potentially benefited from learning-by-doing. To asses whether any returns to experience were realized inside the hacienda, I compile a series of Itzincab's daily output in the years 1905, 1907 and 1910, covering a five year span. I focus on the per-leave yield, that is, the kilos of fiber produced from each rasped leaf. Skilled operators should have been able to extract more pulp from any given leaf (Zamora Pérez 1999), making the most of the available raw materials. As an alternative measure I also consider the rasping rate/worker, the leaves rasped each day as a proportion of total cut leaves divided by the number of active laborers. However, not only is does this variable has a natural upper bound at 1, patterns in the data suggest that the daily rasping rate was set by factors other than the crews' skill levels.

Figure 4: Itzincab Cámara output, 1907



Source: Itzincab Cámara semanarios for January-December 1907.

I then compute the total experience of the crew working in the machine room for each day. Experience is measured in days, and an individual worker's experience increases by one every time

they are recorded as performing any machine room task. These include jobs registered under the "Machine" section in the *semanarios* except for *bagaceros*, who were tasked with waste disposal and so did not directly took part in the rasping process.

To test whether experience had any effect over the hacienda's output, I use the following linear model:

$$y_{mt} = \beta_0 + \beta_1 Rapsers_{mt} + \beta_2 Elevator_{mt} + \beta_3 Fogon_{mt} + \gamma_1 \sum_j \mathbb{I}[j]_{mt} \times Exp_{jmt} + \gamma_2 \left(\sum_j \mathbb{I}[j]_{mt} \times Exp_{jmt} \right)^2 + \theta_m + \varepsilon_{mt} \tag{11}$$

Where Exp_{jmt} is the experience of worker j at day t of the month m and $\mathbb{I}[j]_{mt}$ is and indicator variable that takes a value of 1 if worker j worked in the machine room at time mt. $Raspers_{mt}$, $Elevator_{mt}$ and $Fogon_{mt}$ each indicate the number of laborers using the rasping wheels, operating the platforms that carried leaves into the machine, and feeding fuel into the steam engine, respectively. I include a year-month fixed effects θ_m to control for medium-term factors that might have affected Idizncab's output, such as price movements or equipment upgrades, as well as a possible positive trend in output. Table 2 below reports the results. Newey-West standard errors are used to account for autocorrelation in the model residuals.

The model results show a positive and decreasing effect of experience on output. A laborer who had worked for a year at Itzincab would obtain an extra 2.03 grams of fiber from each rasped leave, compared to a worker with no previous experience. At the standard number of leaves rasped every day, that translantes to over 250 daily additional kilograms of fiber. So, the evidence from Itzincab Cámara indicates that *hacendados* had a tangible incentive to keep experienced peasants at their service. I now turn to the impact of this potential for learning-by-doing on labor arrangements inside the hacienda.

5.3 Labor arrangements in Itzincab

Peonage in Itzincab was a coercive institution: Peasants sometimes appear under "fugitive" in the *semanarios*, meaning they had left the hacienda without settling their obligations to the landlord—some of these escaped laborers reappear latter, going back into service after incurring a fine. As Mattiace and Nonnenmacher (2014) point out, employee turnover at Itzincab increased signifi-

Table 2: Effect of experience over output

	Dependent variable			
	Yield		Rasping rate / worker	
	(1)	(2)	(3)	(4)
Raspers	0.0162	0.0055		
	(0.3308)	(0.3350)		
Elevator	−0.2952	−0.2929		
	(0.3499)	(0.3478)		
Fogon	0.4062	0.3793		
	(0.4945)	(0.5017)		
Experience	0.0085*	0.0083*	0.0083*	0.0079*
	(0.0048)	(0.0048)	(0.0044)	(0.0233)
Experience^2	$-6.3658e^{-6}$*	$-6.2563e^{-6}$	$-3.6222e^{-6}$	$-3.4175e^{-6}$
	$(3.8662e^{-6})$	$(3.8721e^{-6})$	$(3.5024e^{-5})$	$(3.6027e^{-6})$
Weekday dummies	No	Yes	No	Yes
R^2	0.4580	0.4593	0.3019	0.3225
Obvs.	466	466	466	466
Note:				*p < 0.1, **p< 0.05, ***p< 0.01
Source:	Itzincab Cámara semanarios for January 1905–December 1910			

cantly following the abolition of debt peonage. Whatever other roles debts played in the relationship between peasants and *hacendados*, it legally tied workers to the hacienda. I examine how learning-by-doing shaped labor relations in Itzincab given their coercive nature, paying special attention to the dynamics implied by the model in Section 4.

