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Abstract

This dissertation studies three topics in 19^{th} and early 20^{th} century economic history. Chapter 1 studies the causes behind low inter-regional migration from the American North to the South prior to the Civil War. Chapters 2 and 3 focus on topics in the economic history of Egyptian agriculture. Chapter 2 studies the role of transportation infrastructure in agricultural and industrial mechanization in Egypt. Chapter 3 studies the effects of cash crops on living standards in developing countries, using the expansion of cotton cultivation in the Nile Valley following the construction of the Aswan Dam in 1902 as a natural experiment. Finally, Chapter 4 concludes this dissertation and places the chapters on Egyptian economic history in a unified historical context.

The Southern labor market was isolated from the rest of the U.S. during the antebellum period, and few migrants from the North moved there. One popular explanation is that would-be migrants were deterred by characteristics of the South such as slavery, lower wages, and weaker infrastructure. A second is that average temperatures, rainfall, and daylight hours changed more rapidly as migrants moved north or south rather than east or west, imposing additional costs on migrants seeking to preserve environment-specific human capital. In Chapter 1, I evaluate these explanations by developing a discrete-choice model of migration in which agents have preferences over destinations and face moving costs for each destination based on where they are moving from. I estimate this model on a sample of men linked between the 1850 and 1860 U.S. censuses, using the set of U.S. counties as potential

destinations. I find that moving costs are insufficient for explaining low migration from the North to nearby parts of the South, such as Border-South states, Virginia, and the Carolinas. If migrants hadn't viewed these areas as unattractive destinations, we should have observed more migration from nearby areas of the North than did, in fact, occur. I find the opposite pattern for states along the Southwest frontier like Mississippi, Texas, and Louisiana. These states were desirable destinations, even compared to states on the Northern frontier, but migrants faced high costs in moving to them.

In the rest of this dissertation, I turn to topics in Egyptian economic history. Colonial-era investments in transportation infrastructure lowered shipping costs within developing countries, especially to and from major ports. This reduced the price of steam engines and other modern technologies at the point of use, but lower shipping costs also increased competition between imports and domestic products. In Chapter 2, I estimate the effect of lower internal shipping costs on steam-power adoption in Egyptian agriculture and manufacturing using the straight-line distance to Egypt's main port, Alexandria, as an instrument. I find that cheaper transportation within Egypt caused export-oriented cotton farmers to adopt steam power, but I find no change in steam power use for local manufacturers, who produced for local markets and competed with foreign products. Transportation infrastructure built during the Age of Empire disproportionately encouraged technology adoption in primary goods sectors, reinforcing international patterns of specialization.

The construction of the Aswan Dam in 1902 lowered the cost of irrigating long-staple cotton during its summer growing season, causing cotton production in Upper Egypt to triple in just a few years. This cost decrease was localized in perennially irrigated land; most of Upper Egypt still relied on flood basin irrigation and did not grow cotton. In Chapter 3, I use difference-in-differences to estimate the effect of this sudden decrease in the cost of growing cotton on township-level population characteristics collected from the 1897 - 1947 Egyptian censuses, using within-district variation in irrigation technologies to identify the causal effect. I show that the lower cost of cotton cultivation in perennially irrigated townships caused literacy to increase more quickly in subsequent decades relative to townships that did not benefit, yielding 6 and 2.6 percentage point increases for men and women, respectively, in 1947. Using evidence from sex ratios, age distributions, and rates of male and female widowhood, I also find that the reduction in the cost of growing cotton disproportionately decreased female mortality and may have increased male mortality. I argue that this was due to a combination of women gaining a higher proportion of household resources, as a result of their relatively higher productivity in cotton agriculture, and increased male exposure to water-borne illnesses in perennially irrigated land.

Finally, in Chapter 4, I consider the legacy of British colonialism in Egypt and place Chapters 2 and 3 in a unified historical context. I argue that the main difference between the British colonial regime and its predecessor regimes in Egypt was its ability to successfully implement large-scale infrastructure projects, like the repair of the Delta Barrage and the construction of the Aswan Dam. Because cotton was produced by most Egyptian farmers and not restricted to a single geographic area, these infrastructure projects tended to benefit the country as a whole.

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Table of Contents

List of Tables

List of Figures

CHAPTER 1

Causes of Low North-South Migration Before the Civil War

1.1. Introduction

Interstate mobility was higher in the decades leading up to the Civil War than in any subsequent period of American history.[1] However, despite the high mobility of labor overall, there was little migration between Northern free states and Southern slave states during the antebellum period.[2] In 1860, for example, only around 5 percent of whites living in slave states were born in the North.[3] Contemporaries and some modern historians have pointed to slavery as the culprit behind low inter-regional migration between the North and South.[4] Many Northerners blamed slavery for causing political disenfranchisement and for lowering the earnings of free labor.[5] Others simply did not want to live near blacks.[6] Politically motivated lynchings of white new-comers to the South may also have deterred some would-be migrants.[7] Conversely, other historians have stressed human capital preservation as the primary driver behind the general east-west pattern of internal migration observed during the

[1]Interstate mobility is measured as the proportion of the total U.S. population residing in a different state than their state of birth. See Rosenbloom and Sundstrom (2003).
[2]Wright (2006). Throughout this chapter I refer to free states as the North and slave states as the South for convenience. Thus, Missouri, Kentucky, Maryland, and Delaware are all part of the South, for the purposes of this chapter, despite not joining the Confederacy.
[3]Ruggles (2019)
[4]Fleming (1905), Freehling (1991), Dippel (2005)
[5]The belief that slavery diminished the value of labor and lowered the earnings of free worker was part of the Republican party's ideology in the antebellum period, see Foner (1995). Although the belief that slavery lowered wages was common, some modern research has challenged this viewpoint. For example, Field (1988) shows that free and slave labor were complementary inputs on large plantations.
[6]For example, Logan and Parman (2017) document substantial residential housing segregation in the North during the 19^{th} century.
[7]Freehling (1991)

early and middle 19^{th} century. Climate, seasons, and daylight hours changed more quickly as migrants moved north or south as opposed to east or west. Therefore, deviating from lines of latitude imposed additional moving costs on migrants because familiar farming techniques and homemaking methods were less useful in disparate climates.[8] Both explanations have the potential for explaining the lack of North-South migration during the antebellum period, but prior research has been unable to separate these viewpoints.

The goal of this chapter is to evaluate, empirically, whether low migration from the North to the South before the Civil War was due to Northern aversion to characteristics of the South or whether low migration was primarily caused by disproportionately high moving costs. I test these competing hypotheses using a model of locational choice in which migrants have preferences over destinations and migrants face moving costs that are a function of the destination and their place of origin. Destination preferences are modeled using fixed effects that represent economic variables, like wages and land prices, and amenities or non-market factors, like demographics and culture. The model is estimated at the county-to-county level, and destination-specific fixed effects are estimated for each destination county. I define moving costs as permanent relocation costs that are orthogonal to the economic and non-market characteristics of the migrant's destination. I model these moving costs as a function of the distance traveled east-west and north-south, whether the destination county is in the migrant's home state, the presence of out-of-state networks in a destination, and agricultural similarity between the destination and origin counties. By comparing migrants' preferences over destinations in the South to the costs they face in moving to those destinations, this structural model allows me to test which of the above hypotheses better explain low North-South migration. High migration costs and indifference between destinations in

[8] Hulbert (1930), Owsley (1945), Steckel (1983), Walsh (2005)

the North and the South support the viewpoint that high moving costs explain low North-South migration. Dislike of Southern destinations, regardless of moving costs, support the viewpoint that characteristics of the South deterred inter-regional migration. Of course, both explanations may be important and complementary, and there may be heterogeneity across Southern regions.

I estimate this model on a sample of men matched between the 1850 and 1860 U.S. Censuses. I focus on men because most women changed their last name upon marriage, making it difficult to match women across censuses. I assume that the destination choice set for migrants is all non-Western U.S. counties with available data. I exclude California and the sparsely settled West because data quality is poorer for the West, except for those areas which were rapidly settled in a short period of time – for example, counties that were a part of the California Gold Rush (1848 - 1855).[9] I make the necessary assumptions over unobserved taste shocks to assure that the model is multinomial logit, and I estimate the model by numerical maximum likelihood. Past researchers have found that large locational choice models are difficult to estimate when researchers wish to control for unobserved choice-specific characteristics, such as the destination-county fixed effects estimated in this essay.[10] I solved this problem by writing custom gradient and Hessian functions using sparse matrices and feeding them into the Knitro optimization program. Using this method, I can estimate multinomial logit models of migration with thousands of fixed effects quickly.

Model estimates support the hypothesis that migrants found it more costly to move north or south rather than east or west, controlling for county-level destination-specific fixed effects and other moving costs. These results hold across a range of demographic and

[9]See data appendix for estimates from models that include Western counties with available data.
[10]Arzaghi and Rupasingha (2013), Rupasingha, Liu, and Partridge (2015)

occupational categories, and they support the hypothesis, advanced by Steckel (1983), that the disproportionate costs of switching latitudes are the reason behind the general east-west migration patterns observed during the early and middle 19^{th} century. However, I find that this hypothesis is insufficient for explaining the lack of North-South inter-regional migration before the Civil War. To show this formally, I estimate an additional model that only incorporates moving costs and does not include fixed effects. I find that this model over-predicts migration to the South Atlantic and East South Central regions from the Mid-Atlantic and East North Central regions. If only moving costs mattered, this exercise tells us that we should have observed more migration to parts of the South that were near to the North than did, in fact, occur. Estimated fixed effects for the "Old South" states of Maryland, Virginia, and the Carolinas, as well as for the Appalachian states of Kentucky and Tennessee, are systematically lower than for other parts of the country, providing evidence that Northern migrants found these areas to be unattractive after controlling for moving costs. Conversely, I do not find this same pattern holding for the heavily enslaved cotton and sugar cane producing areas of Alabama, Mississippi, Louisiana, and Texas. Migrants tended to evaluate these regions more positively than other areas of the South, but they were deterred from moving there by high costs. This heterogeneity suggests that simple explanations of low North-South migration focusing on the mere presence of slavery are insufficient. I give some possible explanations for this observed heterogeneity across Southern regions below.

Economic historians have shown that early to mid-19th century American migrants tended to follow east-west lines of settlement,[11] preferred destinations with similar agricultural characteristics,[12] moved to regions with higher real wages,[13] and tended to move to destinations with better opportunities for wealth accumulation and upward mobility.[14] This chapter contributes to this literature by demonstrating that migrants faced higher costs of moving north or south after controlling for destination characteristics, but it also underlines the importance of "pull" factors emphasized in prior research for determining patterns of migration. This chapter also speaks to reasons behind the isolation of the Southern labor market during the antebellum period by demonstrating that most areas of Southern Appalachia and the Old South were viewed as unattractive destinations by potential migrants from the North.[15] Those parts of the South that were viewed as attractive destinations, like Louisiana, Texas, and some parts of Mississippi and Alabama, were geographically remote to most Northerners. The fact that these destinations were also some of the most heavily enslaved areas of the South provides indirect evidence of the complementarity of free and slave labor during the antebellum period.

This chapter builds on the methodology of recent papers that study contemporary internal migration and locational choice in the United States and other developed countries.[16] Moving costs within a country, as measured by geographic distances, are generally viewed to be low in a modern context, so the focus of the locational choice literature is on the economic and non-market factors that draw migrants to some areas rather than others. In contrast to

[11]Steckel (1983, 1989)
[12]Schaefer (1989)
[13]Margo (1999)
[14]Schaefer (1987), Ferrie (1997), Stewart (2006), Salisbury (2014)
[15]Wright (1986)
[16]Davies, Greenwood, and Li (2001), Faggian and Royuela (2010), Wozniak (2010), Biagi, Faggian, and McCann (2011), Arzaghi and Rupasingha (2013)

these papers, I abstract from destination-specific characteristics like wages, housing availability, demographics, and so on by using destination-specific fixed effects rather than including separate variables for a finite list of features. Therefore, my approach is similar to models used for demand estimation that incorporate product-specific fixed effects but in which different consumers face different prices or transaction costs for each product.[17] In my framework, counties play the same role as products and moving costs play the role of prices. The advantage of my approach is to control for all possible economic variables and non-market factors at the destination level, but as a consequence, I am unable to state quantitatively what it is about specific destinations that attracted or repelled internal migrants. Additionally, my model does not permit me to perform counterfactuals based on changes in specific characteristics of particular destinations.

Migration decisions made by individuals during the antebellum period impacted national politics. Poor labor market integration between the North and the South in the decades leading up to the Civil War exacerbated regional tensions, and it may have played a causal role in the decision of Southern extremists to secede from the Union.[18] Migrants brought their political preferences with them, and they were more likely to support candidates in their new home that reflected the beliefs and values of their old one.[19] Had migration from the North to the South been higher in the antebellum period, more Southerners would have had economic and personal interests for staying in the Union. Although historical what-ifs are always tentative, it's possible that a truly national labor market might have cooled the heels of the Fire-eaters.

[17] Train (2009)
[18] Egnal (2004)
[19] Steckel (1998)

In the following section, I discuss the methodology used to construct the linked sample used in this chapter, and I compare the sample to the population of men observed in the 1850 U.S. Census. I then describe regional migration patterns observed in the linked sample and demonstrate that migration to the South was lower than to other regions. I show that there is a discontinuity in in-migration at the North-South border for migrants from the North who had moved 100 miles or more, suggesting that a simple model of moving costs is insufficient for explaining low North-South migration. Next, I formally describe the multinomial logit model used in this chapter, and I show that estimating destination-specific fixed effects precludes the inclusion of variables in the model that are linear functions of destination and origin county characteristics, such as differences in wages. Thus, it is not possible to, for example, control for destination-specific characteristics and estimate the effect of wage differences between destination and origin counties in commonly used discrete choice models of migration. After that, I discuss model estimates and compare the performance of my model to alternative models with only moving costs and only destination-specific fixed effects. I map the geographic distribution of fixed effects and draw conclusions based on regional trends. Finally, I end by discussing some implications of this exercise for understanding inter-regional migration patterns in the antebellum period.

1.2. Data Summary

The population of interest in this chapter consists of men who were both living in the North and who were at least 15 years old in 1850. Joseph P. Ferrie provided the sample of $633,231$ men drawn from this population that is used for the analyses. This sample was created by attempting to match all men meeting these characteristics in the digitized 1850 U.S. Census with their records in the 1860 Census using an auditory representation of their last name, known as a Soundex, their first initial, birth year, and place of birth. Individuals with no unique match were discarded. Given a total population of 4, 123, 414 men with these characteristics in the 1850 U.S. Census, the match rate is around 15.4 percent.

Table 1.1. Comparison of Linked Sample and Population

	Sample		Population			
	Mean	SD	Mean	SD	Difference	t
New England	0.30	(0.46)	0.22	(0.41)	-0.08***	(-132.76)
Mid Atlantic	0.37	(0.48)	0.45	(0.50)	0.08***	(114.76)
East North Central	0.32	(0.47)	0.32	(0.47)	0.00***	(7.19)
West North Central	0.01	(0.11)	0.01	(0.12)	0.00***	(8.11)
Age	34.96	(14.38)	33.66	(14.89)	-1.30***	(-66.77)
Literate	0.97	(0.17)	0.79	(0.41)	-0.19***	(-642.22)
Farm Worker	0.47	(0.50)	0.48	(0.50)	0.01***	(19.09)
Has Real Estate	0.44	(0.50)	0.31	(0.46)	-0.12***	(-182.77)
Non-white	0.01	(0.12)	0.01	(0.12)	-0.00	(-0.36)
Foreign Born	0.11	(0.32)	0.21	(0.41)	0.10***	(228.80)
Number of Individuals	633,241		4,123,414		4,756,655	

Source: Ferrie (2016), Ruggles (2019)

Note: Table shows summary statistics for the linked sample used in this chapter and the population the sample is drawn from. The population is all men who lived in the North and were 15 or over in 1850. New England, Mid Atlantic, East North Central, and West North Central are dummy variables equal to 1 if the individual was living in that region in 1850.

Table 3.2 compares the linked sample with the full population from the 1850 Census. In general, the sample is statistically different than the population it is drawn from, but in many cases, this difference is relatively small. We see that the sample has a larger proportion of men from New England than the population and a smaller proportion from the Mid-Atlantic region. For both Midwestern regions, the difference between the linked sample and the population is statistically significant, but smaller than two decimal places. The sample skews older than the population and is much more literate: 97 percent of the linked sample is literate compared with only 79 percent of the population. Men in the linked sample are more likely to own real estate in 1850 and are less likely to be foreign born. Taken together, these differences suggest that men in the linked sample are likelier to be more affluent than the male adult population of Northern states, taken as a whole. These differences between the sample and the population imply that care must be taken in extrapolating from sample estimates to the population. However, given the size of the linked sample, the estimates reported in this chapter reflect the migration choices of a large and important slice of the relevant male population. To address some of the differences between the population and the sample, I split the sample along salient demographic and occupational categories when estimating the models below. In general, I find that results are robust to focusing on specific migrant subcategories, such as native-born whites, foreign born, farmers, and non-farmers.

In the following analysis, I restrict my attention to migrants, defined as men who changed counties of residence between 1850 and 1860. Because I only observe the sample in these two years, I cannot tell if someone moved somewhere and then returned to their county of origin during this period. Although these temporary movers are important as an economic phenomenon, they are less relevant for studying the long-term migration patterns that are the focus of this chapter.

Table 1.2 shows regional migration patterns observed in the sample. The first panel shows the probability that migrants from each region listed in the left-hand column chose to relocate to the region listed in the row header. Men who did not change their county of residence during this decade are excluded from this analysis. This table shows, for example, that approximately 65 percent of migrants who were living in New England in 1850 moved to some other county in New England as of 1860. Overall, migrants were more likely to move within their own region than to move to some other region, with the exception of men living

Table 1.2. Regional Migration Patterns Observed in Linked Sample

	Destination							
	North				South			
Origin	NE	MA	ENC	WNC	SA	ESC	WSC	West
Panel A: Regional Choice Probabilities Conditional on Migrating								
NE	**64.63**	11	13.38	4.92	.99	.64	.98	3.48
MA	5.07	**53.57**	27.52	5.59	3.11	1.11	2	2.03
ENC	1.95	10.05	**59.27**	14.85	2.33	2.66	5.99	2.9
WNC	1.46	6.77	20.14	**41.77**	2.18	1.95	12.49	13.24
Panel B: Migrants per Square Mile of Farmland								
NE	**58.86**	5	4.46	29.76	.18	.18	.56	14.96
MA	7.66	**40.4**	15.21	56.14	.92	.53	1.89	14.43
ENC	2.87	7.38	**31.91**	145.1	.67	1.23	5.51	20.15
WNC	.1	.23	.5	**18.84**	.03	.04	.53	4.24

Source: ISCSR (2005), Ferrie (2016), Ruggles (2019)

Note: Panel A of this table shows the probability that a migrant moves to a region from his region of origin, conditional on changing his county of residence between 1850 and 1860. Panel B shows the number of migrants from each origin region divided by the total square miles of farmland in that region. Farmland is defined as the number of improved and unimproved acres of farmland recorded in the 1850 county-level U.S. Census.

in the West North Central. Conditional on leaving their home region, migrants were more likely to move to regions further west: New Englanders tended to move to the Mid-Atlantic or East North Central Regions, and so on. Movement to the South was limited. Of all regions, men from the East North Central region were most likely to move to the South, although they preferred states along the Southwest frontier rather than states in the Old South or Southern Appalachia.

The second panel of Table 1.2 divides the number of migrants in each origin-destination region pair by the square miles of total farmland in the destination region. Total farmland is defined as land listed as improved or unimproved farmland in the county schedules of the 1850 U.S. census. For example, we see that there were approximately 5 migrants from New England per square mile of farmland in the Mid-Atlantic region, but there were only .18 migrants from New England per square mile of farmland for the South Atlantic region. Overall, Panel B tends to confirm the general patterns shown in Panel A, although Panel B also shows that more migrants tended to move to the West North Central region relative to the total amount of farmland there than for other regions.

1.3. Reduced Form Evidence of Aversion to the South

Figure 1.1 shows the boundary between free and slave states. Counties near to this boundary were similar in geography, climate, and soil, but differed in their economic and social structure. A strong version of the moving cost hypothesis predicts that in-migration from the North to the South will be lower the further one is from the North, but it does not predict a discontinuity at the border. Therefore, one test of a systematic aversion to the South for Northern migrants is to test if in-migration to counties located on the Southern side of this border is discontinuously lower than on the Northern side. I run this test using a regression discontinuity design in which the running variable is the number of miles the county centroid lies away from the Southern side of the North-South border. I restrict my attention to "long-distance migrants", defined as individuals who have moved 100 miles or more. The purpose of this restriction is to concentrate on migrants who've already incurred substantial moving costs and for whom the marginal cost of moving an additional short distance is presumably lower than for those who moved to nearby or adjacent counties.