An important feature of the model is the relation between tied labor demand L^T and the technology level z. However, a shortcoming of the available data is that we do not observe cases of within-hacienda variation in labor-substituting technology. A survey from 1879 states that Itzincab had one decorticating machine, with a 16 horsepower steam engine that powered five rasping wheels (Ortega Polanco 1879). There are no records of a major upgrade until the installation of an additional machine in 1918, four years after the abolition of debt peonage. While some tinkering inside the machine room in the intervening years surely took place, it is not obvious that any individual change would have had economically significant effects, and in any case these would not be readily quantifiable. That means data on a positive link between technology and the use of tied labor is limited to the corss-sectional analysis presented in Table 1, which, as mentioned before, is encouraging but superficial evidence.

Due to this limitation, I instead focus my analysis on the workers' compensation. *Semanarios*

kept detailed records of payments made out to laborers, which include not only wages but also loans.

As mentioned above, the key prediction of the model is that, in some cases, labor-substituting technological change can *increase* demand for tied labor. In the theoretical setup, this translates to both a higher quantity and higher compensation for tied workers; that is:

$$\underbrace{\alpha(w_1 + \delta w_2)}_{w^T\text{, no learning}} < \underbrace{\alpha(w_1 + \delta w_2 + \alpha\delta S_2 \varepsilon(z))}_{w^T\text{, learning possible}}$$

To test for this I estimate the relationship between the variable $Machine_{it}$, which indicates whether peon i performed a machine-room task on day t, and their corresponding compensation W_{it}. Bluntly, I am comparing machine-room workers to field workers, under the hypothesis that the reward to skill in the rasping process incentivized landlords to increase the compensation of this group of tied laborers, as predicted by the model, while the same was not true for the laborers that performed more rudimentary tasks. I am basing this analysis on the assumption that work in the field and other areas of the hacienda held a lower potential for learning-by-doing.

I measure worker compensation in both wages and the combination of wages and loans (I explain how I join these two variables later). Workers' debts were not exactly interchangeable with their salaries, as while they both served as payment for peasants' labor and incentives to enter into the tying arrangement in the first place, debts could also have a punitive character in the event a peasant considered leaving the *hacendado*'s estate. Loans thus may better capture the level of coercion in the hacienda. However, as the model makes no distinction between a wage and loans,[5] in my main specification I look at compensation as a whole to hue closer to the theoretical analysis. A separate estimation dealing solely with workers' debts can be found in Appendix B.2.

With that in mind, I test this hypothesis with a sample of 22 randomly selected entries from the *semanario*'s ranging from 1898–1918 which collect information on all active workers, their task and what they were paid. I then run the following unbalanced panel model with worker fixed

[5] In their theoretical treatments of coercive arrangements, both Acemoglu and Wolitzky (2011) and Naidu and Yuchtman (2013) let the landlord set separate a "compensation" and "punishment" for workers. While analytically useful, this requires the possibility of contract breach. Introducing this feature would complicate Bardhan (1983)'s beyond the scope of the present work.

effects:

$$W_{it} = \gamma_1 Price_t + \gamma_3 Output_t + \gamma_2 Year_t + \delta_1 Machine_{it} + \delta_2 Peonage_t + \delta_3 Peonage_t \times Price_t + \mu_i + \varepsilon_{it} \quad (12)$$

Table 3 reports the estimation results.

Along with the impact of learning-by-doing on tied labor demand, the regression in equation (12) also tests for other implications of the model. I start by looking at the relation between wages and price, which I take as a proxy for the expected value of output αy as it was largely outside the *hacendado*'s control. Both in Bardhan (1983) and in my model a higher expected output leads to higher tied-labor wages, as it raises the expected labor requirements $\alpha z y$.

Besides $Price_t$ I also include a measure of the daily output. As mentioned before, *semanarios* registered workers' performance at certain tasks (e.g., number of leaves cut, firewood collected), which was associated with higher wages. However, it is unlikely that wages were used as a tool to incentivize individual effort, as there is virtually no variation in within-day individual output. This suggests rather that a daily quota was set for all laborers, and higher wages served as compensation for longer hours. The variable $Year_t$ is meant to control for a linear trend that may be driving common variation in prices and wages, while $Peonage_t$ is a dummy corresponding to weeks when debt peonage was legal (that is, before September 1914).