Figure 1.1. Location of North-South Border

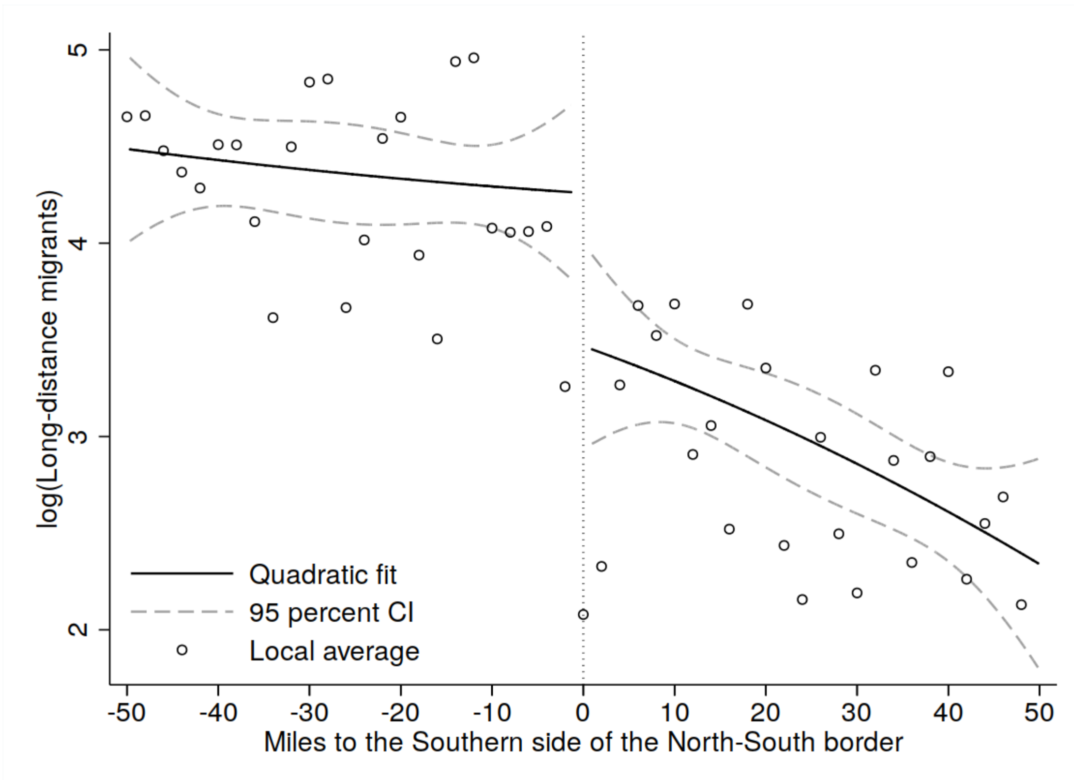
Source: Manson et al. (2019)

Note: This figure shows the border between Northern free states and Southern slave states.

Figure 1.2 plots the natural logarithm of the number of long-distance migrants against the number of miles the county centroid is located away from the Southern side of the North-South border. This variable takes a negative value if the county is located on the Northern side of the border and a positive value if the county is located on the Southern side. Distances between county centroids and the border are measured by the shortest straight-line distance. I've restricted this analysis to counties located within 50 miles of the North-South border. Separate quadratic polynomials are fitted for counties to the North and South of the border. This figure shows that in-migration tends to be lower the further one is to the Southern side of the border, as predicted by the moving-cost hypothesis, but I also find strong evidence of a discontinuity at the border itself. The t-statistic for testing a discontinuity at the border is

−2.23, which leads to the rejection of the null hypothesis of no discontinuity at a 5 percent confidence level.

Figure 1.2. Long-Distance In-Migration to Counties Located within 50 Miles of the North-South Border



Source: Ferrie (2016); Manson (2019); Ruggles (2019)

Note: Figure shows the natural logarithm of the number of long-distance migrants to each county located within 50 miles of the North-South border plotted against the distance that the county centroid is from the Southern side of the North-South border. This variable takes on negative values for Northern counties and positive values for Southern counties. Separate quadratic polynomials are fitted for counties on the Northern and Southern side of the border. Circles indicate local averages of the y-axis variable. 95 percent confidence intervals are depicted by the dashed grey lines.

Although the results of this exercise suggest that Northern migrants were averse to relocating to counties in slave states, the approach has some limitations that motivate the structural model of migration developed in the next section. Firstly, this analysis does not compare the relative impact of different moving costs, such as moving out of state, moving east or west, or moving north or south. Secondly, it may be the case that Southern counties far from the border were, on average, actually viewed as attractive destinations to potential migrants after controlling for moving costs, but the reduced-form analysis presented in this section is not able to detect that possibility.

1.4. Discrete-Choice Model of Migration

I model an agent's decision of where to migrate as the outcome of utility maximization over a discrete set of destination-county choices. I decompose utility into two components. The first component is a destination-specific fixed effect: all agents have the same preferences over destinations and receive the same utility for moving to a given county regardless of where they are from. The second component of utility, which I call moving costs, varies at the origin-destination county level. Agents from different origin counties face different costs in relocating to the same county: for example, an agent from Vermont and another from Ohio face different costs in moving to Kentucky. In keeping with recent literature on internal migration in the United States, I estimate models that consist only of migrants.[20] This approach implicitly assumes that agents decide to move before they decide where to move to. In the attached appendix, I include models in which the decision to migrate and the destination-choice decision are made simultaneously. Coefficient estimates for moving costs are similar across both approaches. However, including non-movers and movers in the same model tends to inflate the value of estimated fixed effects for Northern counties because most people do not move.

[20] Arzaghi and Rupasingha (2013), Rupasingha et al. (2015), and Collins and Wanamaker (2015) are examples of papers which restrict their sample to only migrants when estimating locational choice models. On the other hand, Davies et al. (2001) includes both migrants and non-migrants in a non-nested model.

Suppose we observe I agents who changed their county of residence between 1850 and 1860. Suppose that these I agents are from a set of T origin counties and choose among J possible destination counties. To be completely general, the county of residence in 1850 may be included in the set of possible destinations. The utility agent i living in county t in 1850 receives from moving to county j in 1860 is

$$U_{ij} = \beta X_{tj} + \gamma_j + \epsilon_{ij} \tag{1.1}$$

where X_{tj} are components of utility that depend on the characteristics of destination and origin counties, γ_j is a destination-specific fixed effect, and ϵ_{ij} is an unobserved random utility shock. Thus, βX_{tj} represents the component of migrant utility that is derived from moving costs, and γ_j represents preferences over destinations.

Let $y_{ij} = 1$ if individual i chooses to move to county j and $y_{ij} = 0$ otherwise. Then $y_{ij} = 1$ if and only if $U_{ij} > U_{ij'}$ for all $j' \neq j$. For purposes of tractability, I assume that the unobserved shock ϵ_{ij} is independently and identically distributed according to a Type 1 Extreme Value distribution. It follows that

$$\mathrm{P}(y_{ij} = 1 | X_{t1}, ..., X_{tJ}) = \frac{\exp(\beta X_{tj} + \gamma_j)}{\sum_{k=1}^{J} \exp(\beta X_{tk} + \gamma_k)} \tag{1.2}$$

This expression is the functional form of conditional choice probabilities for a multinomial logit model. Parameters β and $\gamma_1, ..., \gamma_j$ can be estimated by maximum likelihood.[21]

A number of effects of interest are unidentified in this model. The effect of individual-specific or county-of-origin characteristics that do not vary over destination choices are unidentified. This is because individuals compare destinations based on the difference in

[21] See Cameron and Trivedi (2005) for an overview of the multinomial logit model used here.

utilities between potential choices, so adding or subtracting a constant will not affect their decision. Likewise, the effect of characteristics that are specific to destinations and don't vary between individuals are also unidentified due to the presence of destination-specific fixed effects. For example, the effect of the average wage for unskilled laborers at a potential destination is unidentified.

In addition, there is another important class of variables whose corresponding coefficients are unidentified: variables that are comprised of linear combinations of destination and origin county characteristics. This class of variables include commonly used measures of economic differences, such as differences in average wages or housing prices. Due to the properties of logarithms, this class of variables also includes log ratios. The intuition behind this result is that when individuals compare potential destinations based on linear combinations of origin and destination characteristics, the components that are specific to the origin county cancel out. Therefore linear combinations of destination and origin county characteristics are collinear with the destination fixed effects and, as a result, are unidentified. This result follows from linear utility and does not depend on the distributional assumptions applied to ϵ_{ij}. I prove this result formally below.

Theorem. *Suppose the utility agent i from origin t receives from migrating to destination j can be written as*

$$U_{ij} = \beta X_{tj} + \gamma_j + \alpha\omega_{tj} + \epsilon_{ij} \tag{1.3}$$

Agents move to the destination that gives them the most utility. If ω_{tj} is a linear combination of destination and origin characteristics, then α is unidentified.

Proof. Let ω_{tj} be some linear combination of destination and origin characteristics and let X_{ij} contain all other variables of interest. Because ω_{tj} is a linear combination of destination and origin characteristics, ν_t and μ_j, we can write $\omega_{tj} = \sigma_1 \nu_t + \sigma_2 \mu_j$ for all combination of origins t and destinations j where σ_1 and σ_2 are some constants.

$$\begin{aligned} P(y_{ij} = 1 | X_{t1}, ...X_{tj}, \gamma_1, ..., \gamma_j, \omega_{t1}, ..., \omega_{tj}) = P(U_{ij} > U_{ij'} \quad \forall j \neq j') = \\ P(\beta X_{tj} + \gamma_j + \alpha\omega_{tj} + \epsilon_{ij} > \beta X_{tj'} + \gamma_{j'} + \alpha\omega_{tj'} + \epsilon_{ij'}, \quad \forall j \neq j') = \\ P\big(\epsilon_{ij} - \epsilon_{ij'} > \beta(X_{tj'} - X_{tj}) + \gamma_{j'} - \gamma_j + \alpha(\omega_{tj'} - \omega_{tj}), \quad \forall j \neq j'\big) = \\ P\big(\epsilon_{ij} - \epsilon_{ij'} > \beta(X_{tj'} - X_{tj}) + \gamma_{j'} - \gamma_j + \alpha\sigma_2(\mu_{j'} - \mu_j), \quad \forall j \neq j'\big) \end{aligned} \tag{1.4}$$

The first equality follows by utility maximization, and the second by definition. Consider any $\tilde{\alpha} \neq \alpha$. Let $\tilde{\gamma}_j = \gamma_j - (\tilde{\alpha} - \alpha)\sigma_2\mu_j$. By adding and subtracting $\tilde{\alpha}\sigma_2(\mu_{j'} - \mu_j)$ it follows that the above is equal to

$$P\big(\epsilon_{ij} - \epsilon_{ij'} > \beta(X_{tj'} - X_{tj}) + \tilde{\gamma}_{j'} - \tilde{\gamma}_j + \tilde{\alpha}\sigma_2(\mu_{j'} - \mu_j), \quad \forall j \neq j'\big) \tag{1.5}$$

Therefore α is unidentified. $\square$

It may be the case that one is still interested in the effects of variables which are linear combinations of origin and destination county characteristics. These effects may be identified using stronger assumptions about destination-county fixed effects. For example, one could partition the set of destination counties into N sets, where $N < T$, and assume that $\gamma_j = \gamma_j'$ if both county j and j' are in the same set. Alternatively, if one has access to a panel then it is possible to estimate the effects of linear combinations of destination and origin county variables while controlling for destination-specific fixed effects, assuming that the county-level variables in question change over time. However, because there is only one decade in which it is possible to match individuals using U.S. Census data prior to the Civil War, it would not be appropriate to use panel data for my intended application.

I estimate this model using numerical maximum likelihood. Multinomial logit models with large numbers of individuals and choices can be difficult to estimate. Therefore, I adopt an estimation strategy proposed by Guimaraes, Figueirdo, and Woodward (2003) which exploits the equivalence, up to a constant, of the log-likelihood function of the multinomial logit model described above and a Poisson model with county-of-origin fixed effects. These county-of-origin fixed effects have no economic meaning because they are unidentified in the multinomial logit model used in this chapter. However, they must be estimated for the log-likelihood functions of the multinomial logit and the Poisson model to be equivalent.

Despite gaining additional speed and tractability from using the equivalence of the Poisson log-likelihood function, standard numerical maximum likelihood algorithms for the Poisson model, such as that included in Stata, have difficulty converging to the correct maximum when the model includes a large number of fixed effects. Other researchers have also identified this problem, and as a result, they have foregone including destination-specific fixed effects for each destination. Instead, these researchers have estimated state-level fixed effects or fixed effects based on some other level of aggregation.[22] I have solved this problem by writing efficient functions in MATLAB that calculate the gradient vector and Hessian matrix of the Poisson log-likelihood function quickly by using the sparse matrix datatype. In conjunction with the Knitro optimization program, I am able to estimate multinomial logit models with large numbers of fixed effects quickly and accurately. The coefficients and

[22]Davies, Greenwood, and Li (2001), Arzaghi and Rupasingha (2015)

standard errors derived using these gradient and Hessian functions are equal to Stata output on test models, but the run-time is shorter, permitting the estimation of thousands of fixed effects in less than a minute.

Table 1.3. Variable Definition

Variable	Source	Definition
Distance E-W	Manson (2019)	Distance east or west between county centroids in 100s of miles
Distance E-W^2		
Distance N-S		Distance north or south between county centroids in 100s of miles
Distance N-S^2		
Own State		= 1 if destination is in state of origin
Out-of-State Network	Ruggles (2019)	= 1 if 10% of those born out-of-state in destination county are from migrant's home state
Δ Ag. Commodity Mix	Haines (2018)	Described in text

Note: This table shows the definition and source of variables used in multinomial logit estimation.

I use several variables to measure the costs of moving between counties; these variables are listed and described in Table 1.3. I decompose distance into two parts: distance measured north-south and distance measured east-west. I include quadratic terms for both to capture the possibility of decreasing or increasing marginal costs of increasing distance. In addition to distance variables, I include a measure of whether a destination county is in an individual's home state. States varied in their laws, institutions, and culture, so migrants faced additional costs in leaving their home state. For counties out-of-state, I include a dummy variable equal to one if ten percent of the out-of-state population is from the agent's home state.

Prior research has shown that migrants during the antebellum period tended to move to areas that they had information about, and this information was often provided by friends or relatives.[23] This interpretation of the variable is based on network effects in migration. However, in practice, I am unable to differentiate between network effects and the possibility that people from the same state merely tended to have similar tastes.

Internal migrants during the antebellum period tended to move to destinations similar to their place of origin.[24] To measure the similarity of origin and destination counties, I constructed an index that quantifies differences in agricultural commodity production between origin and destination counties.[25] Suppose there are D agricultural commodities listed in the 1850 U.S. Census of Agriculture. These commodities include crops like wheat, cotton, and sweet potatoes as well as other commodities derived from agricultural products like wine and hay. Let $share_{dj}$ indicate the percentage share of total commodity output measured in dollars belonging to agricultural commodity d in destination county j. Then, the agricultural commodity dissimilarity index between destination county j and origin county t is

$$\Delta\text{Ag. Commodity Mix}_{tj} = \sqrt{\sum_{d=1}^{D}(share_{dj} - share_{dt})^2} \tag{1.6}$$

Low values of this index indicate high similarity between origin and destination counties in their mix of agricultural commodities, whereas high values indicate larger differences.

[23]Atack (1987)
[24]Atack (1987), Schaefer (1989), Gray (1996)
[25]This index is constructed using the same methodology as the industrial composition dissimilarity indices in Arzaghi and Rupasingha (2013).

Although distance traveled is likely to be correlated with dissimilarity in agricultural commodity production, this variable allows direct measurement of this concept.

1.5. Results

In this section, I report and analyze the results of estimating the multinomial logit model developed in the previous section. One important characteristic of this model is that all migrants are treated as having identical preferences. They differ only in their realizations of idiosyncratic taste shocks (ϵ_{ij}). This assumption is typical in the migration literature,[26] and it has the shortcoming of not allowing for agent heterogeneity within the model. Consequently, I estimate separate models for agents belonging to different demographic and occupational groups. In particular, I estimate separate models for whites and non-whites, foreign-born whites and native-born whites, and white farmers and non-farmers. I separate non-whites from other demographic and occupational categories because the vast majority of non-whites living in the North in 1850 were free blacks, who faced legal obstacles in migrating to certain states. Therefore, it would be inappropriate to group them with whites who faced no such difficulties.[27] The models estimated in this section exclude non-migrants. In the attached data appendix I consider a model in which agents decide to migrate and decide where to migrate to at the same time.

In the tables shown below, I report moving cost coefficient estimates directly instead of marginal effects. Consider the probability that a person from county t moves to some other county j. Not only will changing the characteristics of county t and county j affect

[26]Davies, Greenwood, and Li (2001), Wozniak (2010), Arzaghi and Rupasingha (2013), Rupasingha, Liu, and Partridge (2015)

[27]Free blacks faced legal restrictions that limited their ability to migrate to certain state in the antebellum period, such as being forced to pay a fee or prove their ability to support themselves. These restrictions were not limited to the South; many Northern states also placed limits on free black migration. See Berwanger (1967).

the probability of moving to county j, but so will changing the characteristics of some other county j' in the migrant's choice set. As a result, it's not feasible to report marginal effects for a multinomial logit model in a convenient and general manner. Model coefficients are informative in a number of ways. Coefficient estimates indicate the sign of the own-county marginal effect: the effect that a change in the value of a variable for a destination-origin county pair has on the probability of someone from that origin moving to that destination. Probabilities sum to one, so a positive own-county marginal effect implies a negative marginal effect for other counties. Additionally, the relative magnitude of different variables of interest within the same model can be discerned by comparing coefficients directly.

Table 1.4. Multinomial Logit Coefficient Estimates for Whites and Nonwhites

	Whites (1)		Whites (2)		Non-whites (3)		Non-whites (4)	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Distance E-W	-0.382	(0.004)	-0.377	(0.003)	-0.595	(0.029)	-0.594	(0.026)
Distance E-W^2	0.029	(0.000)	0.031	(0.000)	0.038	(0.003)	0.040	(0.003)
Distance N-S	-0.910	(0.006)	-1.136	(0.005)	-0.918	(0.046)	-1.118	(0.039)
Distance N-S^2	0.065	(0.001)	0.080	(0.001)	0.076	(0.011)	0.078	(0.006)
Own State	1.430	(0.008)	1.433	(0.007)	1.369	(0.060)	1.206	(0.053)
Out-of-State Network	0.907	(0.008)	0.706	(0.007)	0.692	(0.068)	0.382	(0.053)
Δ Ag. Commodity Mix	-0.024	(0.000)	-0.024	(0.000)	-0.026	(0.002)	-0.018	(0.002)
Destination FE	✓				✓			
Origin Counties	592		592		391		391	
Destination Counties	1548		1548		1548		1548	
Number of People	193035		193035		3339		3339	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for whites and nonwhites. Variable definitions are described in Table 1.3.

Table 1.4 shows model estimates for whites and non-whites. Standard errors for the coefficients are shown in parentheses in adjacent columns. The second and fourth columns show the results of estimating the same models without destination-specific fixed effects. All coefficient estimates are highly significant. Across all models, whether or not destination-specific fixed effects are controlled for, we see that migrants systematically faced higher costs in moving north or south from their place of origin rather than east or west. The sign of the quadratic terms indicates that the marginal cost of travel decreased as one migrated further away. By comparing the first and second models and the third and fourth models, we see that the difference between the marginal disutility of traveling north or south compared with east or west is biased upward in the model without destination-specific fixed effects. This bias is consistent with destinations that tend to be located to the north or to the south being systematically viewed as unattractive by migrants.

Coefficient estimates indicate that both whites and non-whites preferred to stay within their home state. If they moved to other states, they preferred to move to counties in which a large percentage of the out-of-state population was born in their home state. Finally, we see that migrants preferred destination counties that produced agricultural commodities in similar shares to their origin county. This result is consistent with results presented by Schaefer (1989), who found that migrants from the Cotton South tended to move to destinations with similar soil composition and average temperatures.

Table 1.5 shows coefficient estimates for native-born whites, foreign-born whites, white farmers, and white non-farmers. All models include destination-specific fixed effects. Coefficient estimates for the foreign born are smaller than for the native-born, implying that the foreign born were more influenced by destination-specific characteristics. Having already moved once in leaving their home country, foreign-born migrants were probably less sensitive to the additional cost of relocating again. Estimates for the own-state effect and the effect of having an out-of-state network are positive and significant for the foreign born, but are

Table 1.5. Multinomial Logit Coefficient Estimates for Foreign Born, Native Born, Farmers, and Non-farmers

	Native Born (1)		Foreign Born (2)		Farmers (3)		Non-farmers (4)	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Distance E-W	-0.450	(0.004)	-0.241	(0.008)	-0.401	(0.006)	-0.391	(0.005)
Distance E-W^2	0.032	(0.000)	0.019	(0.001)	0.033	(0.001)	0.030	(0.000)
Distance N-S	-1.105	(0.007)	-0.381	(0.012)	-1.050	(0.010)	-0.824	(0.007)
Distance N-S^2	0.078	(0.002)	0.021	(0.002)	0.069	(0.002)	0.059	(0.002)
Own State	1.571	(0.009)	0.594	(0.017)	1.413	(0.013)	1.428	(0.009)
Out-of-State Network	1.034	(0.009)	0.375	(0.018)	1.005	(0.013)	0.857	(0.010)
Δ Ag. Commodity Mix	-0.025	(0.000)	-0.010	(0.001)	-0.027	(0.000)	-0.022	(0.000)
Destination FE	✓		✓		✓		✓	
Origin Counties	592		582		590		590	
Destination Counties	1548		1548		1548		1548	
Number of People	157353		35682		71178		121857	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for native-born whites, foreign-born whites, white farmers, and white non-farmers. Variable definitions are described in Table 1.3.

lower in magnitude than for natives. This is consistent with the foreign born tending to have less of an attachment to their state of residence in 1850.