As Table 3 shows, both working in the machine room and a higher value of potential henquen output—measured either through price or quantity—had a positive effect over daily compensation, in line with the model's predictions. With a rise in prices the *hacendados* had incentives to hire and retain more laborers in order to realize the higher potential earnings. Meanwhile, the observed premium to machine-room workers supports the learning-by-doing effect I have just discussed, but it may also be attributed to other factors: perhaps machine-room tasks were more strenuous or required longer hours. However, further tests described below provide evidence that the positive relation between machine tasks and compensation was, at least partly, due to the role of experience.

Results indicate that debt peonage depressed workers' wages; again, this is reflected in the model by the fact that (in the interior solution) the tied wage is always below the spot wage at $L^T = 0$. This result must be taken with caution, however, as under peonage peasants were also compensated through loans. To combine salaries and loans into a single measure of compensation,

Table 3: Determinants of workers' wages

	Dependent variable				
	Daily wage			Daily wage and loans	
	(1)	(2)	(3)	(4)	(5)
Machine	0.109^{***}	0.119^{***}	0.065^{**}	0.063^{**}	0.042^{**}
	(0.030)	(0.029)	(0.027)	(0.027)	(0.016)
Henequen Price	0.013^{***}	0.011^{***}	0.008^{***}	0.008^{***}	0.014^{***}
	(0.0004)	(0.0004)	(0.001)	(0.001)	(0.001)
Output	0.079^{***}	0.139^{***}	0.151^{***}	0.152^{***}	0.154^{***}
	(0.020)	(0.020)	(0.020)	(0.019)	(0.011)
Year		0.025^{***}	0.024^{***}	0.023^{***}	0.026^{***}
		(0.002)	(0.002)	(0.002)	(0.002)
Muchacho			-0.393^{***}	-0.408^{***}	-0.355^{***}
			(0.039)	(0.038)	(0.023)
Peonage			-0.236^{***}	-0.255^{***}	
			(0.082)	(0.082)	
Price × Peonage			-0.007^{***}	-0.006^{***}	
			(0.001)	(0.001)	
Experience					0.002^{***}
					(0.0005)
Experience^2					-3.831e^{-6**}
					(1.925e^{-6})
Worker FE	Yes	Yes	Yes	Yes	Yes
Obvs.	1,888	1,888	1,888	1,888	1,287
	$N = 271$	$N = 271$	$N = 271$	$N = 271$	$N = 216$
	$T = 1 - 18$	$T = 1 - 18$	$T = 1 - 18$	$T = 1 - 18$	$T = 1 - 12$
R^2	0.419	0.466	0.555	0.555	0.577
Adjusted R^2	0.320	0.376	0.479	0.478	0.489
Note:					*p<0.1; **p<0.05; ***p<0.01
Source:			Itzincab Cámara semanarios for January 1898–December 1918		

I add any registered loan to workers daily wage as if the amount had been granted daily over the course of a year, instead of a lump sum. A year is an arbitrary length of time, but the basic results of this exercise do not change much when considering longer terms. Model (4) in Table 3 confirms the negative effect of peonage over compensation. Without the possibility of peonage, the landlord cannot take advantage of the peasants' risk aversion to secure lower wages ex ante and must instead let the price of labor be determined by the market.

In model (5) I examine the effects of experience on compensation. I combine the machine-room experience data from the previous section with the wages and loans panel. As with output (see Table 2), experience had a positive and decreasing impact on worker compensation, in line with findings in more modern contexts (Lemieux 2006). This is evidence that, at least at Itzin-

cab, *hacendados* rewarded skilled workers. However, it also goes against the model's predictions, which assign no role for experience in determining the tied wage w^T.

This discrepancy might be explained by the fact that the model does not allow for breach of contract: once a peasant enters a tying agreement with the landlord they can not exit it even if the spot wage or their outside option at $t = 2$ might offer a higher payoff. As the *semanarios* show, workers in Itzincab did break their agreements, escaping from the hacienda. Back to the model, a tied laborer leaving at $t = 2$ would have been costlier to the landlord than at $t = 1$, as they would not only need to replace their labor in the spot market, they would also have a lower expected share of experienced workers. So if breach-of-contract were possible landlords might have an incentive to offer a better tied wage at $t = 2$, as a higher share of workers would choose to stay.