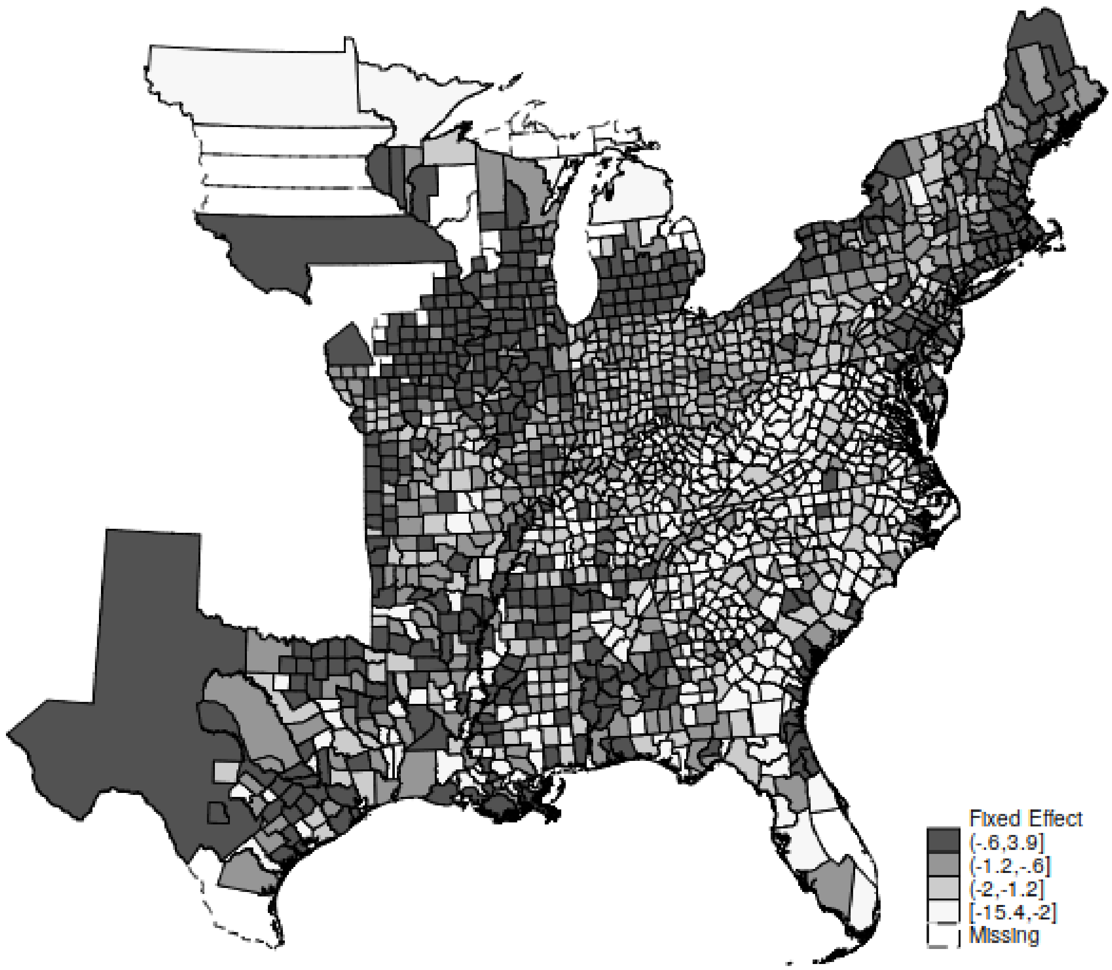
As expected, farmers faced a higher cost of moving north-south relative to non-farmers, but the coefficient estimate on distance moved north-south is still significantly larger than the distance moved east-west for non-farmers. Although farmers faced a higher cost of switching latitudes, because seeds and livestock they were familiar with performed worse in different climates, non-farmers would also have possessed some latitude-specific human capital in the form of acclimatization and knowledge of homemaking techniques.[28] It's also possible that men who were non-farmers in 1850 changed occupations within the decade after moving.[29]

[28]Steckel (1983)

[29]Ferrie (1996), for example, shows that immigrants from foreign counties in the antebellum period frequently changed occupations after arriving in the United States.

This may explain why the coefficient on the change in the agricultural commodity mix index is negative and significant for non-farmers, and almost the same magnitude as for farmers.

Figure 1.3. Geographic Distribution of Fixed Effects for Native-Born Whites



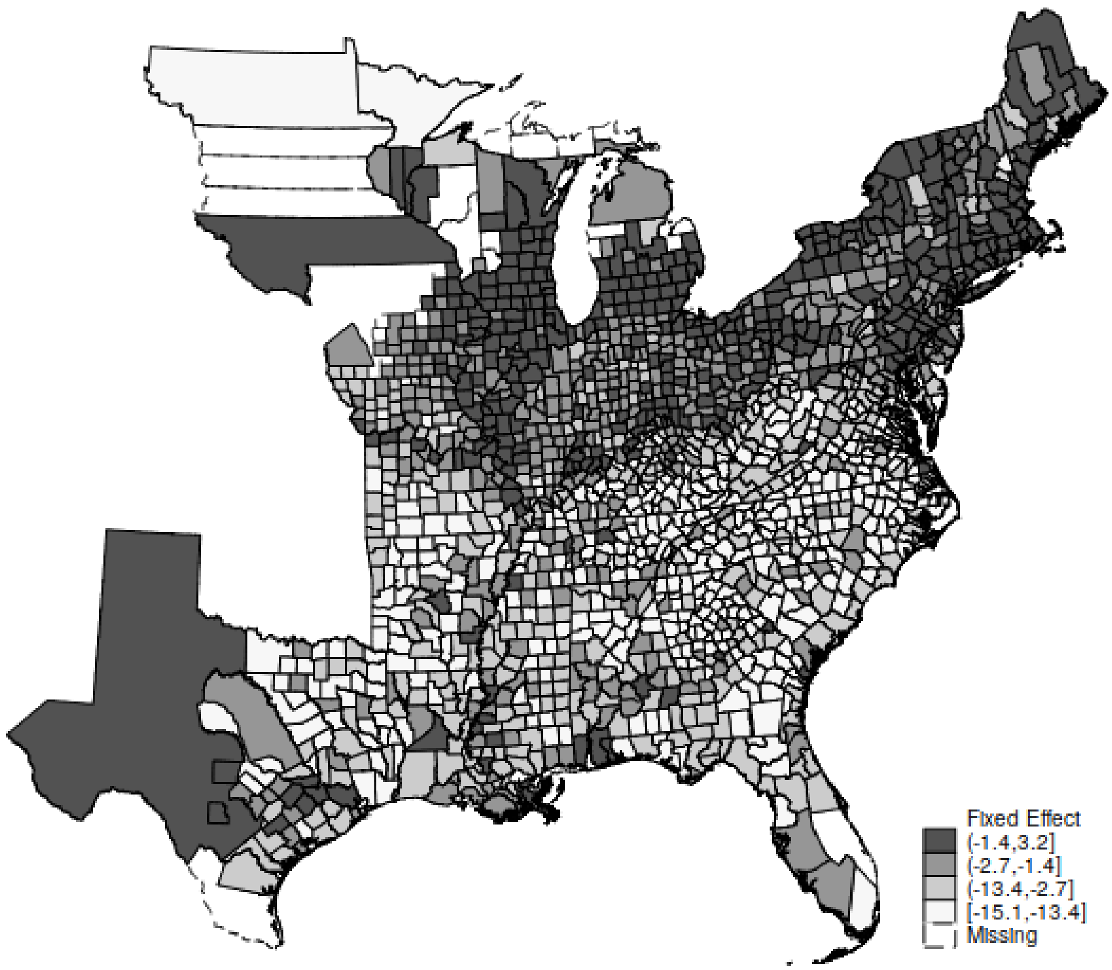
Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: This figure shows estimated destination-specific fixed effects for each destination county. Counties depicted in white are missing data and were not included in the choice set of the estimated model.

Figures 1.3 and 1.4 show maps of fixed effect estimates for native-born whites and foreign-born whites respectively. Taking the model literally, fixed effects represent the attractiveness of destination counties to migrants, after controlling for moving costs. A less literal interpretation is to view fixed effects as a measure of how much a model with moving costs alone over-predicts or under-predicts migration to a particular county. More positive fixed effects imply more migrants moved to a destination county than can be accounted for by moving costs and unobserved taste shocks, and vice versa. Counties with larger and more positive fixed effects are depicted in dark gray and were considered more attractive destinations by migrants. Conversely, counties that are depicted in light gray have more negative fixed effects and were viewed as less attractive destinations. Looking first at the fixed effect estimates for native-born whites, it is clear that there are geographic patterns in the distribution of fixed effects. Large urban centers, New England, the Upper Midwest, and the many parts of the Southwest were viewed as favorable destinations. The Old South and Southern Appalachia were viewed as the least attractive destinations. This pattern does not hold for foreign-born whites, who viewed destinations in the South negatively, with the exception of eastern Missouri, Maryland, and major cities.

The geographic distributions of estimated fixed effects strongly suggest that explanations of low North-South migration that focus entirely on moving costs are likely to be inadequate. It's clear that foreign-born whites were averse to moving to the South. However, there is a significant amount of heterogeneity across Southern regions for native-born whites. In particular, many counties along the Southern Frontier or in the black-belt regions of Mississippi and Alabama were viewed as positive destinations. The fact that migration to these regions was low, despite their attractiveness to migrants, suggests that high movement costs were an effective deterrent. This raises the question of what sort of "pull factors" drew migrants to the Southern Frontier and the Deep South, but deterred them from moving to the Old South states of Virginia and the Carolinas, as well as Southern Appalachia.

Figure 1.4. Geographic Distribution of Fixed Effects for Foreign-Born Whites



Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: This figure shows estimated destination-specific fixed effects for each destination county. Counties depicted in white are missing data and were not included in the choice set of the estimated model.

Although my methodology does not permit me to say, with certainty, what aspects of the Southwest frontier and the deep South attracted migrants in the antebellum period, there are several possibilities that are worth highlighting. Compared to the rest of the South, wages were higher in the West South Central region than in other areas of the South, as were skill premiums, defined as the gap between wages for skilled and unskilled labor.[30] Prior research has shown that migrants preferred to move to locations with higher wages and a better potential for higher earnings conditional on skill-upgrading.[31] Higher wages may have been, in part, due to the complementarity of free labor with the highly productive slave-gang system used on large plantations that specialized in cotton, sugar, and other cash crops. White skilled workers had many opportunities for employment on a plantation, for example as overseers or carpenters.[32] Finally, slave states closer to the frontier tended to support political egalitarianism for whites, but states in the Old South tended to embrace hierarchy both within and across races. In practice, this led to political disenfranchisement and compelled poor whites to defer to the wishes of powerful plantation owners.[33] Some thinkers in the Old South, like Virginian proslavery sociologist George Fitzhugh, went further still, and even questioned the purpose of the color line in determining who was a slave and who wasn't.[34]

The evidence presented above suggests that any explanation of migration patterns in the antebellum period needs to incorporate both the costs of moving and the fact that some areas of the U.S. were viewed as more attractive destinations because of the their economic and non-market characteristics. In Table 1.6, I compare the performance of the model presented above with the actual migration patterns observed in the linked sample for all white migrants. I also show the performance of a model that only includes moving costs with no destination-specific fixed effects as well as a model with only destination-specific fixed effects. I report

[30] ICPSR (2005)
[31] Margo (1990); Salisbury (2014)
[32] Field (1988); See Fogel and Engerman (1974) for the economics of the gang system used on larger plantations.
[33] Freehling (1991)
[34] Fitzhugh (1860)

Table 1.6. Actual and Predicted Regional Choice Probabilities for White Migrants

			Model		
Origin	Destination	Sample	Full	Only Moving Costs	Only FE
New England	New England	66.2	60.0	50.0	17.1
	Mid-Atlantic	13.5	19.3	22.6	29.8
	East North Central	14.7	11.9	14.9	38.7
	West North Central	3.4	6.3	7.4	9.4
	South Atlantic	1.1	0.8	3.1	2.5
	East South Central	0.8	0.6	1.0	1.8
	West South Central	0.4	1.0	1.0	0.8
Mid-Atlantic	New England	5.6	8.8	6.3	17.6
	Mid-Atlantic	55.9	56.0	54.4	29.3
	East North Central	28.5	24.1	23.4	38.7
	West North Central	5.1	6.6	5.8	9.4
	South Atlantic	3.1	3.2	8.4	2.5
	East South Central	1.2	0.8	1.3	1.8
	West South Central	0.6	0.6	0.4	0.8
East North Central	New England	2.2	2.3	1.6	17.5
	Mid-Atlantic	11.5	8.2	6.9	29.7
	East North Central	63.8	70.2	68.3	38.4
	West North Central	15.7	12.1	8.0	9.3
	South Atlantic	2.5	2.7	9.3	2.5
	East South Central	3.0	3.6	5.6	1.8
	West South Central	1.1	0.8	0.5	0.8

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: This table evaluates model performance by comparing actual regional choice probabilities for white migrants with regional choice probabilities predicted by each of three models: the full model with moving costs and destination-specific fixed effects, a model with only moving costs, and a model with only destination-specific fixed effects. This table shows, for example, that 66.2 percent of white men in the sample from New England who migrated during the 1850's moved to another county in New England. The full model predicts 60 percent of white men would move to another county within New England, the model with only moving costs predicts 50 percent, and the model with only fixed effects predicts 17.1 percent.

the regional choice probabilities for three regions of origin: New England, Mid-Atlantic, and the East North Central. I focus on regional choice probabilities conditional on the region of origin rather than unconditional probabilities because the multinomial logit model imposes the condition that predicted probabilities equal the sample average probabilities for each choice.[35]

The model with only destination-specific fixed effects performs the worst across most regions because it implicitly makes the unreasonable assumption that migrants can relocate costlessly. The model with only moving costs performs much better, but it is less accurate than the model with both moving costs and fixed effects. In particular, the model with only moving costs tends to over-predict migration to the South Atlantic and East South Central from nearby Northern regions. Thus, if only moving costs mattered, we should expect to see more migration from New England and the Mid-Atlantic region to the South Atlantic than did, in fact occur, and likewise from the East North Central to the East South Central. Although the full model does not accurately reproduce the sample probabilities in every case, it tends to perform well for most regions. For example, New Englanders were much more likely to stay within their region than the full model predicts. A more complicated model that incorporated agent heterogeneity might have fixed some of these discrepancies, but it probably would have done so at the cost of model tractability.

1.6. Conclusion

This chapter measured the role of moving costs and destination-specific characteristics in determining migration patterns during the antebellum period. Multinomial logit estimates reported here bear out the viewpoints of prior researchers that both moving costs and "pull" factors mattered. In particular, I find robust evidence for disproportionately higher costs of moving north or south rather than east or west. However, despite having a high amount of

[35]Cameron and Trivedi (2005)

explanatory power, moving costs are unable to account for Northern aversion to many areas of the South before the Civil War.

Low North-South migration was caused by a combination of high moving costs to desirable locations along the Southwest Frontier and an avoidance of relatively accessible states in Southern Appalachia and the Old South. Border-South politicians in the antebellum period who blamed slavery for the South's inability to attract free labor, like James Birney and Cassius Clay, were most likely incorrect.[36] Although it's possible that the very negative fixed effects estimated in states like Virginia and the Carolinas were connected with slavery as practiced in those areas, other highly enslaved areas of the South have more positive fixed effects that are comparable with Northern industrial centers and the Midwest frontier.

[36] Clay (1848), Freehling (1991)

CHAPTER 2

Effects of Foreign Infrastructure Investment on Steam-Power Adoption in Colonial Egypt

2.1. Introduction

Colonial powers and European investors revolutionized the transportation infrastructure of developing countries during the 19^{th} and early 20^{th} centuries. This infrastructure was built to facilitate trade with Europe and other parts of the developed world, rather than with neighboring countries.[1] Railroads and other transportation infrastructure built during this period have received scholarly attention in recent years, but the effect of this infrastructure on technology adoption is not well understood.[2] Cheaper transportation decreased the prices of foreign inputs, like fuel and machinery, and it increased revenue net of export costs for exporters. Therefore, economic theory predicts that firms in colonized nations and developing countries that produced raw commodities for export would have responded to lower transportation costs by adopting new technology. Conversely, by lowering the cost of bringing goods from the dock to consumers, transportation improvements also increased competition between domestic and foreign producers, forcing domestic firms to cut production or reduce prices. As a result, it's possible that colonial-era transportation infrastructure could have had no net effect on, or even delayed, technology adoption in some sectors.

[1]This point was made by Headrick (1988). Recently, Bonfatti and Poelhekke (2017) show this for colonial railroads built in mineral-rich African countries.
[2]Recent papers on colonial-era railroads include Andrabi and Kuehlwein (2010), Jedwab, Kerby and Moradi (2015), and Donaldson (2018).

Internal shipping costs within countries are a large part of trade costs between countries, especially in the developing world.[3] Although high trade costs may impede technology adoption in poor countries, the historical record shows that modernizing transportation infrastructure does not always go hand-in-hand with a greater use of modern technology. Africa's investments in transportation infrastructure during the 1960's and 70's were intended to increase commodity exports and, in turn, allow firms to import modern physical capital like tractors and machinery. Although commodity exports increased as a result of these investments, firms did not embrace more technologically sophisticated production processes.[4] This failure, and others like it, led to pessimism regarding the value of transportation infrastructure for development. Recently, there has been renewed international interest in large infrastructure projects. Since 2013, for example, China has spent billions of dollars developing transportation infrastructure in Central Asia as part of its Belt and Road Initiative. This new infrastructure is expected to lower trade costs by up to 10 percent in some areas.[5] Likewise, in 2017, the World Bank lent 14 percent of its funds to projects in the transportation sector, with Africa as the largest beneficiary.[6] Understanding transportation infrastructure's ability to promote technology adoption is an important historical question, but it's also essential for evaluating the impact of current and future development projects.

In this chapter, I study the effect of internal shipping costs on steam-power adoption in Egyptian cotton farming and local manufacturing during the first decade of the 20^{th} century. The Egyptian economy was heavily specialized in the production and export of long-staple cotton during this period, and as a result, it is an ideal case study. Cotton was grown almost

[3] Anderson and Wincoop (2004)
[4] Mold (2012)
[5] de Soyres, Mulabdic, Murray, Rocha, and Ruta (2019)
[6] World Bank (2017)

everywhere in the Nile Delta, and Egyptian cotton farmers produced almost exclusively for export.[7] Egypt had no other important exporting industries outside of major cities, like Cairo and Alexandria, but many towns contained local manufacturers that produced primarily for local markets.[8] Statistics collected by the British colonial administration in Egypt show that both cotton farmers and local manufacturers mechanized production by purchasing steam engines imported from abroad.[9] As in other colonies, Egypt's rail infrastructure was built to increase market integration with Europe. Although Egypt had as many miles of railroad track per person and per inhabited area as some European countries, Egypt's only external rail connection was with the Sudan, another British colony.[10]

The effect of cheaper shipping from the interior of Egypt to European markets can be decomposed into two parts. First, cheaper shipping reduced the price of foreign inputs like coal and machinery. Egypt had no known coal reserves in the early 20^{th} century, and alternative fuel sources, like timber, were rare. Consequently, the cost of shipping goods to and from Alexandria was the main determinant of price variation in fuel and imported machinery at the point of use. Shipping costs within Egypt accounted for, on average, one quarter of the price of coal in the Eastern Delta, the part of Egypt covered by the dataset used in this chapter.[11] Theory predicts that firms would have substituted away from local means of power generation, primarily animal and human labor, and used more foreign technology, holding output constant.

The second effect of shipping costs on steam-power adoption was through final good prices. The predicted direction of this effect depends on whether a firm produced for export

[7] *Annuaire Statistique*
[8] Owen (1993)
[9] Boinet (1902)
[10] Issawi (1961)
[11] See appendix for details.

or local markets. Cotton farmers either shipped cotton to Alexandria and sold to exporters themselves, or they sold directly to wholesalers, who bought from the farm and resold the cotton to exporters. Cheaper shipping raised cotton revenue net of export costs either directly or indirectly, by increasing the prices that wholesalers were willing to pay.[12] This encouraged an increase in production, leading some farmers to adopt steam-powered agricultural machinery to take advantage of economies of scale. In contrast, cheaper shipping put downward pressure on the price of goods sold in local markets that were close substitutes for imports. Two of the most commonly mechanized industries in Egypt were flour mills and textiles. Locally manufactured textiles were typically produced from imported low quality short-staple cotton yarn and scraps.[13] The small scale of manufacturers outside of major cities suggests that they produced for surrounding villages and did not ship long distances. Corn flour, wheat flour, and textiles were also some of Egypt's largest imports at the time.[14] Because cheaper shipping reduced the prices consumers paid for foreign substitutes for local products, the impact of lower shipping costs on technology adoption among local manufacturers is uncertain.

To estimate the impact of colonial transportation infrastructure on steam-power adoption, I regress steam power in each township and industry on the cost of shipping goods to and from Alexandria. Townships were the smallest unit of Egyptian governance and had populations ranging from a couple hundred to a couple thousand.[15] Alexandria was Egypt's main port and handled almost all of its European trade. For the sake of brevity, I use the phrase "shipping costs" to refer to the cost of shipping one ton of bulk freight between each

[12]Roux (1908)
[13]Owen (1993)
[14]*Annuaire Statistique*
[15]*Nahiya*, the Arabic word I translate as township, can also mean village. Because Egyptian townships often contained multiple villages, in addition to surrounding estates, I've used a less confusing word.

township and Alexandria. I do not observe shipping costs directly. Instead, I constructed shipping costs using the methodology of Donaldson and Hornbeck (2016), who calculated the cost of shipping freight between each US county. I first built a cost network of standard-gauge state railways, narrow-gauge agricultural railways, and navigable waterways using digitized period maps. I assumed that shippers incurred a transshipment fee when transferring goods between transportation modes and different gauge railways. Rates for each of the various transportation modes were taken from historical sources; more details are provided below. I then calculated the cost of shipping one ton of bulk freight along the cheapest route between each township and Alexandria using an optimal combination of transportation modes.

I measure steam power use in agriculture by the number of irrigation pumps in a township and in manufacturing using a binary variable equal to one if a township had a manufacturer that used steam power. Irrigation pumps were the most common means of mechanizing agriculture in Egypt during the late 19^{th} and early 20^{th} century.[16] Cotton grew during the summer when the Nile was lowest, so water had to be lifted from the bottom of deep canals. Pumps substituted for animal and, to a much lesser extent, man-powered irrigation devices. I use a binary variable for steam-power adoption in manufacturing because my data source indicates power sources but does not list the number of steam engines used in each industry. In manufacturing, steam engines substituted for wind, animal, and human-generated power.[17] Unlike other coal-poor countries, the Nile did not generate enough force for water power to be viable in manufacturing.[18]

[16]Owen (1993)

[17]Boinet (1902)

[18]Foaden and Fletcher (1908). Like Egypt, Italy lacked coal reserves. However, it was able to utilize its substantial water resources to generate electricity. See Bardini (1997).

I collected data on irrigation pumps and power use in manufacturing from the encyclopedia *Géographie Économique et Administrative de l'Égypte Volume 1* (Economic and Administrative Geography of Egypt), referred to as Boinet (1902) in the rest of the chapter. This encyclopedia contains extensive data on the economy and population of each township east of the Damietta branch of the Nile. Only one volume of this encyclopedia was ever published. As a result, the sample in this chapter is limited to the three provinces included in this volume: Daqahlia, Sharqia, and Qalyubia. These provinces contained about 35 percent of all cotton-producing land in the Nile Delta.[19] To my knowledge, Boinet (1902) is the only township-level resource on agricultural mechanization and power use in manufacturing available during British colonization. I know of no firm-level data sources on steam-power adoption in Egypt during this period.

Steam-power adoption in agriculture and manufacturing was an equilibrium outcome. Egypt's transportation network influenced the viability of mechanization, and conversely, mechanization probably had an influence on placement of the railroad network. As a result, estimates treating shipping costs as exogenous may suffer from simultaneity bias, in addition to other problems stemming from omitted variables. To address these issues, I instrument for shipping costs using the straight-line distance between each township and Alexandria.[20] The identifying assumption necessary for satisfying the exclusion restriction is that distance to Alexandria only affects steam-power adoption within each district, conditional on observable geographic and population characteristics, through its impact on the cost of shipping.

Distance-based instruments frequently have the problem that the distance to one landmark is correlated with the distance to something else that may have a causal effect on the

[19] *Annuaire Statistique*
[20] In other words, the distance to Alexandria "as the crow flies."

second-stage outcome of interest. Townships closer to Alexandria are also, on average, closer to the Nile, closer to the Mediterranean Sea, and further from Cairo. It might be the case, for example, that villages closer to these landmarks had better access to foreign technology or skilled workers, and this could bias estimates. I address these concerns in several ways. First, I include a number of control variables in all regressions, such as cultivated area, population, and literacy rates. These variables are intended to proxy for unobserved prices that influenced mechanization like unskilled wages and the price of draft animals. Both soil quality and elevation, important variables determining crop selection and the cost-saving benefits of agricultural mechanization, vary systematically with distance to the sea, and therefore distance to Alexandria, so I also control for soil fixed effects and elevation in each regression. I include district-level fixed effects in all regressions to control for unobserved confounders that varied across geographic areas. In geographic terms, districts were about the size of large US counties, but because of Egypt's high rural population density, they contained much larger populations. In addition, I run robustness checks with controls for the distance to each of the landmarks mentioned above, and others. I find that point estimates are robust across specifications.

The identification strategy used in this chapter differs from common approaches for estimating the effects of historical railroad construction found in other papers. These papers typically use a dummy for the presence of railroads as the primary explanatory variable. They contend with the endogeneity of railroad placement by comparing areas near railroads with areas along hypothetical routes that were planned but not built, or by using the deviation of rail lines from a least-cost or straight-line path between two points as a source of exogenous variation.[21] My approach has a number of strengths compared with these approaches that are specific to the context studied here. For Egyptian cotton farmers, better transportation incentivized mechanization by lowering the price of coal and machinery relative to alternatives and by reducing the cost of exporting. The mechanics of cotton farming during this period are known in detail, so I am able to concentrate on the first-order effects of railroads from the perspective of these producers, which is reducing shipping costs. Rather than thinking of railroads as a binary variable, my approach recognizes that railroads were valuable to firms to the extent that they lowered the costs of trade, as Fogel (1964) argued. For example, townships with waterway access benefited less from railroad construction than townships without access because shipping costs were already low. Policy evaluations based on the assumption that railroads had the same effect across all areas are likely to yield implausible conclusions. Compared with cotton farmers, the production functions of local manufacturers are less well documented and differed by industry, so my approach applied to manufacturing has some additional caveats. Regardless, so long as the exclusion restriction is met, the IV estimates reported in this chapter yield consistent estimates of the impact of shipping costs on mechanization both sectors.

Model estimates bear out predictions of the heterogeneous effects of transportation improvements. Lower shipping costs increased irrigation pump adoption in agriculture, and this result is robust across specifications. On the other hand, I find no net effect of shipping costs on steam power use in manufacturing. I use these estimates to evaluate the effect of Egypt's agricultural railways, built in the 1890's, on the use of irrigation pumps. This policy counterfactual is based on the assumption that farmers hired labor and purchased

[21]For example, Banerjee, Duflo, and Qian (2012), Atack and Margo (2011), and Jedwab, Kerby, and Moradi (2015).

draft animals from local markets, so the only relevant effect of new railroads was lowering shipping costs to and from Alexandria. Between 1895 and 1900, private companies built 900 kilometers of railroad track in Egypt, increasing total track length by around 50 percent. Dates of track completion from Weiner (1932) and descriptions in Boinet (1902) indicate that these railroads were in use at the time data on steam power use was collected. I find that Egypt's agricultural railways caused average shipping costs to fall by 4.6 percent and caused pump use to increase by 14 percent, implying an elasticity of around 3. The largest increases in pump adoption occurred in areas without prior rail or waterway access.

Foreign infrastructure investments reinforced the already "lop-sided" nature of Egypt's economy: lower shipping costs encouraged productivity enhancing capital investments in the export-oriented primary goods sector while leaving local manufacturing relatively untouched.[22] A number of economists have argued that productivity increases in primary goods sectors may impede long-term development if dynamic scale effects or learning-by-doing in manufacturing are the main drivers of economic growth.[23] Cheaper shipping to and from ports acted like a productivity shock to primary goods sectors. This exacerbated patterns of international specialization and, if this view is correct, may have ultimately impeded long-run economic development. The results in this chapter are in line with recent work by Pascali (2017), who showed that decreases in trade costs caused by steamships replacing sailing vessels in the latter half of the 19^{th} century increased non-manufacturing exports in poorer countries but negatively impacted their long-run GDP growth.

Finally, this chapter contributes to the historical understanding of steam-power adoption. Allen (2014), using Egypt and India as case studies, argued that developing countries during

[22]Issawi (1961) describes Egypt's economy as "lop-sided" because it had sophisticated primary goods and transportation sectors but little industry.
[23]Krugman (1987), Matsuyama (1992)

this period failed to mechanize production because wages were too low for steam power to be cost effective. This may have been true for some countries, but clearly was not the case for Egypt. Data on steam power across countries is not available during this period, but a good proxy for mechanized activity in the late 19^{th} and early 20^{th} centuries is domestic coal consumption. In 1913, Egypt consumed 3 times more coal per person than India and 5 times more than China, despite having no known coal reserves.[24] Although this was less per capita than any European country, it indicates that Egypt occupied a middle ground in terms of production mechanization. There were at least 2,000 - 3,000 irrigation pumps operating in the Nile Delta at the turn of the century.[25] Ignoring steam engines used in manufacturing and transportation, there were more steam engines used in Egyptian agriculture in the early 1900's than were used in any industry in England in 1800.[26] The main competitor for steam power in cotton farming was not human labor but another capital-intensive production technology: ox-driven water wheels. Although laborers were employed to supervise the oxen, wages accounted for only a quarter of total costs. Other irrigation technologies which exclusively employed human labor were available, but they were rarely used in cotton-growing regions. Cheaper shipping caused farmers to replace one type of capital, livestock, with another cheaper form of capital: steam engines. One implication of this is that some developing countries in the early 20^{th} century may not have mechanized production because modern technology was too expensive to compete with other forms of capital.

[24] Imperial Mineral Resources Bureau (1920), Bolt et al. (2018)
[25] See appendix for details.
[26] Kanefsky and Robey (1980)

2.2. Literature Review

I compiled historical background for this project from a number of important secondary sources. For background on Egyptian agriculture, I rely on Owen (1969), Owen (1993), and Richards (1982). Tignor (1966) and Daly (1998) were indispensable sources on the legacy of Britain's colonization of Egypt. The two major sources on the mechanics of Egyptian irrigation and cotton agriculture are Foaden and Fletcher (1908) and Willcocks (1913). Headrick (1988) is the major historical reference on technology transfer during this period between the West and its colonies, and he features Egypt prominently as a case study. Headrick argued that although European empires exported technology to colonies, the geographic transfer of technology was not sufficient to encourage its adoption among local entrepreneurs. In contrast, I find that changes in the relative prices of technology were, in fact, sufficient to induce steam-power adoption in Egyptian cotton agriculture.

This chapter adds to the growing literature on railroads built during the 19^{th} and early 20^{th} centuries. Scholars have shown that railroads increased urbanization,[27] increased total cultivated land,[28] harmonized prices across regions,[29] and improved living standards.[30] To my knowledge, no other applied econometrics papers have explicitly considered the effect of railroads and other transportation improvements on technology adoption in developing countries during this period.

Steam engines were a novel Western technology that became one of the most important means of power generation in agriculture and industry prior to the widespread introduction of electricity and the combustion engine. As a "General Purpose Technology", steam engines

[27]Atack et al. (2010), Berger and Enflo (2017)
[28]Atack and Margo (2011)
[29]Abdrabi and Kuehlwein (2010)
[30]Donaldson (2018)

were used in many sectors and spurred additional technical advances in areas where they were adopted.[31] The majority of papers on steam engine adoption have focused on the United States and Great Britain in the 18^{th} and 19^{th} centuries. In general, studies have found that steam engines were adopted where coal was cheaper and alternative power sources, like water power, were less available.[32] Rosenberg and Tratjenberg (2004) find that counties with larger populations and a greater number of books in public libraries were also more likely to adopt steam engines. A working paper by Bogart, Bottomley, Satchell, and Taylor (2017) studied the effect of transportation infrastructure on steam engine adoption in Great Britain and found that parishes closer to waterways and roads were more likely to adopt. This chapter improves upon Bogart et al. (2017) by accounting for the endogeneity of transportation costs with respect to mechanization. In addition, no previous econometric study of steam-power adoption has been done on colonies or developing countries during this late 19^{th} and early 20^{th} centuries.

Many papers writing about early agricultural mechanization have focused on reaper and tractor adoption in the United States.[33] Tractors directly substituted for horses so this literature is especially relevant to the case of Egypt, where pumps primarily substituted for ox-driven waterwheels. Studies have generally found that farmers switched from horses once tractor prices fell and wages increased during the 20^{th} century.[34] This chapter adds to the literature on early agricultural mechanization by studying a society in which labor was cheap and the primary purpose of steam-power adoption was to conserve capital costs rather than wages.

[31] Rosenberg and Trajtenberg (2004)
[32] Atack et al. (1980), Rosenberg and Tratjenberg (2004), and Nuvolari et al. (2011)
[33] For example, David (1966), Olmstead (1975), and Olmstead and Rhode (1995)
[34] Kislev and Peterson (1982), Manuelli and Seshadri (2014)

2.3. Historical Background

Egypt's financial and economic integration with Europe increased over the 19^{th} century, even before Egypt was occupied by British troops in 1882. The primary reason for increased economic integration was trade: cotton for raw materials, manufactured goods, and technical expertise.[35] Figure 2.1 shows Egyptian cotton production from 1821 until 1908. In less than a century, cotton production went from almost nothing to being Egypt's largest export and the second largest crop in the Nile Delta by area. In 1900, total Egyptian cotton production was about 10.5 percent of the United States', the world's largest cotton producer.[36] Although Egypt made up only a moderate percentage of global production, its high-quality long-staple cotton dominated the upper end of the market.

Egypt's specialization in cotton during the 19^{th} century is a story of comparative advantage due to its arid climate and highly productive land, supplemented by active state involvement in agriculture. Both before and after Egypt was colonized, the Egyptian government invested in infrastructure to lower the cost of cotton irrigation and transport.[37]

In the beginning of the 19^{th} century, most land in the Delta was irrigated each fall by the Nile flood. Flood-irrigation was well suited for staple crops but poorly suited for cotton cultivation, which requires a large amount of water during the summer when the Nile is lowest. Due to this summer water shortage, long-staple cotton was initially grown only on the banks of the Nile.[38] To increase cotton cultivation, the Egyptian government, starting under Muhammad 'Ali, dredged deep *saifi* (summer) canals across the Delta. These canals

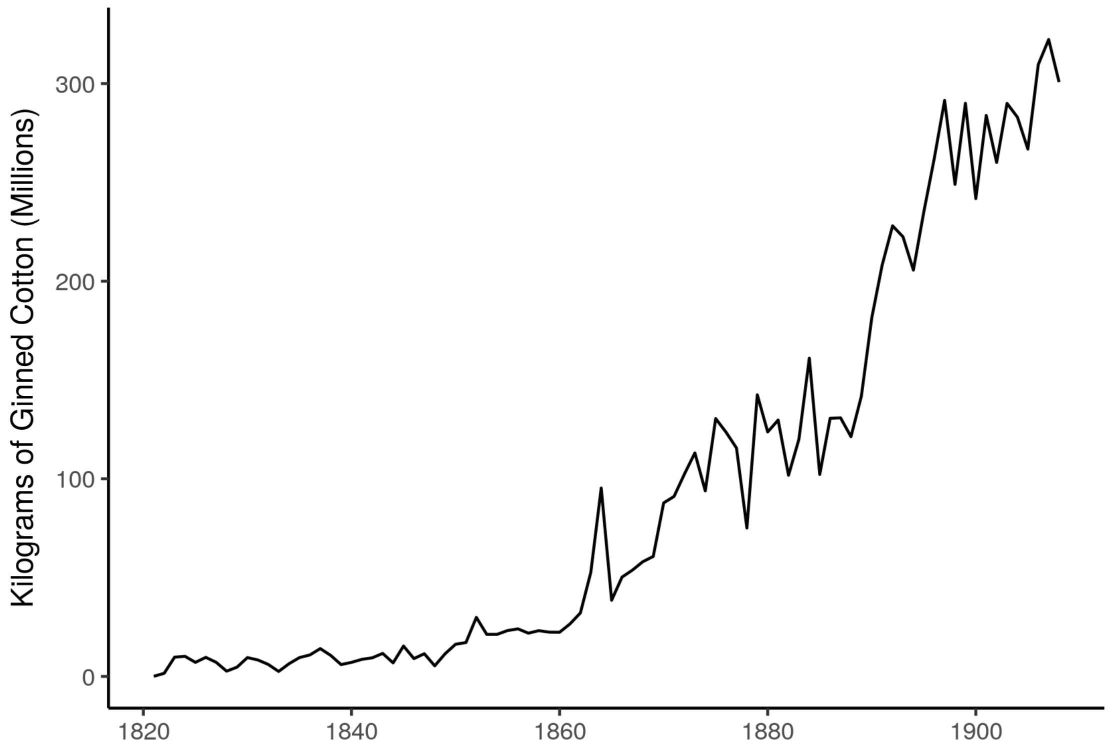
[35]For example, the value of Egyptian exports increased by a factor of 8 between 1840 and 1880. By 1880, cotton accounted for more than 60 percent of all Egyptian exports, and this proportion increased over time. See Own (1969) p. 166-168

[36]United States and Egyptian production in 1900 was around 2.3 million and $241,000$ tons, respectively. *Annuaire Statistique, American Historical Statistics* p. 518

[37]Owen (1969), Rivlin (1961)

[38]Owen (1969), Richards (1982)

Figure 2.1. Long-Staple Cotton Production During the 19th Century



Source: *Annuaire Statistique*

Note: This figure shows Egyptian cotton production in millions of kilograms of ginned cotton from 1821 until 1913.

often exceeded a depth of six meters, retaining water during the summertime by gravity alone. Over 900 kilometers of saifi canals were dredged in Lower Egypt during 'Ali's reign.[39] His successors and the British colonial administration maintained this system and expanded perennial irrigation to the rest of Lower Egypt and large parts of the Nile Valley.

In addition to overhauling irrigation, the Egyptian government built modern railways to supplement the Delta's navigable rivers and canals. These railways were first built for the transit trade between Suez and Alexandria, which had previously relied on camel caravans

[39]Rivlin (1961) p. 281

and river barges.[40] After the Suez Canal was completed in 1869, railroads were increasingly used to transport cotton from Delta ginning centers like Mansourah, Tanta, and Zagazig to the port of Alexandria. Egyptian State Railways, the state-owned company that managed Egypt's standard-gauge railroads, carried more than 100 percent of the ton-weight of the total ginned cotton crop in 1900.[41] Available statistics don't distinguish between ginned and unginned cotton (which weighs about three times more), so this indicates that some cotton was shipped twice: first to a cotton gin, then to Alexandria.

Egypt's rapidly expanding railroad and canal infrastructure exacted a financial toll. During the 1860's and 1870's, the Egyptian government borrowed nearly £100 million through a combination of bond issues and private bank loans. Some of the borrowed money was spent on useful projects like railroads, irrigation canals, and funding the Suez Canal. But a significant portion was spent financing military adventures and the lifestyle of the vice-regal, Isma'il Pasha.[42] State revenues failed to increase as fast as the balance of debt, and a lack of funds caused the Egyptian government to suspend interest payments in 1876. Soon after, an international debt commission, led by Britain and France, consolidated the debt and pressured the state to resume payments.[43]

Between 1876 and 1879, Isma'il Pasha became increasingly unwilling to cooperate with the terms of debt repayment set forth by the international commission. British and French administrators in Egypt responded by organizing a coup d'etat, deposing him in favor of his more pliable son Tewfiq. Growing nationalist outrage against European influence and favoratism by 'Ali's dynasty toward fellow Turco-Circassians culminated in the 'Urabi rebellion of

[40]Ettouney (2010)
[41]*Annuaire Statistique* (1909)
[42]Dawkins (1901), Tignor (1966)
[43]Hunter (1998)

1879 - 1882. The rebellion, with the slogan "Egypt for the Egyptians," concerned Europeans and exacerbated fears that payment on the unified debt would stop entirely.[44] However, few shareholders anticipated that Britain would colonize Egypt and assume responsibility for the debt.[45] European countries had intervened in response to debt non-repayment before, such as the French invasion of Mexico in 1861, but this was viewed as an exception rather than the rule. The strategic importance of the Suez Canal and Egypt's key position in Africa may have forced a reconsideration of this policy, but the precise reasons behind the British Empire's intervention in Egypt are still a point of contention among historians.[46]

In 1882, the British army invaded and put down the 'Urabi rebellion. Realizing that withdrawal may cause Egypt's collapse and embarrass Britain, the British consulate took control of Egypt's domestic and foreign affairs, although Tewfiq retained his title. It's interesting to note that Egypt remained a province of the Ottoman Empire this entire time. It continued to pay tribute to the High Porte until the British abolished the Khedivate and formally declared Egypt a Protectorate at the outbreak of World War 1.

Although limited by external constraints set by the international debt commission, the British colonial administration successfully borrowed additional money for important public works at lower interest rates than prevailed under Isma'il Pasha.[47] Better borrowing terms

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[44] Daly (1998)

[45] Feder and Just (1984) estimate a structural model of Egyptian bond markets in which prices reflect shareholder beliefs about the ratio of debt to government revenue and the risk of default. The authors conclude that European bondholders in the 1870's both overestimated the probability that Egypt would remain solvent and underestimated how much money would be recovered if it defaulted.

[46] Robinson and Gallagher (1961) argue that the main reason was the Suez Canal. Tignor (1966) agrees but contends that economic and financial factors played a role in setting the stage for occupation. Hopkins (1986) argues that the canal was a post hoc justification for acting to protect bondholders. Galbraith and al-Sayyid-Marsot (1978) and Halvorson (2010) argue the British were unwilling to lose face negotiating with the 'Urabis, but also agree that financial interests played a role.

[47] Dawkins (1901)

may have been due to changes in domestic policy which increased investor confidence,[48] or they may have been a response to the British Empire putting its reputation and prestige on the line in Egypt.[49] Both explanations are plausible. Regarding domestic policy, British management of Egypt's financial situation between 1882 and 1913 is generally regarded as a complete success.[50] Useful public works increased agricultural output. The post-occupation boom in cotton cultivation, likely due to the repair of an important dam across the Nile in the 1880's, can be seen in Figure 2.1. Tariff revenue grew, land taxes fell, and the proportion of debt service to total government revenue dropped by half. Estimates of per-capita GDP growth vary, depending on methodology and estimated level of income prior to the 1880's, but a 1.2-2 percent increase in per-capita income over this period is plausible.[51] The distribution of benefits skewed towards the wealthy, but Egypt's rapidly increasing population during this period suggests that economic growth trickled down to the peasant class.

The post-colonization boom ended during the 1910's. Agricultural output outpaced population growth during the pre-War period, primarily because public works like the Aswan Dam and the Delta Barrage's repair increased the amount of cotton-growing land. However, the infeasibility of converting more land to year-round irrigation or reclaiming more land from the desert caused agricultural output growth to stagnate. In recent years, some historians have characterized falling agricultural yields after 1909 as an "ecological crisis"

[48] Davis and Huttenback (1986) and Ferguson and Schularick (2006) argue that being part of the British Empire reduced borrowing costs. On the other hand, Obstfeld and Taylor (2003) find no effect. Regardless of the average experience, ample historical evidence indicates that Egypt was considered more credit-worthy after colonization.