Despite the fact that it not adequately captured by the model, the observed effects of skill over compensation provide strong evidence for the effect I have discussed. It establishes a link between workers' experience with the new technology and labor arrangements. Experience with the decorticating machine translated not only into higher output but also higher loans and wages, suggesting that, at some level, landlords recognized that it was in their best interest to keep skilled laborers under their control.

6 Conclusions

A large literature has developed a conception of coercive labor arrangements as responses to the economic incentives generated by the environment and political institutions. This understanding implies in turn that labor institutions do not move linearly towards a free wage market, but instead evolve accordingly as said incentives shift. The boom of the henequen haciendas represents a dramatic example of this proposition.

This work offers an explanation as to why peonage expanded in Yucatán at the same time rapid mechanical innovation cut down labor requirements. I have shown theoretically how the possibility for learning-by-doing could generate contrary incentives for economic elites, pulling their demand for coerced labor in opposite directions in response to changes in technology. I then examined the impact of experience with the decorticating machine on production and labor at a particular hacienda through the lenses of the theoretical model. The empirical results confirm conclusions established in the literature on coercive institutions, such as their negative impact on wages. But I additionally find that working with the rasping machine commanded a wage premium over field work, and that skilled workers produced a greater output and received higher compensation, both through wages and loans. Thus, the evidence suggests that learning-by-doing played a role in the organization of hacienda labor, prompting landlords to invest on retaining experienced workers.

Learning-by-doing may not account for all the changes Yucatán went through during the henequen boom. Due to time limitations I have not been able to discuss alternative—though not mutually-exclusive—explanations in depth, but these are not without validity. For example, the shift in henequen supply, i.e., the invention of the decorticating wheel, coincided with important exogenous shocks to demand: the adoption of McCormick combine reapers in the US and the naval buildup preceding the First World War. A large enough increase in henequen demand could have resulted in an expansion of peonage even in the absence of a skill premium. At the same time, the response to the Caste War and the policies of the Liberal and subsequent Porfirian national governments towards indigenous populations eroded peasants' outside options and their bargaining power within the hacienda, meaning the political landscape was favorable to the proliferation of tying agreements. So not only did the benefits of coercion to the landlords increase, its costs may have fallen as well.

But even if the mechanism I have discussed in this thesis was not the only factor, or even the biggest factor, driving the growth of peonage in Yucatán, the results of this analysis point to a link between technology and labor arrangements that is yet to be sufficiently examined in the literature—both in economic history and in the history of the henequen episode. It thus opens the door to further work that can overcome the limitations of this study: A richer model able to distinguish between the extensive and intensive margins of coercion could better describe the relation between each of these and technology. Likewise, more comprehensive archival work could provide stronger empirical evidence of this relation beyond a single hacienda. More importantly, the analysis could be extended to other historical contexts, testing the relevancy of this phenomenon on a wider set of experiences of technological change and institutional environments.

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Appendix

A Model

A.1 Corner solutions

I briefly sketch out two possible corner solutions to the model. Particularly, when equilibrium tied labor demand is either $L^T = 0$ or $L^T = z/y$.

$L^T = z/y$ implies that the landlord fulfills all his labor needs through tied workers. So that there is no need to turn to the spot labor market even when output is $Y_t = y$. This will be optimal for the landlord when the marginal benefit of coercion is greater than the marginal cost ($(1+\delta)w^T$) for any $0 \leq L^T \leq z/y$. For this to be consistent in equilibrium, the landlord's choice must align with the peasants'. Since there is no demand for free labor, wages are $w_1 = w_2 = 0$, and the peasants choice to enter a tying contract is determined at the margin by

$$(1+\delta)u(w^T) = u(\hat{x}) + \delta \int_0^{\bar{x}} f(x_2)u(x_2)dx_2$$

We know the exact value of $\hat{x}$, as tied labor demand is $L^T = z/y$, so $\hat{x} = G(zy/N)$: this is equal to the value of the first-period wage in the interior solution. Then we can rewrite the previous condition as

$$(1+\delta)u(w^T) = u\left(G\left(\frac{zy}{N}\right)\right) + \delta U(\bar{x})$$

Of course for this contract to maximize the landlord's expected profits, the tied wage w^T must be smaller than $G(zy/N)$, otherwise they could simply turn to the spot market at a cheaper cost. That meas the condition above holds only when the expected utility from self-subsistence, $U(\bar{x})$, is small enough, either because self-subsistence payments are skewed toward low values, or because peasants are extremely risk averse. Notice there is no reason why the landlord would want to acquire any additional labor when $L^T = zy$: this would add a redundant laborer, and increase the tied wage for all workers in the process. Even in the scenario with returns to experience, said returns are determined not by the absolute number of skilled workers, but by their share of the total (S_t).