[49] Accominotti. Flandreau, and Rezzik (2011)

[50] Daly (2006) p. 242

[51] Hansen (1979), Yousef (2002)

due to insufficient investment in drainage canals, even going so far as to criticize the conversion of land to perennial irrigation altogether.[52] These critics provide little supporting evidence for their claims and ignore research showing that overall agricultural output was increasing as fast as population until the 1950's.[53] While some fall in yields was due to poor drainage, a significant portion of the fall in yields was a mechanical consequence of bringing marginal agricultural land into production. Additionally, some farmers purposely switched to more profitable higher-quality but lower-yielding cotton varieties. Thus, the fall in yields may partly reflect a change in international tastes and available cotton varieties, rather than a deterioration in the agricultural environment.[54] Finally, available evidence indicates that improved drainage did little to restore yields when they did recover in the 1930's. A working paper by Karakoç and Panza (2017), the first and only econometrics study on Egyptian cotton yields in this period, found that improved access to finance and the switch to a higher-yielding cotton variety were responsible for most of the recovery.

Egyptian manufacturing growth was flat until the 1930's when an important textile sector began to emerge. Manufacturing grew during the decade leading up to World War II, but low consumer demand hampered Egypt's ability to industrialize via import substitution.[55] The country's initial promise and eventual stagnation led to a significant amount of academic attention. Charles Issawi (1961) famously characterized Egypt as a lop-sided economy: cash-crop agriculture and transportation infrastructure were highly developed, even state-of-the-art, while other parts of the economy remained stagnant. There's no evidence that Britain deliberately sabotaged Egypt's industrialization. If colonialism played a causal role

[52]See for example, Mitchell (2002) and Jakes (2017).
[53]Hansen and Wattleworth (1978)
[54]Goldberg (2006)
[55]Karakoç (2014)

it was by preventing a more active industrial policy, which, in the view of colonial officials, was neither in the interest of Egypt or Britain.[56]

Egypt's "growth without development" is a case study of the limits of economic liberalism in generating sustained increases in per-capita GDP. This is not to say that alternative policies would have performed better, but rather to state that liberalism was tried and did not deliver. Both Britain and the Egyptian government that gained power in the 1920's maintained free markets, low taxes, low and uniform tariffs, a balanced budget, and peace. The state spent tax revenues on useful public works like dams, roads, and sewers. Despite these policies, Egypt's export-oriented growth strategy failed to establish linkages between agriculture and other sectors, leaving it vulnerable to diminishing returns in agriculture and commodity price swings. While some scholars have argued that a more aggressive industrial policy may have helped Egypt develop a manufacturing base earlier and prevent stagnation between the World Wars, it's not clear that structural constraints, like the lack of additional agricultural land and poor educational attainment, could have been easily overcome in a short time.[57]

2.4. Economics of Irrigation in Egypt

3.1 million acres of land were cultivated in the Nile Delta during the agriculture year that began on September 1st, 1900. About half of that land was double-cropped, meaning that the total cultivated area was over 4.5 million acres. Corn, cotton, wheat, clover, barley, and

[56]Owen (1993). Lord Cromer, British consul-general and ruler of Egypt from 1882-1907, directly addresses this point: "There can be no sort of reason why the Government should oppose any proposal which involves placing the home-made on precisely the same footing as the imported goods. On the other hand, it would, for obvious reasons, be detrimental to both English and Egyptian interests to afford any encouragement to the growth of a protected cotton [textile] industry in Egypt." Baring (1899) p. 14

[57]Karakoç (2014), Youssef (2000)

beans were the most cultivated field crops, in that order.[58] Long-staple cotton accounted for 26 percent of total crop acreage, and it was planted in around 39 percent of Lower Egypt's arable land.[59] Farmers typically grew cotton on a two or three-year crop rotation, along with clover and either corn or wheat.[60] Fallows lasted only a few months. These numbers imply that the vast majority of arable land in the Delta was planted under cotton once every two or three years.

The distribution of landholding in Egypt skewed toward the wealthy: in 1900 44 percent of all land was owned by landholders who owned 50 acres of more. The vast majority of landholders in Egypt, around 84 percent, held plots of land under 5 acres.[61] By contemporary Western standards, this would have been an incredibly small farm. However 5 acres was considered more than sufficient for a smallholder to feed a family. Owning land at all elevated one to the middle class. Around 20 percent of families were landless and either rented land for cash payments, sharecropped, or worked for hire.[62] Smallholders were no less likely to grow cotton than owners of large estates. If anything, smallholding peasants may have cultivated cotton more intensively because they were credit constrained.[63]

The most common means of irrigation in the Nile Delta during the 19^{th} and early 20^{th} centuries was the *saqia*, a water wheel powered by oxen or other livestock. Other devices like the *shaduf*, a bucket on a rope attached to a counter-weighted lever, and the *tabout*, another type of ox-driven water-wheel, were also used. Despite requiring one or two laborers to operate effectively, saqias were primarily capital intensive. Table 2.1 shows the prices of

[58] Egyptian clover is also known as *birsim*.
[59] *Annuaire Statistique* (1909)
[60] Foaden and Fletcher (1908)
[61] *Annuaire Statistique*
[62] Owen (1993)
[63] Richards (1978), Arcand (1995)

Table 2.1. Wages and Prices of Agricultural Capital

	1900 £		1900 £
Oxen - Full Grown	11.65	Steam Pump	160.00
Buffalo Full Grown	20.97	Tabout	1.72
Sheep	1.40	Shadoof	0.15
Goats	0.93	Saqia	1.89
Camels	11.65		
Horses	16.31	Daily Wages	
Mules	6.99	Unskilled Laborers	0.03
Donkeys	2.33	Native-Born Mechanic	0.11

Source: *Annuaire Statistique*, Radwan (1974), Mitchell (1988), American Well Works (1900)

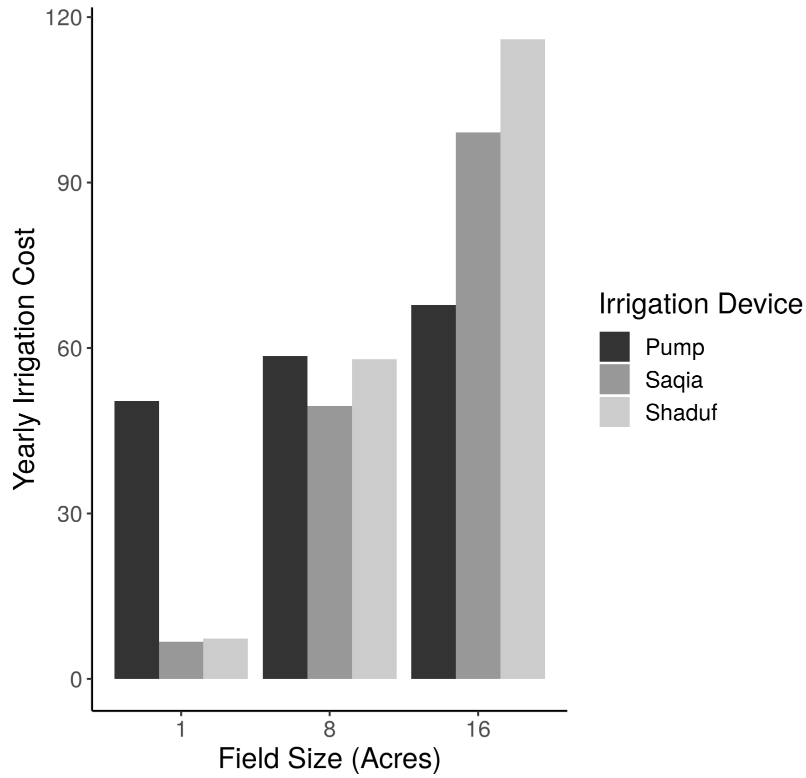
Note: See appendix for details.

draft animals and irrigation devices in Lower Egypt in 1900. A single ox cost more than a year's wages for an unskilled worker, and it cost about 6 times more to purchase than a saqia. Assuming two unskilled laborers were hired to manage the animals used to power the saqia, the cost of draft animals accounted for around 75 percent of the cost per watering.[64]

Figure 2.2 shows the average cost per year of watering cotton fields of 1, 8, and 16 acres by shadufs, saqias, and steam pumps. Cotton fields were typically watered 12 times between planting and harvest. I assume a 3 meter lift and that fixed capital fully depreciated over a 3 year period. On the 1 acre field, shadufs and saqias are similar in terms of cost efficiency, however saqias have a slight cost advantage. Even on very small fields where economies of scale were unlikely to be realized, saqias were a more cost-efficient irrigation technology, which explains the near absence of shadufs in the Nile Delta. Saqias had a cost advantage over pumps for smaller fields, but they lost this advantage as field sizes increased. Figure 2.2 shows that even moderately sized cotton estates could have realized economies of scale

[64]Details for these calculations are described in the Data Appendix.

Figure 2.2. Yearly Irrigation Cost for Cotton Fields of Various Sizes



Source: Foaden and Fletcher (1908), Willcocks (1913)

Note: This figure shows the yearly irrigation cost in British pounds of watering cotton fields of 1, 8, and 16 acres using irrigation pumps, saqias, and shadufs. See data appendix for details.

from adopting steam pumps. As a caveat, it should be noted that these costs are calculated from average prices, not prices in particular areas. The uneven distribution of technology use across the Delta indicates that prices, including shipping costs of fuel and machinery, differed widely from the average in many areas.

The low-cost effectiveness of labor intensive devices like shadufs is borne out in available statistics. The 1873 *Annuaire Statistique* is the only source that lists shaduf numbers by province before agricultural censuses began to be conducted in the 1920's. Saqias and pumps were regulated and had to be recorded with a central office, but there were no laws regulating small labor-intensive devices. This source lists 25,000 saqias, 7,000 tabouts, 8,000 shadufs, and nearly 500 pumps operating in Lower Egypt in the early 1870's. One shaduf could irrigate between 1/10 and 1/5 of an acre a day depending on whether it was worked by one or two men.[65] Taking these numbers at face value, shadufs irrigated no more than 8,000 - 16,000 of the total acres under summer crops in the delta. Compared with saqias and tabouts, which typically irrigated fields of 6-14 acres, only a small percentage of land was irrigated by shadufs. Under-counting may be present, but it would need to be very large to explain the disparity. Other unreported labor-intensive devices like the hand-cranked archimedean screw were also used, but they were only used on lifts of 1 - 2 meters, which limited them to the Northern portion of the Delta.

Despite being rare in Lower Egypt, shadufs were widely employed in Upper Egypt. Most of the Nile Valley relied on flood irrigation during this period, which included a long summer fallow. In Upper Egypt, summer crops like sorghum and millet were only grown along the banks of the Nile. Because of the long fallow, farmers who didn't plant during the summer had a low opportunity cost of working for hire, and this depressed summer wages there. Consequently, in contrast to Lower Egypt, it was cost effective to use large numbers of shadufs to irrigate summer crops. In Lower Egypt, where small-holding peasants grew cotton during the summer, wages were substantially higher. Additionally, far fewer livestock were maintained in Upper Egypt.[66] This may have been because draft animals were not needed for irrigation, but it could also have been because differences in crop cycles between Lower and Upper Egypt limited the amount of clover grown for fodder.

[65] Willcocks (1913)
[66] *Annuaire Statistique*

There is some historical debate over whether Egypt was a labor-scarce or labor-abundant economy, and whether this changed as Egypt's population grew. For example, Egypt was cited as a classic example of an economy with "unlimited supplies of labor" by Lewis (1954), which meant, in his view, that unskilled workers were available in practically infinite quantities at the subsistence wage. Papers by Hansen (1966, 1969) and Richards (1994) challenge this position, arguing instead that Egyptian farm wages fluctuated along with supply and demand, rather than being fixed by custom and dietary needs. Recent research by Muhammad Saleh (2018) shows that the spike in international cotton prices brought on by the Union Blockade of the Confederacy during the American Civil War caused a short-lived increase of agricultural slavery in the Nile Delta, using slaves imported from Ethiopia and Sub-Saharan Africa.[67] While not a dispositive indicator of high wages, agricultural slavery was often an institutional response to labor scarcity.[68]

Wages in the Nile Delta were low compared with developed countries like the United States, but overwhelming evidence points to wages being high enough in Lower Egypt for firms to find ways of substituting capital for labor. Malthusian pressures in population dense agricultural economies, like China's Yangtze Delta or Dutch Indonesia, caused decreases in the marginal product of farm labor because agricultural land was constrained on the extensive margin.[69] In these economies, human labor became cheap enough to replace livestock in tasks where the disproportionate strength of draft animals was not technically necessary. This decreased the demand for livestock, and, as a result, decreased the demand for animal fodder relative to human staples. The combination of low wages, widespread use of shadufs,

[67] Slavery was abolished in the 1870's.

[68] Domar (1970), Lagerlöf (2009)

[69] This process is sometimes called "involution" in the historical literature. See Geertz (1969) and Huang (1990) for descriptions of this process in Indonesia and China, respectively.

the lack of livestock, and limited cultivation of fodder crops like clover in Upper Egypt give some evidence that Malthusian pressures may have been at work there, but there's no evidence for similar pressures in Lower Egypt. Lower Egypt's most common crop rotation resembled the Norfolk four-course system of wheat-turnips-barley-clover used in England with cotton substituted in for one of the human staples. Lower Egypt's crop rotation differs noticeably from the rice-wheat-cotton-mulberries regime of the Yangtze Delta by including a fodder crop.[70] Fodder crops were valuable in Lower Egypt because a large number of livestock needed to be maintained to transport crops, plow fields, and power irrigation devices. It's important to note that livestock were not technically necessary for irrigation. If labor was sufficiently abundant, cotton farmers could have used shadufs instead of saqias. A parsimonious explanation for the lack of Malthusian symptoms in Lower Egypt is that the introduction and expansion of cotton cultivation caused agricultural productivity growth to get ahead of population increase, or at least keep pace with it.

The cost evidence presented in Figure 2.2 indicates that irrigation pumps competed with the next best available technology, which was typically ox-driven waterwheels. It took 17 hours of pump operation spread over 12 waterings to irrigate an acre of cotton over the course of a year. Based on technical descriptions of steam-powered centrifugal pumps in use at the time, 50 kilograms of coal per year would have been sufficient to irrigate one acre for the year. However, most pumps were poorly maintained and burned 8-10 times as much coal.[71] For this reason, cost calculations in this chapter assume that irrigating one field required 400 kilograms per year and that cotton cultivators hired a native-born mechanic to operate and maintain the pump. Using the wages and prices provided in Table 2.1, and costs

[70]Mulberries were used in the cultivation of silk.
[71]Foaden and Fletcher (1908)

calculated from the transportation-cost network I created (described below), it cost about £1.13 to irrigate one acre of cotton in the Eastern Nile Delta by steam pump for the year, not including the cost of the pump itself, depreciation, or spare parts. Transportation costs within Egypt accounted for 26 percent of the price of coal and 22 percent of the total variable cost of irrigation. These numbers are consistent with irrigation cost estimates reported in Willcocks (1913).

Pumps wasted fuel because they tended to be poorly maintained and used low-quality coal. Typically, farmers needed to hire foreign engineers to achieve a high level of fuel efficiency. Available data, in addition to historical accounts, suggests this practice was rare.[72] 68 percent of townships in my data sample with at least one irrigation pump have no Europeans at all living in them, implying that most farmers relied on native-born workers for maintenance. This suggests that despite both fuel and skilled labor being scarce in Egypt, prices were such that it was more economical to waste fuel than to maintain machinery in peak condition. Although there are data on European skill premiums, reported wages for European mechanics are too low to explain why many farmers chose to waste so much coal.[73] One reason for this discrepancy may be that available wage statistics are reported for larger towns and cities, so they don't apply to the small rural settlements that made up most cotton producing areas. It may have cost significantly more to persuade a skilled worker to leave the comfort and familiarity of the foreign quarter in the city and move out to the countryside to work on a smaller farm. Another possible answer is that information deficiencies on the part of farmers as well as transaction costs due to language and cultural barriers may also have increased the cost of hiring. Research on firms in modern-day developing countries shows

[72] Foaden and Fletcher (1908), Willcocks (1913)

[73] European and native wages are listed in *Annuaire Statistique* (1914)

that many firms do not adopt efficient practices, even when it would be profitable for them to do so.[74]

2.5. Egypt's Agricultural Railways

Egypt's transportation network in the early 20^{th} century mixed ancient and modern shipping techniques. Wooden barges moved goods along the Nile and canals, as had been done for thousands of years. Roads were rare. Like many countries in the Middle East and North Africa, most overland freight transport was still by camel caravan.[75] On the other hand, Egypt had the best rail network in Africa. In miles of track per person and per inhabited area, it compared favorably with many European countries.[76]

Egypt's railroad network was a dual system. Standard-gauge tracks connected major population centers with each other and Alexandria. This part of the network was built by the Egyptian government between the 1850's and 1870's and funded, in large part, by state borrowing from European banks and floating bonds on international markets. The second half of the network consisted of narrow-gauge agricultural railroads built and operated by private companies. Between 1895 and 1897, the Egyptian government conceded partial monopoly rights to a number of European companies to build light railroads in the Nile Delta. Although the government-run Egyptian State Railways (ESR) ran on a standard 1.435 meter gauge, narrow gauges were chosen for the new lines because they were cheaper and easier to construct along the narrow roads and canal dikes of the Nile Delta. Between 1895 and 1905, nearly 1200 kilometers of new narrow-gauge lines were constructed by private companies in the Nile Delta and Fayoum Oasis, increasing total rail track length in Egypt

[74] Bloom, Eifert, Mahajan, McKenzie and Roberts (2013)
[75] Roux (1908), Bulliet (1975)
[76] Issawi (1961)

by about 50 percent.[77] About 25-30 percent of all freight traffic on these lines was cotton or cotton seed, and 6-10 percent was coal.[78] The newer agricultural railroads complemented the existing ESR network: ESR lines ran between major cities, Suez, and Alexandria, while agricultural lines connected outlying towns and cotton-producing areas to major cities.

One reason that private companies were given concessions to build agricultural rail lines was Egyptian government finances. For example, the British consul-general complained about wanting to invest £1.5 million to improve ESR lines, which was close to the amount of money ultimately invested in agricultural railways. However, he was unable to borrow the money due to the terms of Egypt's debt repayment and international pressure.[79] Monopoly rights for agricultural railway construction were granted for a period of 50 years, at which point the state inherited ownership of the track. In exchange for track construction and the right to operate the railroads, the government guaranteed agricultural railroads the right-of-way on intersecting lines and promised that no future concessions would be given to any other company to build a competing line. The government took a percentage of the profits and also promised to subsidize railroad revenue up to a set point, but operating revenues were high enough that the guarantee was rarely invoked.[80]

The construction of Egypt's agricultural railways by European joint stock companies in the 1890's provide a case study of the two ways in which colonization encouraged foreign investment in infrastructure. First, colonization tended to increase the production of primary goods for export, increasing the demand for transportation. After Britain occupied Egypt in 1882, British irrigation engineers repaired an important dam at the fork of the Nile

[77]Weiner (1932)
[78]*Annuaire Statistique*
[79]Baring (1899) p. 19
[80]Weiner (1932)

by Cairo, the Delta Barrage, which had been condemned and barely functional since the early 1860's. This repair, and other improvements to Egypt's irrigation system, more than doubled the production of long-staple cotton. Second, colonization improved protections for foreign investors and reduced expropriation risk. Europeans extracted treaties, known as the Capitulations, from the Ottoman Empire in the middle of the 19^{th} century, increasing legal protections for foreigners doing business in Egypt.[81] The Egyptian government attracted foreign investment in railroads by promising monopoly rights along constructed lines and guaranteed minimum yearly revenues. Even in Western countries, national- or municipalization was a major risk in the 19^{th} and early 20^{th} centuries for businesses investing in long-term fixed capital like railroads. For example, American municipalities frequently expropriated water-provision infrastructure from private companies who had previously been promised monopolies.[82] Egypt could not break its promises to the railroads without the consent of Britain, and the latter risked embarrassment and stood to gain little if the rights of private companies in Egypt were violated. Ultimately, the agricultural railroads were, in fact, seized by the state after Egyptian nationalists gained power in the 1950's.[83]

2.6. Data

This chapter combines a number of data sources on late 19^{th} and early 20^{th} century Egypt. The dataset used here is the first to allow estimation of the causes of steam-power adoption in Egypt and includes the first transportation-cost network of Egyptian railroads and navigable waterways during the early 20^{th} century.

[81] Egypt was nominally a province of the Ottoman Empire during this period. See Daly (2006) Ch. 7 for a discussion of the Capitulations.
[82] Troesken and Gedes (2003)
[83] Foreign Office (1974)

Figure 2.3. Example of Raw Township-Level Data

AKHMIYINE (el). — *El Akhmeeyeen.*

الاخمين

Population : 567 habitants (masc. 298 — fém. 269).

CENTRES DE POPULATION.

	hab.
Nahieh : Akhmiyine (el)	509
Dépendance :	
Ezbeh : Fathallah bey el Nahhas	58
TOTAL : 2 centres — 94 maisons. — Habitants	567

Nationalités : Égyptiens 557 — Étrangers 10.
Tribus des bédouins : Sa'adiyine, etc. (masc. 22 — fém. 19).
Religions : Musulmans 553 — Chrétiens 14, dont 4 cophtes.
Deux Mosquées.
Écoles : 2 Kouttabs.
Superficie *cultivée :* 510 feddans — (non cultivée 5 feddans).
Canaux : Irrigation par les canaux Deil el Timsah, el Sawaleh et el Mostagadda dérivé du Bahr Facous.
Pompe à vapeur — 21 Sakiehs à puisards et sur les canaux.
Masraf : Écoulement des eaux par le Masraf Bahr el Bakar.
Cultures : Coton, blé, maïs, bersim, orge, oignons.
Arbres *fruitiers :* Dattiers 1.093 — Grenadiers, oliviers, figuiers.— *divers :* Sycomores.
Animaux *de ferme :* Bœufs et vaches 90 — buffles et bufflesses 11 — chèvres 4 — chameau 1 — ânes 50 — chevaux 3 — lapins. — Volaille, pigeons.
Industrie : Moulin à farine à vapeur.
Marché : à Facous.
Remarques. — Station du ch. de fer de l'État la plus proche : Facous. à 1 heure 15 m. de distance.