On the other hand, the landlord may wish to acquire labor only through the spot market when

the (strictly increasing) marginal cost of coerced labor is greater than its benefits for any $L^T \geq 0$. This can happen because even peasants that where assigned an outside option $x_1 = 0$ at the start of the first period must still be compensated for the potential loss of spot market wages and their self-subsistence option in the next period. Thus a simple way to examine this corner solution is to realize that it is equivalent to the situation where it is too expensive to tie the peasant with $x_1 = 0$. That implies that the tied wage w_0^T that satisfies

$$(1+\delta)u(w_0^T) = (1-\alpha)u(0) + \alpha u(w) + \delta\left[(1-\alpha)U(\bar{x}) + \alpha(F(w)u(w) + U(\bar{x}) - U(w))\right]$$

is such that $(1+\delta)w_0^T \geq \alpha(1+\delta)w$, which can be rewritten as

$$w_0^T \geq \alpha G\left(\frac{zy}{N}\right)$$

Whether this is the case depends, again, on the particulars of the peasants' outside options and utility functions

A.2 Computational solution parameters

The parameter sets $\{N, z, y, \bar{x}, \alpha, \delta, \theta\}$ used to calculate numerical solutions to the model where generated through a random process, with each parameter's distribution specified to avoid reaching an edge solution as described in the previous section. The next table reports the descriptive statistics for the generated parameters from a sample of 5,000 draws.

Table 4: Simulation Parameters, Whole Sample

	N	z	y	α	θ	δ	$\bar{x}$
Mean	0.652	38.451	0.085	0.779	1.632	0.471	0.074
Median	0.552	7.314	0.047	0.789	1.388	0.427	0.062
Minimum	0.005	1.640	0.001	0.502	0.003	0.121	0.001
Maximum	3.053	6,425.775	0.863	0.999	8.293	0.999	0.341
Std. Dev.	0.448	860.031	0.099	0.096	1.228	0.211	0.056
Obvs.							5,000

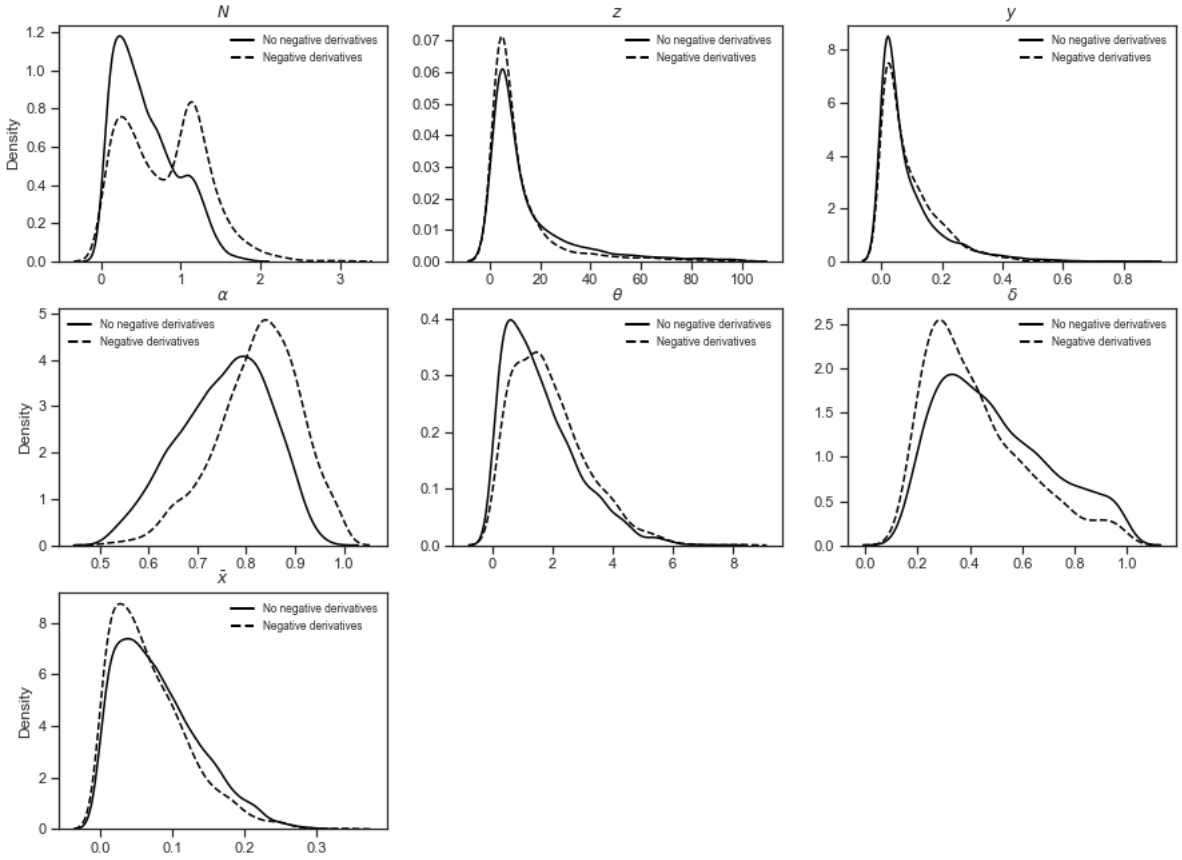
Source: Data generated by the author through computational simulation of the model, with the fundamental parameters picked at random (see Section 4.2). Results from 5,000 draws of the parameter set.