Source: Boinet (1902)

My source for irrigation pumps at the township level is Volume 1 of the encyclopedia *Géographie Economique et Administrative de l'Égypte*, published in 1902. It was compiled on behalf of A. Boinet, the Secretary General of the Ministry of Public Works. No other volume was ever completed and it provides a unique and idiosyncratic snapshot of the economy and population of every township in the three provinces of Qalyubia, Sharqia, and Daqahlia, as well as the Governorate of Damietta. A township was the smallest Egyptian unit of governance, and was typically made up of a single village and surrounding estates. Figure 2.3 shows an example of an entry in the *Géographie*. The township, called Akhimiyine in French, consisted of a single village sharing the same name and a large *izba* (estate) belonging to Fathallah bey el Nakhas. Izbas had their origin in semi-feudal arrangements, but by this time were for-profit agricultural enterprises with no remaining reciprocal obligations between tenants and the estate proprietor. The secondary literature has not reached a consensus on the dominant form of production in izbas during this period. Most izbas probably had tenants under some form of sharecropping arrangement with the proprietor, but many were worked by the owners with hired labor. Cash rents were also used.[84]

As was the case in all rural townships, the vast majority of the population in Akhmiyine was employed in agriculture; the only other noteworthy employer was a steam-powered flour mill. More precise data on labor force composition is not available until the 1927 census. 510 feddans were cultivated in the township,[85] implying a population density of around 1 person per acre or 266 people per square kilometer. High rural population density was typical throughout Egypt. Akhmiyine's major crops were cotton, wheat, corn, and birsim (clover), which were also the most common crops planted in Lower Egypt.

Akhmiyine's only summer crop, cotton, was irrigated by one steam pump and 21 saqias. The typical 8-horsepower centrifugal pump widely used at this time could irrigate as much as 115 acres per watering.[86] A saqia powered by two oxen was typically used to irrigate fields of 6-14 acres.[87] Assuming 40-50 percent of cultivated land in Akhmiyine was under cotton in a given year, these numbers suggest that around 60-80 percent of the cotton fields were irrigated by saqia while the single steam pump irrigated around 10-30 percent. Labor-intensive irrigation devices like the shaduf were probably also used to irrigate smaller plots, but the *Géographie* doesn't report information on these. Both saqias and pumps had to be

[84] Owen (1993)
[85] 1 feddan = 1.034 acres
[86] Foaden and Fletcher (1908), Willcocks (1913)
[87] Willcocks (1913)

registered with central authorities, so their numbers and location were recorded, but there was no law regulating the use of small man-powered lifting devices.[88]

Table 2.2. Summary Statistics

	Mean	SD
Population	1737.17	1407.49
% European	0.08	0.63
Male Literacy Rate	7.60	5.35
Cultivated Acres	1321.28	1608.78
Cotton	0.99	0.07
Sugar	0.30	0.46
Rice	0.39	0.49
Elevation (m)	15.33	5.79
Large Izbas	2.13	3.10
On Nile	0.06	0.23
Has Saifi Canal	0.84	0.37
Saqias and Tabouts	43.25	49.15
# Irrigation Pumps	1.13	1.56
Pumps > 0	0.54	0.50
# Steam-Powered Industries	0.27	0.59
Steam Industries > 0	0.22	0.41
Observations	946	

Notes: Summary statistics of townships in Daqahlia, Sharqia, and Qalyubia provinces. SD stands for standard deviation. Cotton, Sugar, and Rice are dummy variables = 1 if the township cultivates the crop. A large izba is defined as having 50 residents or more. Male literacy is reported as a percentage.

Table 2.2 reports aggregate summary statistics for townships in the main estimation sample. I excluded cities with a population of over 8,000 people and townships with no cultivated area. This was to avoid including non-agricultural areas and because major cities had a much different industrial composition than the mostly rural townships making up the majority of the sample. Most townships in the sample were larger than Akhmiyine: the average population and cultivated acres was around 1,700 and 1,300, respectively. 99 percent

[88] Willcocks (1913)

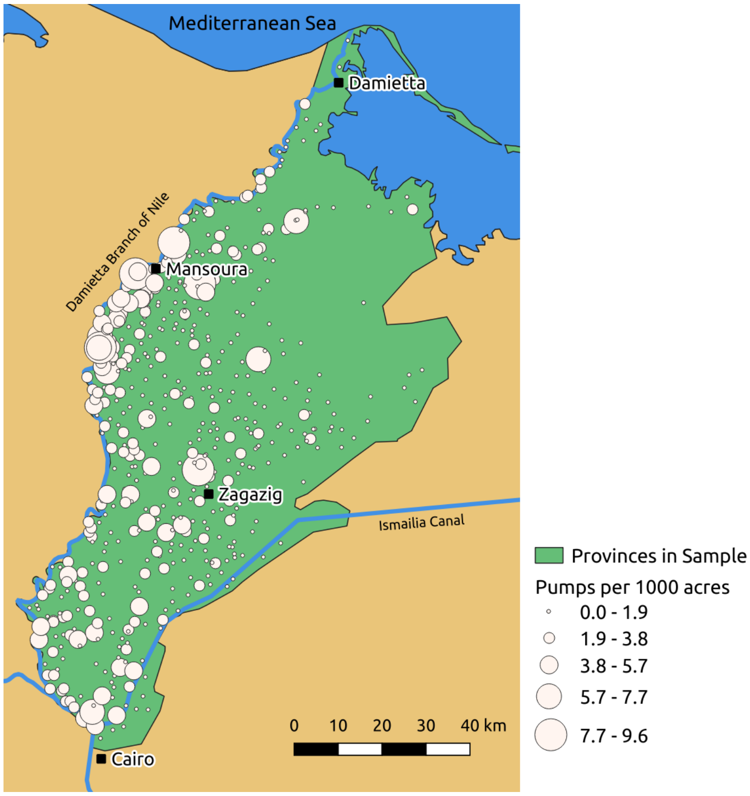
of townships grew cotton, but around 1/3 also cultivated sugar or rice, Lower Egypt's other summer crops. Although Boinet (1902) does not report how much acreage was devoted to each crop, aggregate figures show that the total area devoted to sugar and rice was less than 10 percent of the area under cotton. On average, each township had 2 large izbas, defined as an izba containing 50 or more people. The average number of irrigation pumps per township was a little more than one, with 54 percent of townships having at least one pump. 13 townships report multiple pumps and no other lifting devices, suggesting that nearly all irrigation in those townships was mechanized.

Boinet (1902) does not systematically list the number of steam engines used in each firm or the number of firms using steam engines within each industry. Therefore, I code steam power use in manufacturing as a dummy variable indicating that at least one industry in a given township had a firm using steam power. Around 22 percent of townships had at least one industry that used steam power. The most common steam-powered industry was flour mills, like that used in Akhmiyine in Figure 2.3. Other commonly mechanized industries also processed agricultural products and included cotton gins, sugar processing, and sesame oil pressing.

Figure 2.4 shows a map of the geographic distribution of steam pumps in the Eastern Nile Delta. The sample provinces are in green. Pump density is shown in white circles; larger circles indicate more pumps per cultivated acres. Pump use was spread across most of the populated areas of the Eastern Delta. The sparsely populated northeast had brackish soil unsuitable for most agriculture. There were also a few centers of high-density pump usage, especially around major cities like Mansoura, Cairo, and Zagazig.

The transportation network used to calculate shipping costs between townships and Alexandria is shown in Figure 2.5. The network is based on a series of high-resolution

Figure 2.4. Irrigation Pumps in 1900

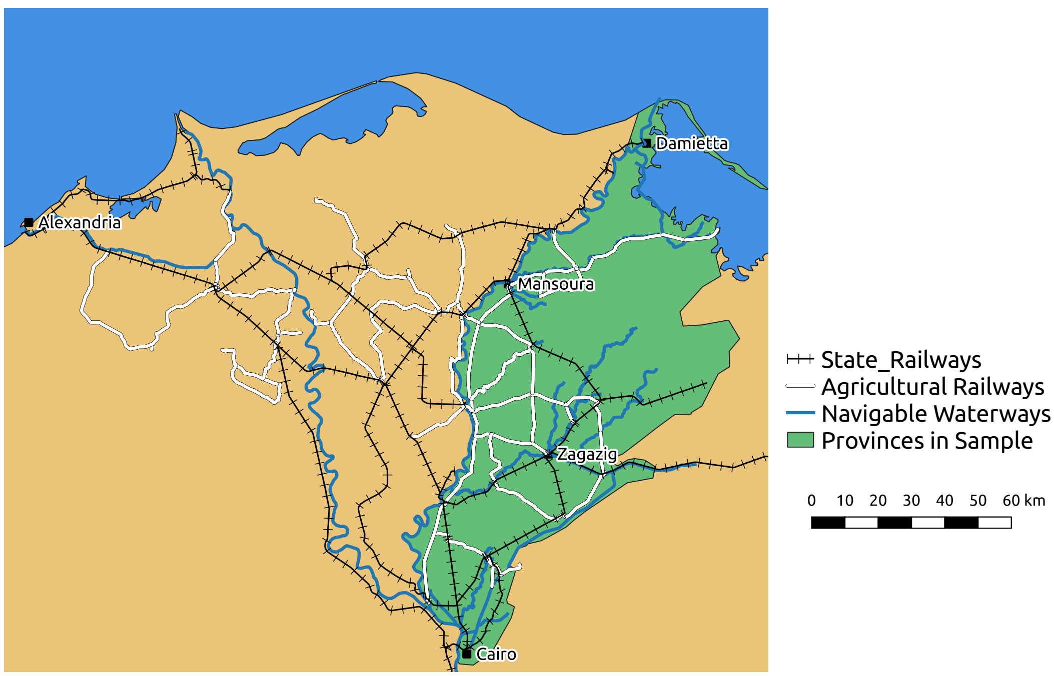


Source: Boinet (1902)

Note: This map shows the number of irrigation pumps in each township. Townships with zero irrigation pumps are not shown. The provinces of Qalyubia, Sharqia, and Daqahlia are depicted in green.

Egyptian maps made between 1896 and 1923. Most maps were based on surveys conducted in the 1900's and early 1910's. I digitized each map and manually plotted each township, using the primary village as the location. Some townships listed in Boinet (1902) had no clearly identifiable population center, or I was unable to find its location labeled on the map. In these cases, I used the shape-file for townships in 1996 included with the CD-ROM version of the Egyptian Century Census to assign an approximate location. Some townships merged, split, or changed their shape, so I could not use this method for all townships. I manually digitized railroad lines and navigable waterways. Because many maps were made after the *Géographie* was published, I verified the dates of railroad line completion using Weiner (1932), information from the *Annuaire Statistique*, and data on railway stations from Boinet (1902). I used the lists of waterways provided in Boinet (1902) and map labels to identify navigable canals.

Figure 2.5. Lower Egypt's Transportation Network in 1900



Source: Egyptian Topographic Maps, Wiener (1932)

Note: This map shows state railways, agricultural railways, and navigable canals in the Nile Delta as of the year 1900. The provinces of Qalyubia, Sharqia, and Daqahlia are depicted in green.

My approach to calculating the least-cost route from each township to Alexandria is similar to the methodology used in Donaldson and Hornbeck (2016). My transportation network consists of state railways, agricultural railways, navigable waterways, and overland routes. Following Donaldson and Hornbeck (2016), overland routes connect each township to each feature of the railway network by the shortest straight-line overland path. State railways and agricultural railways ran on different gauges, so goods could only trans-ship between them in specific towns and rail stations. I identify rail trans-shipment points as towns with both a state rail and an agricultural rail station. I identify waterway-railway trans-shipment points as towns with navigable canals, railway stations, and that are listed as having a *batellerie* or inland port in Boinet (1902). Alexandria could be reached by both the Mahmudia Canal which fed from the Rosetta (Western) branch of the Nile, by rail, or via intercoastal shipping.

Table 2.3. Shipping Rates per Ton

	Rate (Hundredths of a £)	
Mode	Egypt	United States
State Railways	.195	.078
Agricultural Railways	.146	
Inland Water	.098	.061
Inter-coastal	.147	.061
Overland	4.66	2.87
Trans-shipment	2	10

Note: Rates are in 1900 British pounds and per ton-kilometer except for trans-shipment. Egyptian rates are based on Roux (1908), Weiner (1932), and revenue statistics from the *Annuaire Statistique*. Shipment by water is 1/2 the cost of state railways. Inter-coastal shipping is assumed to be 50 percent more expensive than shipping via inland water. I assume trans-shipment rates are 1/5 of trans-shipment rates used in Donaldson and Hornbeck (2016) based on the ratio of Egyptian and American wages reported in Allen (2014). Donaldson and Hornbeck (2016) do not list separate fares for narrow-gauge railways. All prices are in 1900 British pounds.

I used historical sources as well as income statements on railroads included in the 1909 *Annuaire Statistique* to infer the ton-mile cost of each mode of transportation. Rates per ton-mile are listed in Table 2.3. For comparison, I also listed the rates used in Donaldson and Hornbeck (2016) for rail and water shipment in the United States in the 1890's, converted into British pounds. Despite lower labor costs, transport in Egypt was more costly than in the United States in all areas except for trans-shipment. Rail transport was about 2.5 times more expensive, most likely because coal, machinery, and skilled labor had to be imported from abroad. Overland transport was more expensive in Egypt because Egyptian roads weren't sufficiently developed for wagon transport to be viable in most of the Delta. Instead of wagons, camel caravans were used to carry cotton to rail stations and ginning centers.[89] It took 10 camels to carry one ton of cotton, which was 3 or 4 times larger than the number of horses needed to haul the same amount by wagon.[90] Inland waterways were about 50 percent more expensive than in the United States. I have the least information on water transport prices, so I rely on the statement in Roux (1908) that inland water transport in Egypt charged about half the rate of state railways. One reason that waterways were more expensive in Egypt, despite lower labor costs, was that tolls were charged for going under bridges along the Nile and canals until 1905, so water transport firms had to share profits with bridge owners. Most river barges were not steam powered. Barges floated downstream with the current and either sailed upstream or were pulled by donkeys along the river or canal bank.

I don't have information on inter-coastal shipping rates, but historical evidence indicates that it was rare. The only plausible port to ship inter-coastally from the Eastern Delta to Alexandria was Damietta. Although Damietta was an important shipping center in the Middle Ages, by 1902 Damietta accounted for less than 1 percent of all imports and exports.

[89]See Bulliet (1990) for a description on how camels came to replace wheeled carriages in much of the Middle East and North Africa.
[90]Roux (1908)

Descriptions of Damietta in Boinet (1902) indicate that it was an important port for shipping along the Nile, and for trade with the Levant and Turkey, but it was not well equipped for the intercoastal trade. The prevailing winds in the Mediterranean near Egypt flow from west to east, and steam ships did not stop in Damietta. I have encountered no description in secondary sources like Roux (1908) of cotton being shipped to Alexandria inter-coastally. Rather than discard the route, I set the price equal to that 1.5 times that of other inland water routes. Least-cost routes using this price indicate that a few townships do ship inter-coastally, but I found that setting the price of inter-coastal shipping equal to that of inland waterways induces a large portion of townships in the Northern Delta to ship inter-coastally, and this is inconsistent with the historical evidence. I provide additional details on how I arrived at these shipping costs in the Data Appendix.

I also collected data on soil quality from the International Soil Reference and Information Centre's www.soilgrids.org website and elevation data from the Global Digital Elevation Model created by NASA.[91] Townships may differ in agricultural mechanization because of their soil quality. Soil quality deteriorates as one moves toward the periphery of the Delta, becoming more salinated as a result of sea-water infiltration and a lack of sustained irrigation. Because soil quality is correlated with both agricultural production and distance to Alexandria, it could bias results if not controlled for. Elevation is also an important control variable. Saqias needed to be worked longer as lift height increased, which increased irrigation costs per acre by a relatively large amount, while pumps only needed more fuel.[92]

[91]See Hengl et al. (2014) for details on the construction of www.soilgrids.com data. Department of the Interior (2011)
[92]Willcocks (1913)

Because elevation is lower closer to the sea, this may also be an important confounding variable to control for. Finally, I linked each township in Boinet (1902) to the 1897 Egyptian census in order to calculate township-level literacy rates.

2.7. Effects of Shipping Costs on Steam-Power Adoption

Imports like coal, flour, and finished textiles were either bought locally in each township, or they were purchased in Alexandria and shipped at the expense of the purchaser. Likewise, cotton and other exported products were either purchased by wholesalers in each township or shipped to Alexandria by the farmers themselves and sold to exporters there.[93] In either case, lower shipping costs decreased the net price of imports and increased the price of exported goods from the producer's perspective. Producers who bought foreign imports and exported their final product, like Egyptian cotton farmers, unambiguously benefited from better transportation. These producers were more likely to mechanize because the substitution and scale effects induced by changes in internal shipping costs worked in the same direction. On the other hand, cheaper shipping caused the price of imported goods to fall, putting downward pressure on the price of locally sold manufactured goods that competed with foreign imports, especially in the case of homogeneous goods like corn and wheat flour. This tended to reduce output, so from a theoretical standpoint it's not possible to predict how cheaper transport affected mechanization in manufacturing.

Aside from the effect of shipping costs, economic theory predicts that entrepreneurs were more likely to mechanize production where unskilled wages were higher, alternative power sources like draft animals were more expensive, and where skilled labor was more readily available. Large producers would have been more likely to adopt steam engines because of

[93] See Roux (1908) for more details.

economies of scale and lower financial constraints. Although I use an instrumental variable to identify the main effect of interest, it may be the case that the exclusion restriction isn't met if these variables aren't conditioned on. For that reason, I use proxies where available. I proxy for wages using the total cultivated area and population density of each township. Population density is likely to be correlated with wages for unskilled workers. I proxy for skilled workers' wages by literacy rates. For cotton farming, I proxy for economies of scale with the number of large estates in a township. Finally, I use district-level fixed effects in all regressions to account for geographic variation in relevant prices. Districts typically consisted of 50-70 townships and were about the geographic size of a large US county.

Let Y_i be an outcome of interest for township i: either the number of steam-powered irrigation pumps or a dummy variable equal to one if a local manufacturer uses steam power. Each specification has the following second-stage form:

$$\mathrm{Y}_i = f\Bigg(\beta_1 \log(\text{Shipping Costs}_i) + \beta_2 \log(\text{Cultivated Acres}_i) +$$
$$\beta_3 \log(\text{Population}_i) + \beta_4 \text{Large Izbas}_i + \beta_5 \text{Male Literacy}_i + \alpha X_i + \sigma_i + \gamma_{d_i}\Bigg)$$

X_i is a vector of additional controls, σ_i are soil quality fixed effects, and γ_{d_i} are district-level fixed effects. $f(\cdot)$ function is the Poisson pdf, Probit pdf, or identity function where appropriate.

I use the number of steam-powered irrigation pumps in a township to measure agricultural mechanization. Although OLS models are generally useful for recovering average treatment effects, I prefer the Poisson model as the main specification for two reasons. The outcome variable, irrigation pumps, has a characteristic count distribution. The modal township has zero pumps, with a mass point at one and a long right tail. Regression models that better reflect the underlying data process yield more precise estimates and better counterfactual predictions. The second reason I use Poisson estimates is that I'm interested in evaluating the impact of Egypt's agricultural railroads on mechanization. Linear estimates can yield negative predicted values for specific townships, even if they approximate average effects well.[94] For similar reasons, I prefer the Probit model when estimating the effect of shipping costs on whether a local manufacturer uses steam power.

I instrument for log(Transport Costs) using log(Km to Alexandria). Instrument validity is testable; F-statistics in the tables below meet conventional thresholds, so a weak instrument is not a concern.[95] The identifying assumption necessary for the exclusion restriction is that the distance to Alexandria only affects the outcome variable – whether pump adoption or steam power use in manufacturing – through its effect on shipping costs after controlling for other variables in the regression. For example, the exclusion restriction would be violated if, conditional on regression covariates, townships closer to Alexandria systematically had better access to skilled labor or paid more for unskilled workers in a way not measured by literacy rates, district fixed effects, and other controls.

As with all distance instruments, there's a concern that unobserved factors correlated with the instrument could be affecting the outcome of interest, causing violation of the exclusion restriction. Townships closer to Alexandria tended to also be closer to the sea, and therefore tended to be lower in elevation (implying lower irrigation lifts), had more salinated soil, and were more likely to grow rice in addition to cotton. I control for all of these factors directly in regressions, but other unobserved confounders may also be an issue. Although district-level fixed effects should address some of these concerns, I also run regressions with

[94]Cameron and Trivedi (2005)
[95]Staiger and Stock (1997)

the distance to other landmarks such as the Nile, the Mediterranean, Damietta (the only port in the Eastern Delta), and Cairo as controls.