Table 5: Simulation Parameters, Negative $L_z^{T*}(\bar{\varepsilon})$

	N	z	y	α	θ	δ	$\bar{x}$
Mean	0.816	21.735	0.089	0.825	1.830	0.423	0.068
Median	0.832	6.392	0.057	0.832	1.619	0.378	0.055
Minimum	0.007	1.640	0.001	0.508	0.009	0.121	0.001
Maximum	3.053	2,970.791	0.652	0.999	8.293	0.998	0.341
Std. Dev.	0.514	114.216	0.091	0.085	1.232	0.194	0.053
Obvs.							1,700

Source: Data generated by the author through computational simulation of the model, with the fundamental parameters picked at random (see Section 4.2). Results from 5,000 draws of the parameter set.

Figure 5: Parameter distribution



Note: Kernel density function estimates for the computation parameters. Solid lines show cases in which the derivative of L^{T*} with respect to z were always positive (n = 3300) while in the dashed lines cases the derivative was negative for at least some values of $\bar{\varepsilon}$ (n = 1700).
Source: Data generated by the author through computational simulation of the model, with the fundamental parameters picked at random (see Section 4.2). Results from 5,000 draws of the parameter set.

B Case study

B.1 Model specification tests

To asses the best panel model for the data, I run Hausman specification tests. The tests were run on the models that include loans on the dependent variable, both with and without workers experience—corresponding to models (4) and (5) in Table 3. The results of these tests, reported in Table below, were then applied to the rest of the models to allow for proper comparison. In both cases fixed effects are preferred over random effects, indicating that some variables in the regression are correlated to the unobserved individual effect.

Table 6: Hausman specification tests

	Models	
	Without experience	With experience
Chi^2	74.91^{***}	61.78^{***}
Degrees of freedom	7	9
Note:		*p<0.1; **p<0.05; ***p<0.01
Source:	Itzincab Cámara semanarios for January 1898–December 1918.	