Table 2.4. Effect of Shipping Costs on Pump Adoption in Agriculture

	Poisson (1)	IV Poisson (2)	OLS (3)	IV (4)
log(Shipping Costs)	-1.022***	-8.530**	-0.760**	-4.905***
	(0.275)	(3.302)	(0.253)	(1.278)
log(Cultivated Area)	0.667***	0.925***	0.573***	0.761***
	(0.0890)	(0.150)	(0.0938)	(0.123)
log(Population)	0.150	-0.0387	0.0392	-0.179
	(0.0863)	(0.124)	(0.0909)	(0.116)
Large Izbas	0.0121	0.0256	0.0572*	0.0733**
	(0.0120)	(0.0188)	(0.0249)	(0.0260)
Male Literacy	0.00380	-0.00956	0.0140*	0.00907
	(0.00793)	(0.0118)	(0.00653)	(0.00752)
Observations	946	946	946	946
First-Stage F-Stat		47.002		47.002

Note: Standard errors in parentheses. * $p < 0.05$ ** $p < 0.01$ *** $p < .001$. OLS and IV use heteroskedasticity robust standard errors. The sample is all townships in the provinces of Sharqia, Daqahlia, and Qalyubia with a population less than 8,000 and positive cultivated area. IV Poisson estimates are calculated using GMM. In addition to the listed variables, all specifications include district-level and soil-quality fixed effects, log(Elevation), dummy variables for cultivating sugar or rice, and dummy variables for being on the Nile and having a saifi canal.

Table 2.4 reports estimates for irrigation pump adoption. It includes coefficient estimates for Poisson and linear specifications using both instrumental variables and specifications that treat shipping costs as exogenous. Lower shipping costs raise pump adoption across all specifications, and the estimates are highly significant. The linear IV specification indicates that, controlling for population and geographic characteristics, a 1 percent increase in shipping costs lowers the number of pumps used in a township by about .05. OLS and regular Poisson estimates are closer to zero than IV estimates. The direction of the bias indicates that areas with lower shipping costs had unobserved characteristics discouraging mechanization. One explanation is that townships with lower unobserved agricultural productivity tended to have better access to the transportation network. For example, areas with a high density of canals and drains tended to be better at cultivating summer crops, but they were also more costly to build in. Canals and drains had to be bridged, and berms had to be widened to accommodate larger trains. This was one reason narrow-gauge railways were built in the 1890's instead of extending the standard gauge network.[96] IV estimates are about 8-9 times larger in magnitude than OLS and regular Poisson specifications. Although this is sometimes indicative of a weak instrument problem, the first-stage F-statistics reported in the tables above indicate that weak instruments are not a concern. A more plausible explanation for the large difference is that estimates from the OLS and regular Poisson specifications are, in part, biased towards zero because of measurement error in the independent variable, log(Shipping Costs), in addition to bias caused by endogeneity.[97]

Cultivated acres are positively associated with agricultural mechanization, controlling for other variables, and the coefficient on population is statistically insignificant. There is no robust association between large *izbas* (estates) and agricultural mechanization. One explanation is that smaller landowners may have been able to overcome high transaction costs and collectively purchase and utilize pumps. This is consistent with research on reaper adoption in the United States.[98]

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[96]Weiner (1932)
[97]Cameron and Trivedi (2005)
[98]Olmstead (1975), Olmstead and Rhode (1995)

Table 2.5. Robustness Checks: Controlling for Distances

	(1)	(2)	(3)	(4)
log(Shipping Costs)	-14.13*	-7.256*	-6.796*	-8.315**
	(6.182)	(2.832)	(2.943)	(3.227)
log(Nile)	0.274*			
	(0.120)			
log(Sea)		0.289		
		(0.236)		
log(Damietta)			0.318	
			(0.190)	
log(Cairo)				0.102
				(0.293)
Observations	946	946	946	946
First-Stage F-Stat	7.983	50.901	46.878	47.49

Note: Standard errors in parentheses. * $p < 0.05$ ** $p < 0.01$ *** $p < .001$. Estimates from IV-Poisson model described in text. The sample is all townships in the provinces of Sharqia, Daqahlia, and Qalyubia with a population less than 8,000 and positive cultivated area. log(X) is the logarithm of the distance in kilometers from the township to X. In addition to the listed variables, all specifications include district-level and soil-quality fixed effects, log(Elevation), dummy variables for cultivating sugar or rice, and dummy variables for being on the Nile and having a saifi canal.

To address concerns related to the distance IV, I control for a number of important land marks and cities in Table 2.5. All estimates reported here are from the Poisson model. Coefficient estimates in columns (2) - (4) vary between -6.796 and -8.315, which are close to the estimates reported in Table 2.4. However, column (1) controls for distance to the Nile and has a coefficient of -14.13, which is significantly larger in magnitude than the other estimates reported in Table 2.4 and Table 2.5. The difference in column (1) may be because sample townships are all located in the Eastern Delta, with both the Nile and Alexandria lying to the west. Correlation between the logged distances to Alexandria and the Nile is 0.52, and this may explain the decrease in the first-stage F-statistic. All second-stage estimates in Table 2.5 remain significant at the 5 percent level and the F-statistics are large enough for weak instruments to not be a concern, again with the exception of the first specification.

Table 2.6. Effect of Shipping Costs on Steam Power in Manufacturing

	Probit (1)	IV Probit (2)	OLS (3)	IV (4)
log(Shipping Costs)	-0.805*	0.531	-0.147	0.220
	(0.386)	(1.668)	(0.0755)	(0.379)
log(Cultivated Area)	0.209	0.150	0.0320	0.0153
	(0.134)	(0.144)	(0.0262)	(0.0314)
log(Population)	0.578***	0.644***	0.101***	0.120***
	(0.141)	(0.158)	(0.0289)	(0.0358)
Large Izbas	-0.0131	-0.0179	0.00281	0.00138
	(0.0201)	(0.0215)	(0.00598)	(0.00610)
Male Literacy	0.0135	0.0155	0.00520**	0.00564**
	(0.0136)	(0.0148)	(0.00184)	(0.00190)
Observations	916	916	946	946
First-Stage F-Stat		47.002		47.002

Note: Standard errors in parentheses. * $p < 0.05$ ** $p < 0.01$ *** $p < .001$. The sample is all townships in the provinces of Sharqia, Daqahlia, and Qalyubia with a population less than 8,000 and positive cultivated area. In addition to the listed variables, all specifications include district-level and soil-quality fixed effects, log(Elevation), dummy variables for cultivating sugar or rice, and dummy variables for being on the Nile and having a saifi canal.

Table 2.6 reports regression estimates for the effect of shipping costs on steam power usage in manufacturing. Probit estimates are reported in the first two columns and OLS in the second two. IV estimates of the effect of shipping costs on steam-power adoption in manufacturing are imprecise and statistically indistinguishable from zero. Only the coefficient on log(Population) is statistically significant across all four columns, which is consistent with other research that found higher population was positively correlated with steam engine use in the United States and Great Britain.[99]

Table 2.7. Steam Power in Cotton Farming at Extensive Margin

	Probit (1)	IV Probit (2)	OLS (3)	IV (4)
log(Shipping Costs)	-1.204***	-5.895***	-0.346***	-1.810***
	(0.323)	(1.623)	(0.0960)	(0.483)
log(Cultivated Area)	0.721***	0.934***	0.206***	0.273***
	(0.131)	(0.139)	(0.0358)	(0.0470)
log(Population)	0.0242	-0.213	0.00437	-0.0726
	(0.125)	(0.147)	(0.0371)	(0.0475)
Large Izbas	-0.0149	0.00404	-0.00101	0.00469
	(0.0205)	(0.0233)	(0.00606)	(0.00687)
Male Literacy	0.00198	-0.00381	0.000768	-0.000987
	(0.00997)	(0.0124)	(0.00224)	(0.00265)
Observations	941	941	946	946
First-Stage F-Stat		47.002		47.002

Note: Standard errors in parentheses. * $p < 0.05$ ** $p < 0.01$ *** $p < .001$. The sample is all townships in the provinces of Sharqia, Daqahlia, and Qalyubia with a population less than 8,000 and positive cultivated area. In addition to the listed variables, all specifications include district-level and soil-quality fixed effects, log(Elevation), dummy variables for cultivating sugar or rice, and dummy variables for being on the Nile and having a saifi canal.

To check if the difference in results between steam power use in manufacturing and agriculture was driven by the extensive margin, I estimated models coding pump adoption as a binary variable. Table 2.7 shows estimates for the case where the dependent variable Y_i equals one if the township had at least one steam-powered irrigation pump. These estimates, which show the causal effect of shipping costs at the extensive margin, are statistically significant and relatively large. Using specification (4), which is a linear IV, we see that a 1

[99] Rosenberg and Tratjenberg (2004), Nuvolari et al. (2011)

percent increase in shipping costs lowers the probability that a township has a steam pump by approximately .02.

Table 2.8. Effect of Agricultural Railways on Total Pump Adoption

	# Pumps	% Change Costs	% Change Pumps	Implied Elasticity
Panel A: All Townships				
Observed	1071			
Poisson	1036	-4.61	3.38	-0.73
IV Poisson	940	-4.61	13.94	-3.02
Panel B: Agricultural Rail Reduced Costs of Shipping				
Observed	251			
Poisson	228	-15.67	10.09	-0.64
IV Poisson	107	-15.67	134.58	-8.59
Panel C: No State Rail or Waterway Access				
Observed	103			
Poisson	90	-12.91	14.44	-1.12
IV Poisson	15	-12.91	586.67	-45.43

Note: Percent increase is the estimated percentage increase in the number of pumps caused by agricultural railways. Implied elasticity is the percent change in pump adoption divided by the percent change in shipping costs due to railroad construction. Counterfactual estimates are based on the Poisson estimates reported in Table 2.4.

I use the estimates reported in Table 2.4 to evaluate the impact of Egypt's agricultural railroads on steam-power adoption in agriculture. Because no statistically significant effect was reported for local manufacturers, I do not include them in the counterfactual. This analysis relies on the assumption that railroads only affected steam pump adoption through changes in shipping costs. This is consistent with a model in which cotton farmers purchase inputs from local and overseas markets and export cotton abroad. Historical sources on cotton farming, like Willcocks (1913) and Foaden and Fletcher (1908), indicate that this is a reasonable assumption. As of 1900, agricultural railways were operating 901 kilometers of rail in the Nile Delta East of the Damietta Branch. This new railway construction increased the value of total rail track in this part of Egypt by about £820,000 and caused average shipping costs to fall by about 4.6 percent. Table 2.8 reports the implied change in irrigation pump usage as a result of this railroad construction. Panel A consider changes for the entire Eastern Delta. Poisson estimates with endogenous shipping costs, labeled IV Poisson in the table, indicate that agricultural railways caused total pump use in the eastern delta to increase by 14 percent. This implies an elasticity of -3.02 with respect to shipping costs. On the other hand, ignoring endogeneity would suggest that agricultural mechanization was inelastic with respect to transport costs.

Panels B and C consider the subset of townships that experienced changes in shipping costs and which had no rail or waterway access prior to the agricultural railroads' construction, respectively. The cost change in these townships is much larger, as is the predicted percentage change in irrigation pump adoption. For IV models, the implied elasticities are very large, showing that shipping costs played a large role in explaining pump adoption in areas where existing infrastructure was poor.

2.8. Conclusion

Foreign infrastructure investments in Egypt lowered shipping costs, allowing firms to purchase foreign inputs like coal and machinery at lower prices. This benefited cotton farmers by decreasing the cost of moving goods to Alexandria, but it may have harmed local manufacturers by increasing competition with foreign imports. I showed that lower shipping costs encouraged cotton farmers to adopt steam-powered irrigation pumps. These pumps primarily replaced ox-driven waterwheels, another capital-intensive means of production. Conversely, shipping cost reductions had little impact on local manufacturing, suggesting that increased import competition blunted the substitution effect induced by cheaper foreign inputs. These changes tended to reinforce Egypt's comparative advantage as a producer of raw commodities.

I expect that the results reported here will generalize to other contexts, but more research is still needed. I hesitate to make strong policy recommendations given the differences in technology used during the period of study and that used today. Steam engines required heavy fuel in larger quantities than similar technologies require today. Moreover, many important modern technologies, like computers, run on electricity, and firms in developing countries often produce services rather than commodities or manufactured goods. Nevertheless, policymakers considering investing in transportation infrastructure that has the primary effect of reducing trade costs between rich and poor countries should consider how lower shipping costs are likely to change incentives for technology adoption across various industries.

CHAPTER 3

The Aswan Dam's Effect on Literacy and Mortality in Colonial Egypt

3.1. Introduction

By the early 20^{th} century, the cultivation of long-staple cotton was the most important economic activity in Egypt and the cornerstone of its export-oriented development strategy.[1] Yet prior to the 19^{th} century, Egypt grew little cotton. Traditional Egyptian agriculture relied on yearly fluctuations in the Nile's water level, which meant that water was scarce during cotton's summer growing season.[2] In order to expand the amount of land that could grow cotton profitably, the Egyptian government converted land irrigated by annual Nile floods to land with irrigation available year-round by investing in canal networks and dams. The motivation behind these infrastructure investments was primarily fiscal. Muhammad 'Ali, Egypt's ruler between 1805 and 1848, monopolized cotton production and directly profited from its export. After his death, the state monopoly on cotton ended, but cotton continued to play a vital role in government revenues through land taxes and tariffs, much of which went to servicing Egypt's heavy foreign debt burden.[3] By 1900, the vast majority of arable land in the Nile Delta was planted in cotton once every two or three years, and by 1910, cotton agriculture had spread into much of the Nile Valley.[4] There's little doubt that the

[1]Issawi (1961)
[2]Richards (1982)
[3]Owen (1969)
[4]*Annuaire Statistique*

expansion of cotton cultivation was a fiscal boon for the Egyptian government, especially after the British Empire, which occupied Egypt in 1882, installed highly capable "estate managers" like Lord Cromer (Evelyn Baring).[5] A far more controversial question is whether the expansion of cotton cultivation during the 19^{th} and early 20^{th} centuries benefited the average Egyptian at all.

Prior historical research on the effects of cotton cultivation on living standards in Egypt has relied on national statistics or narrative accounts.[6] Several historians have been critical of cotton agriculture in Egypt, and they have argued that the expansion of perennial irrigation and cotton production failed to boost the incomes of poor Egyptians.[7] However, other historians have argued that year-round irrigation allowed Egyptian agricultural output to keep pace with population growth by intensifying land use.[8] In addition, some historians have criticized the spread of perennial irrigation for increasing the rural population's exposure to a number of water-borne illnesses, such as schistosomiasis, a disease caused by an intestinal parasite that infected most of the men in perennially irrigated areas.[9] The debate over cotton's legacy in Egypt mirrors current debates over expanding cash crop production in developing countries.[10] For this reason, understanding cotton agriculture's effect on living standards in Egypt could play a role in contemporary development policy, in addition to resolving an important historical question.

This chapter assesses the effect of long-staple cotton cultivation on living standards by studying a localized fall in the cost of cotton cultivation in Upper Egypt caused by the

[5]Daly (1998)
[6]See, for example, Owen (1969), Richards (1978), Richards (1982), and Hansen (1979)
[7]Owen (1969), Richards (1978)
[8]Tignor (1963), Yousef (2002)
[9]Richards (1982), Mitchell (2002)
[10]Maxwell and Fernando (1989), Wiggins et al. (2011)

construction of the first Aswan Dam in 1902.[11] Long-staple cotton was grown in the Nile Delta since the 1820's, but Upper Egypt lacked the irrigation infrastructure for its cultivation until the Egyptian government dredged a large summer canal system in the 1870's. This canal system, which was centered on the Ibrahimiya Canal, ran for over 250 kilometers through the provinces of Asyut, Minya, and Beni Suef. It did not extend the entire width of the Nile Valley, and farmland adjacent to the canal system still retained flood basin irrigation.

Until the construction of the Aswan Dam, the quality of perennial irrigation in the Ibrahimiya Canal system was poor. The summer water supply there was both meager and unreliable, which limited the amount of land planted in cotton.[12] After its construction in 1902, the Aswan Dam increased the supply and reliability of summer water in the Ibrahimiya Canal system, causing cotton production in the provinces of Asyut, Minya, and Beni Suef to triple in just a few years.[13]

The Ibrahimiya Canal system was expanded between 1902 and 1911, and an additional 405,000 acres in the Nile Valley were converted to perennial irrigation. Fertile land on the edges of the Nile Valley adjacent to perennially irrigated land was left under flood basin irrigation. These flood basins were not converted because of engineering concerns related to the health of the irrigation system in Upper Egypt, not because the land was viewed as inferior or unsuitable for perennial irrigation.[14] By lowering the cost of cotton cultivation in perennially irrigated areas, the construction of the Aswan Dam created a natural experiment in which long-staple cotton cultivation expanded rapidly in some areas while remaining unchanged in other nearby areas.

[11] After the Aswan High Dam was built in the 1960s, the first Aswan Dam came to be called the Aswan Low Dam. Throughout this chapter, I write "Aswan Dam" to refer to the dam finished in 1902.

[12] Willcocks (1913)

[13] See Table 3.2

[14] Willcocks (1913)

The main empirical analysis in this chapter uses difference-in-differences to estimate the causal effect of a reduction in the cost of growing cotton relative to other crops (the treatment) on township-level population characteristics collected from the 1897 - 1947 Egyptian censuses. Townships are the smallest unit of observation in the Egyptian censuses: they contained a few hundred to a few thousand people and were, on average, around eight square kilometers in area. I lack data on agricultural output at the township level, so I am only able to identify the intention-to-treat (ITT) effect of lowering the cost of cotton production, rather than the effect of increased cotton production itself.

I classify townships as treated or control based on their irrigation technology using historical maps of the Egyptian irrigation system. I group townships in areas that had access to perennial irrigation prior to the construction of the Aswan Dam and townships that were converted to perennial irrigation between 1902 and 1911 as a single treatment group. I incorporate district-time fixed effects to control for government policies enacted at the district level and geographic trends. On average, districts used in this chapter's main sample contained about 94,000 people and had an area of around 300 square kilometers, making Egyptian districts' geographic area smaller than most US counties. The necessary identification assumption for this analysis to recover the desired treatment effect is as follows: average trends in outcome variables would have been the same in treated and control townships within the same district but for the construction of the Aswan Dam and the subsequent fall in the cost of cotton cultivation in perennially irrigated areas.

The outcomes of interest considered in this chapter were collected from digitized versions of the Egyptian censuses that were conducted between 1897 and 1947.[15] The primary outcomes of interest I consider are chosen based on their availability in the censuses: male and

[15] CEDEJ (2003)

female literacy rates, population growth, and the number of people per dwelling. Literacy is an important goal of development programs in poor countries and is used to evaluate the efficacy of schooling.[16] Researchers have used literacy to proxy for living standards,[17] and literacy has been used as a component of several important development indices.[18] To the extent that population growth is caused by people having more surviving children or living longer, rather than from in-migration, higher population growth may reflect increases in agricultural incomes and living standards. Conversely, this relationship need not hold if the Egyptian economy was not Malthusian, a proposition considered controversial by several historians.[19] Finally, increased numbers of people per dwelling may indicate lower living standards through overcrowding, but it may also indicate an increase in fertility.

I find that the reduction in the cost of cultivating cotton due to the construction of the Aswan Dam caused large and sustained increases in literacy for both sexes. Literacy rates begin to show divergence in 1927, 25 years after the construction of the Aswan Dam, and this difference increased over time. In 1947, the treatment caused an average increase in male and female literacy of 6.10 and 2.60 percentage points, respectively, in treated areas relative to the literacy rates that would have been observed had the Aswan Dam never been built. For comparison, in 1947, only 14.48 and 3.59 percent of men and women, respectively, could read and write in control townships. Both of these findings are statistically significant at the 0.1 percent level using standard errors clustered at the township level. I find that a

[16] World Bank (2018)

[17] Kimura (1993), Kakwani (1995)

[18] Literacy is a component of the Physical Quality of Life Index and was one of the components of the Human Development Index until 2009, when it was replaced with expected years of education. See Morris (1979) and United Nations Development Program (2009). Linares-Lujan et al. (2019) is an example of a recent paper that uses literacy as a component of a development index.

[19] Lewis (1954) cited Egypt as an example of an economy with "unlimited supplies of labor." On the other hand, Hansen (1966, 1969) and Richards (1994) challenge this assertion.

decrease in the cost of cotton cultivation had no significant effect on population growth in treated areas, but it did cause an increase in the number of people per dwelling, indicating that the housing supply did not increase as fast as the population in treated areas.

One potential threat to identification involves the geographic nature of the treatment effect. Townships with access to perennial irrigation were disproportionately located in the center of the Nile Valley or near the Nile itself, while townships with flood basin irrigation were located on the periphery. Although the Nile Valley is narrow – it is no more than 25 kilometers wide in the part of Upper Egypt considered for this analysis – it is still possible that trends in population characteristics in townships closer to the Nile would have differed with those further away for reasons correlated with, but separate from, irrigation technology. Examples of these confounding factors are market access and access to transportation. To test the robustness of estimates to these concerns, I estimate the same difference-in-difference model on a restricted sample of townships within a short distance of the canals that separated flood basin and perennially-irrigated areas. I find that point estimates are robust to this sample restriction although standard errors are substantially larger.