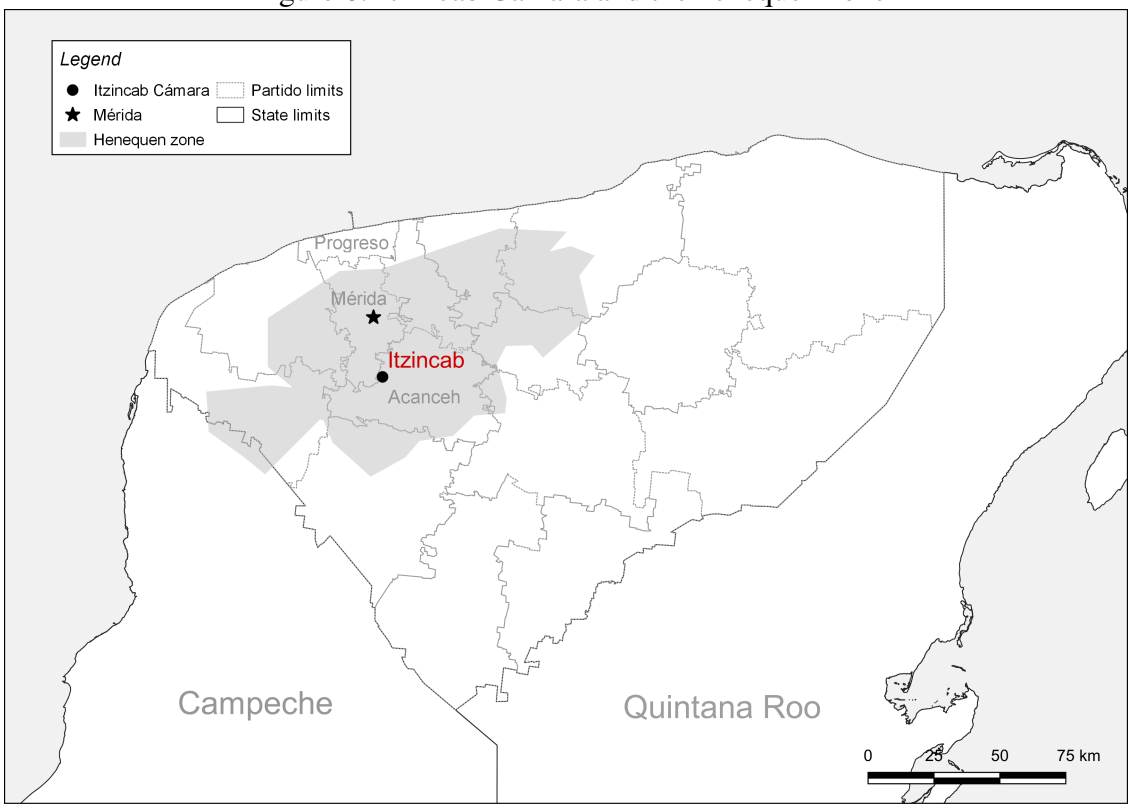
B.2 Loan determinants

As an alternative to my preferred empirical test, I also estimate the relation between machine-room work and labor demand using only debts, rather than a combination of wages and loans, as a measure of compensation. Since, unlike with wages, it is not clear that there should be a link between the timing of the loans and the tasks performed on any single day or week, I take a cross-section approach, instead of the panel I use for the main specification.

Data for debts comes from Itzincab's 1910 *carta cuenta*. This document registers workers' outstanding debts to the hacienda. As the explanatory variable of interest, I redefine $Machine_i$ to a dummy variable, which takes a value of 1 if peasant i performed a machine-room task at any point before or during 1910. I perform a standard OLS regression with robust standard errors, the results of which are reported in Table 7.

The control variables Age_i and $Muchacho_i$ account for the likely possibility that older workers had accrued larger debts by 1910, and that this relation between age and debt was not linear, as

Figure 6: Itzincab Cámara and the henequen zone



Source: Author's own elaboration with geographical data from SIEGY (2015). Partido borders are approximated from current municipalities based on Wells and Joseph (1996).

underage peasants could not legally receive loans form the *hacendados*. Note that in model (1), while the point estimate for the coefficient of $Machine_i$ is positive and large, it is not statistically significant; however, the variable $Experience_i$, defined much as in section 5.3, has a positive and significant effect. This suggests there was an effort to exert a tighter grip on those peasants that knew how to use the new rasping technologies—by increasing the debt they would need to repay before leaving Itzincab—, even if the variable $Machine_i$ is too crude to adequately capture it.

Table 7: Determinants of workers' debts

	Outstanding debt in 1910	
	(1)	(2)
Machine	25.173	−37.810
	(25.436)	(31.920)
Age	0.514	0.644
	(0.709)	(0.629)
Muchacho	−14.410	−12.327
	(18.115)	(17.419)
Experience		0.744***
		(0.207)
Intercept	107.417***	102.160***
	(28.115)	(25.080)
R^2	0.044	0.171
Adjusted R^2	−0.006	0.111
Obvs.	61	61

Note: *p< 0.1, **p< 0.05, ***p< 0.01

Source: Itzincab Cámara semanarios and 1910 carta cuenta