Prior historical research suggests that perennial irrigation disproportionately increased men's exposure to water-borne illnesses, and may have, as a result, disproportionately increased male mortality. To test whether the expansion of cotton cultivation caused differential changes in the mortality rates of men and women, I estimate the same difference-in-differences model on the sex ratio, defined as the number of men per hundred women. I find that the treatment caused the sex ratio to fall in perennially irrigated areas by 2.48 and 2.73 men per hundred women in 1927 and 1937, respectively. I also find negative point estimates for 1917 and 1947, but these are not statistically significant. Although the effect of the treatment on the sex ratio in 1927 and 1937 is suggestive, it does not provide definitive evidence in favor of increased male mortality in perennially irrigated areas. Using data on age distribution and rates of widowhood that are only available in later censuses, I provide evidence of an increase in male mortality and a decrease in female mortality in townships in the treatment group, especially among older women. Below, I argue that reduced female mortality is potentially attributable to the better household bargaining position of women in cotton producing areas as a result of their marginal product in cotton agriculture being higher than for staple crops.[20]

The effect of cash crops on incomes and living standards in developing countries is controversial. On the one hand, farm households who switch to planting crops with high market prices rather than staples may experience welfare improvements if they are able to purchase a superior bundle of goods in local markets.[21] Moreover, cash crop agriculture may provide additional labor opportunities for the non-landowning rural workforce and may ease liquidity constraints, allowing the financing of land improvements, new technology, or better inputs.[22] Several researchers have found positive effects of cash crop cultivation on rural incomes[23] or food security.[24] On the other hand, some scholars have been skeptical of increasing living standards in developing countries through cash crop cultivation, arguing that the effects may be short-lived and that benefits often accrue only to the wealthy.[25] These arguments echo the concerns of Egyptian scholars about the distributional consequences of cotton agriculture. Moreover, economic historians have shown that cash crop cultivation has tended to exacerbate wealth inequality, which in turn manifests itself in inegalitarian institutions

[20] Goldin and Sokoloff (1984)
[21] Timmer (1988)
[22] Poulton et al. (2001), Govereh and Jayne (2003)
[23] Edwards (2019)
[24] von Braun (1995), Negash and Swinnen (2013), Kuma et al. (2019)
[25] Easterly (2007), World Bank (2008)

that are detrimental for long run growth.[26] Finally, another line of research has suggested that investments in cash-crop agriculture may ultimately harm poor countries by diverting investment and workers into industries with little potential for learning-by-doing over time.[27]

By studying a large expansion of cotton cultivation in Egypt, this chapter contributes to the literature about the effects of export-oriented cash crop cultivation on living standards in developing countries. My finding that literacy increased in land in which the cost of cotton cultivation fell after the construction of the Aswan Dam is in line with recent research showing that higher agricultural exports increased literacy in Brazil in states that had fewer slaves.[28] Insofar as literacy may be an indirect measure of incomes, this finding is comparable with recent research showing that incomes increased in Indonesia following an increase in palm oil production.[29] Women disproportionately benefited from cotton cultivation through lower mortality rates. To the extent that this occurred because of changes in household bargaining due to women's higher marginal product in cotton agriculture compared with wheat agriculture, it suggests that the introduction of similar cash crops in other developing countries may have similar positive distributional effects.

This chapter also builds on the literature studying the effects of irrigation dams on agriculture in developing countries. 50 percent of all dams have the primary or sole purpose of increasing irrigation. Irrigation dams can increase rural incomes by expanding irrigation for existing crops or allow farmers to switch to more lucrative cash crops. Conversely, many dams have caused environmental deterioration, displaced local populations, and adversely affected agricultural land.[30] Researchers have generally found positive effects on income and

[26] Sokoloff and Engerman (2000)
[27] Krugman (1987), Matsuyama (1992)
[28] Musacchio et al. (2014)
[29] Edwards (2019)
[30] World Commission on Dams (2000a)

agricultural production in areas downstream from the dam.[31] On the other hand, research has shown that dams can increase mortality rates by causing water quality deterioration.[32] This chapter contributes to that line of research by providing evidence that the Aswan Dam may have increased male mortality by exposing men to water-borne illnesses in perennially irrigated areas. An additional contribution made by this chapter which sets it apart from previous research on dams is using knowledge of the Egyptian irrigation system to identify which areas downstream were affected by the Aswan Dam rather than using an upstream/downstream distinction.

3.2. Perennial Irrigation and Cotton Agriculture

The Egyptian economy underwent three distinct stages during the 19^{th} and early 20^{th} centuries.[33] During the early part of the 19^{th} century, the Egyptian economy was controlled by its ruler Muhammad 'Ali, who placed most agricultural commodities, including cotton, under state monopolies. Although he attempted to force the traditional Egyptian economy to industrialize using Soviet-style methods, this attempt at rapid development failed, and most of the factories opened during his rule were forced to close down. During the reign of 'Ali's descendants, trade with Europe intensified and Egypt transformed into an export-oriented market economy centered around the cultivation of long-staple cotton. The British Empire, which occupied Egypt in 1882, maintained a liberal market policy in Egypt and reinforced the country's position as a major cotton producer. Finally, starting in the 1920's, Egypt tried and failed to transition to a more complex market economy with a diversified industrial and agricultural sectors. Egypt's industrial growth was slow in the interwar period

[31] Duflo and Pande (2007), Blanc and Strobl (2013)
[32] Mettetal (2019)
[33] Issawi (1961)

compared to similarly situated countries like Turkey, and it has failed to develop, even after achieving political independence in the 1950's.[34]

This chapter studies Egypt during the commodity-exporting stage of its economic development, when cotton was its dominant agricultural product. Figure 2.1 (Chapter 2) shows Egyptian cotton production from 1820 until the beginning of World War 1. The total amount of cotton produced in Egypt grew from close to nothing in 1820 to almost 300 million kilograms of ginned cotton in 1900. This made Egypt the third largest producer of cotton in the world, after the United States and India.[35] Changes in international cotton prices are important for explaining short-term fluctuations in Egyptian cotton production, but are less important for explaining long-term trends during this period. Instead, the reasons behind Egyptian cotton's expansion during the 19^{th} century lay on the supply side. Aside from railroad construction, a topic addressed in the previous chapter, the most important supply-side factor propelling the increase in cotton production was large infrastructure projects like canals and dams that increased the supply of water during the summertime.[36]

Rainfall is negligible in Egypt, so management of the Nile's water supply is necessary for agriculture. With the exception of farmland along the banks of the Nile, all of Upper Egypt and most of Lower Egypt used flood basin irrigation until the beginning of the 19^{th} century. The Nile's water level follows a regular yearly pattern, rising rapidly in the fall and ebbing during the summer. In flood basin areas, canals and dikes channeled the autumn floods into enclosed basins, inundating fields and depositing a layer of silt that alleviated the need for fertilizer. As water levels receded, the fields were drained and farmers sowed crops

[34] Karakoc (2014, 2017)
[35] *Annuaire Statistique*, Panza (2013)
[36] Owen (1969) p. 149 - 152

in the mud. No further irrigation was needed to grow crops planted in this way. Fields were typically cropped once a year and grew staples such as wheat, barley, and beans.[37]

Flood basin agriculture had a number of important benefits which explain its long-standing use. First, once the system of canals and basins were in place, the marginal cost of irrigation during the autumn floods was negligible. Egyptian peasants grew staples like wheat and beans with few labor inputs beyond canal maintenance and harvesting. For example, it only took 15 man-days per acre per year to cultivate wheat planted directly after the autumn flood, compared with 86 man-days per acre per year for wheat planted in the spring or grown outside of flood basins.[38] Secondly, flood basin irrigated land was less reliant on fertilizer because Nile silt replenished soil fertility. The major deficiency of flood basin irrigation was that the cost of watering fields varied throughout the year, causing spring and summer irrigation to be prohibitively expensive for most farmers.

Perennially irrigated land in Egypt is farmland with access to water in nearby canals year-round. Land along the banks of the Nile always had access to irrigation all year. This land typically specialized in staples like sorghum and millet, even after cotton became the dominant crop.[39] Infrastructure investments made over the course of the 19^{th} century, discussed below, extended year-round irrigation to agricultural land far from the Nile. By equalizing the marginal cost of irrigation throughout the year, perennial irrigation made cultivation of staples planted in the autumn more expensive, but it also allowed farmers to double-crop by planting crops in the summer. For this reason, perennial irrigation increased the total amount of land available for agriculture in Egypt by allowing more crops to be planted per acre of arable land. Although cotton was the most widely cultivated summer

[37] Richards (1982) p. 14-15
[38] Girard (1813) p. 565 - 581
[39] Richards (1982) p. 15, Willcocks (1913) p. 345

crop in perennially irrigated areas, farmers also grew cane sugar, indigo, rice, and other cash crops. The most common crop cycles included cotton, Egyptian clover, and a staple: typically wheat, corn, or beans.[40]

Despite several regime changes during the 19th century, the Egyptian government maintained a constant policy regarding cotton: grow more. Initially, Egyptian cotton production was controlled by Muhammad 'Ali as a state monopoly. He expanded cotton production in order to increase his access to foreign goods, typically industrial and military equipment.[41] 'Ali increased the land under perennial irrigation in the Nile Delta by digging deep *saifi* or summer canals that held water in the summer simply by being deep and having a steeper grade than the Nile.[42] Following Egypt's liberalization, cotton retained its importance to Egyptian government finances by allowing land taxes, which were based on the rental value of land, to be increased on cotton-producing land and by increasing trade volume, which, in turn, increased tariff revenue. As a result, the state continued to invest large sums expanding and maintaining the infrastructure necessary for perennial irrigation. For example, between 1863 and 1979, the Egyptian government spent nearly £750,000 each year on irrigation canals – about the same as it spent on railroads or on the Suez Canal.[43]

In 1873, the Egyptian government dredged the Ibrahimiya Canal, the first summer canal in Upper Egypt, providing farmland near its course with perennial irrigation. The Ibrahimiya stretches from the city of Asyut to the northern tip of Giza 250 kilometers away and runs through the provinces of Asyut, Minya, and Beni Suef. Although the canal expanded perennial irrigation into Upper Egypt for the first time, the quality of summer irrigation in the

[40]Owen (1969) p. 253
[41]Owen (1969) p. 28 - 57
[42]Rivlin (1961)
[43]Crouchley (1938) p. 117

Ibrahimiya Canal region was poor. The land did not perform as well as cotton-growing land in the Nile Delta because summer water levels were unpredictable. The Ibrahimiya lacked an intake weir and water could not be diverted from the Nile. As a result, many farmers refrained from growing cotton at all.[44]

Over the course of the 19^{th} century, the deficiencies of relying on summer canals for irrigation became apparent. Summer canals often reached depths of over 6 meters, making irrigation very costly in an era when water was often lifted only by animal or human effort.[45] In addition, summer water levels in canals were often unreliable, subjecting cotton farmers to the risk that they would not have enough water after the crops were in the ground. For these reasons, the Egyptian government began to consider the construction of large reservoirs to store flood waters that could be used during the summer cotton season. The first dam that attempted to create a large reservoir in the Nile Delta, the Delta Barrage, failed. Built on unstable river mud, the Barrage was immediately condemned after it opened in the 1860's when an attempt to close the flood gates shifted the foundation. It was not until British engineers repaired the dam in the 1880's that the dam's reservoir, located at the fork of the Nile by Cairo, was large enough to supply the Delta's water needs. Figure 2.1 (Chapter 2) shows that Egyptian cotton production increased by over 150 million kilograms within just a few years of the Barrage's repair in 1889.[46]

On the heels of the Barrage's success, the Egyptian government decided to construct a new reservoir at Aswan. The first Aswan Dam was one of the most ambitious irrigation projects build in Egypt during the 19^{th} and early 20^{th} centuries. Costing £3.5 million pounds,

[44]Willcocks (1913) p. 388 - 389
[45]Willcocks (1913) p. 766. Although steam-powered irrigation pumps were commonly used in the Nile Delta, see Chapter 2, they were rare in the Nile Valley because of the high cost of fuel.
[46]Brown (1896), Tignor (1963)

Figure 3.1. Location of Aswan and Asyut Dams

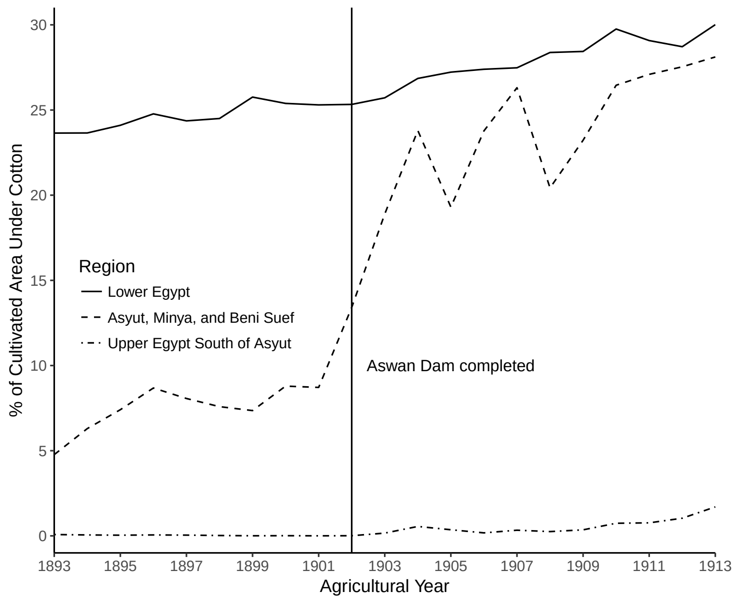
Source: Egyptian Topographic Maps

Note: Map shows the location of the Asyut Barrage and Aswan Dam as well as the area of arable land in Egypt.

it was the largest masonry dam in the world at the time of its construction in 1902.[47] Figure 3.1 shows the location of the Aswan Dam as well as another important dam, the Asyut Barrage, described below. Although Egypt's indebtedness played a major role in the events leading to British occupation, by the turn of the century Egypt's finances had recovered to the point where the dam could be paid for by government savings, plus a private loan from a European financier.[48] One unique aspect of the Aswan Dam was that it contained sluices that opened and closed, allowing Nile floodwaters to pass unimpeded. This allowed flood-basin land to function as it had prior to the dam's construction, while simultaneously creating a reservoir to improve summer irrigation.[49]

[47] Tignor (1966) p. 223
[48] Tignor (1966) p. 222
[49] Willcocks (1913) p. 681

Figure 3.2. Percent of Cultivated Area Under Cotton by Region Over Time



Source: *Annuaire Statistique de l'Egypt*

Note: Figure shows the percent of the total cultivated area planted in cotton in each region by year. Double cropped land is counted twice when computing total cultivated area. Lower Egypt consists of the provinces of Behera, Daqahlia, Gharbia, Qalyubia, Menufia, and Sharqia. Upper Egypt south of Asyut consists of the provinces of Qena, Sohag, and Aswan. The provinces of Fayum and Giza are not shown. The Egyptian agricultural year begins in September.

The Aswan Dam improved the quantity and reliability of summer irrigation throughout Egypt, but it had the largest immediate impact in areas of Upper Egypt located along the Ibrahimiya Canal. A diversion dam, the Asyut Barrage, was also completed in 1902 and diverted the additional water supplied by the Aswan Dam's reservoir into the Ibrahimiya Canal. As a consequence, the supply of summer water tripled in perennially irrigated areas of Upper Egypt and caused an immediate increase in cotton production.[50] Figure 3.2 shows the percent of cultivated area planted with cotton in three regions between the years of 1893

[50]Willcocks (1913) p. 389 states that, following the construction of the Aswan Dam, the discharge of water in the Ibrahimiya canal increased from 55 to 145 cubic meters per second.

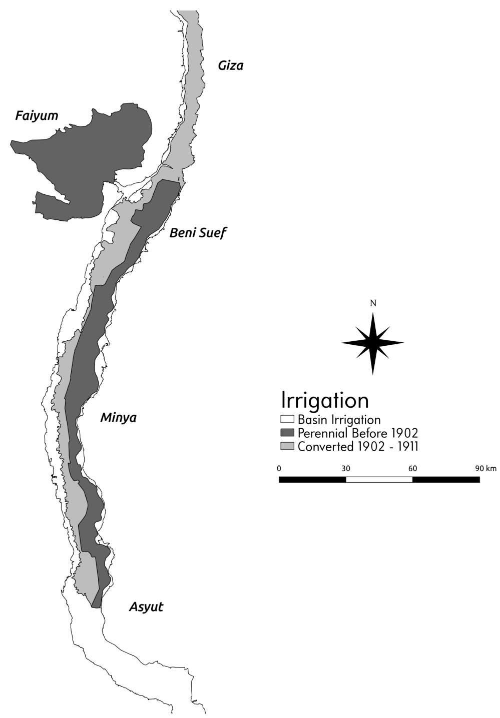
and 1913: Lower Egypt or the Nile Delta; the provinces containing the Ibrahimiya Canal system, Asyut, Minya, and Beni Suef; and Upper Egypt south of Asyut. Double-cropped land is counted twice in the denominator. Between 1902 and 1905, cotton cultivation in the three provinces that contained the Ibrahimiya canal system - Asyut, Minya, and Beni Suef - tripled from 8 percent to around 24 percent of all cultivated area. The Aswan Dam did not cause a substantial change in cotton acreage in the provinces south of Asyut. And although cotton acreage steadily rose in the Nile Delta, due in part to the water provided by the Aswan Dam, there was no trend change around 1902.

Figure 3.3 shows the location of land that retained flood basin irrigation, land along the Ibrahimiya Canal that had access to perennial irrigation prior to the construction of the Aswan Dam, and land that was converted to perennial irrigation between 1902 and 1911. After the construction of the Aswan Dam, the Egyptian Ministry of Public Works converted an additional 1,600 square kilometers of basins to perennial irrigation to take advantage of the improved water supply created by the Aswan Dam.[51] These basins lay between the Ibrahimiya Canal to the east and the Bahr Yusef, a distributary of the Nile that supplies water to the Fayum Oasis, to the west. In Giza, all basins between the Lebbeini Canal and the Nile were converted to perennial irrigation. All basins south of the city of Deirut in Asyut, basins on the eastern bank of the Nile south of Giza, and basins between the Bahr Yusef and the western desert were not converted. There were three reasons some flood basin tracts were converted but not others. First, the Aswan Dam did not store enough water for perennial irrigation to be viable everywhere. In addition to the unconverted basins along the sides of the Nile Valley, basins south of Asyut were not converted until the Aswan High Dam was built in the 1960's. The second reason had to do with the geography of the Nile Valley.

[51] Willcocks (1913) p. 343

The Nile Valley is highest in elevation near the river and slopes downward as it reaches the desert, before it rises steeply in elevation again. Because of this geographic characteristic, perennially irrigated areas located downhill from basins interfered with drainage. Finally, the government also believed that preserving flood irrigation between the western desert and the Bahr Yusef would prevent the encroachment of the desert into arable land.[52]

Figure 3.3. Irrigation Technologies in the Nile Valley North of Asyut



Source: Willcocks (1913)

Note: Map shows irrigation technologies in the five provinces of Asyut, Minya, Beni Suef, Giza, and Faiyum. Areas depicted in dark grey had access to perennial irrigation prior to the construction of the Aswan Dam in 1902. Areas depicted in light grey were converted between 1902 and 1911. Finally, areas depicted in white retained basin irrigation during the entire period of study.

[52]Willcocks(1913) p. 347

The Aswan Dam was raised twice: once between 1907 and 1912 and again in the 1930's. However, the rest of Upper Egypt was not converted to perennial irrigation until the construction of the Aswan High Dam in the 1960's. Cotton retained its preeminence in the rural economy through both World Wars and the beginning of Nasser's rule, but it began to decline in importance after 1960 to be replaced by other crops like rice, corn, fruit, and vegetables.[53]

The expansion of perennial irrigation was essential for boosting Egyptian agricultural output over the 19^{th} and early 20^{th} centuries.[54] The only fertile land in Egypt is located along the banks of the Nile and in the Delta. Some arable land was reclaimed from the desert and heavily salinated lowlands during this period, but the scope for agricultural expansion along the extensive margin was limited.[55] Agricultural output kept pace with Egyptian population growth over the early 20^{th} century because perennial irrigation allowed farmers to grow more crops on the same amount of land and to supplement staple-production with cash crops like cotton.[56]

Despite cotton's role in increasing agricultural output, historians have also been critical of Egyptian cotton agriculture for exacerbating wealth inequality. Studies addressing the distribution of wealth have typically focused on aggregate statistics or narrative accounts. For example, per-capita agricultural output and trade volumes suggest that less food and more imported goods were consumed by the average Egyptian during the 1920's and 1930's than in previous decades. Per capita income remained more or less constant over this period, suggesting a shift in the wealth distribution toward the wealthy and away from the lower

[53] Richards (1982) p. 199
[54] Yousef (2002)
[55] Karakoc (2014)
[56] Hansen and Wattleworth (1978)

classes who spent a greater proportion of their income on basic foods.[57] Perennial irrigation probably lengthened the rural workday and may have caused rural diets to decrease in quality. This is because farmers in perennially irrigated areas stopped growing beans, a traditional staple, in favor of cash crops. The caloric loss was probably offset by additional maize consumption, a crop more easily cultivated in perennially irrigated tracts, but the loss of bean protein in the diet was not offset by protein from other sources.[58] Attempts by the Egyptian government to ameliorate rural poverty have generally been viewed as ineffective or even counterproductive. For example, the Five Feddan Law passed by the British colonial government attempted to protect smallholders by making it impossible to seize farms smaller than five acres for debt non-repayment. However, this may have ultimately limited smallholders' access to rural credit and forced them to borrow through informal means at higher interest rates.[59]

Despite these criticisms, there are reasons to think that the rural lower classes may have shared in the benefits of increased overseas trade. The Egyptian population grew at an annualized rate of 0.8 percent over the course of the 19^{th} century compared with an annualized rate of 1.4 percent between 1897 and 1947.[60] It's unlikely that this change in population growth rates is due to changes in child-rearing preferences, but rather reflects improvements in child nutrition and public health. The British colonial government, which occupied Egypt in 1882, is generally viewed to have been hostile towards education during this period.[61] However, literacy increased by substantial amounts during British rule and under the interwar Egyptian government. Excluding large urban centers, rural literacy rates

[57] Hansen (1979)
[58] Richards (1978)
[59] Arcand (1996)
[60] Panzac (1987), Beinin (2006) p. 313
[61] Daly (2006) p. 243

in Egypt increased from 6.4 in 1897 to 20.9 in 1947 for males and 0.1 to 6.22 for females during this period.[62] Finally, even if cotton agriculture caused lower-class Egyptians to adopt inferior diets, this is not dispositive proof of lower living standards. Researchers have, for example, explained the improving incomes and decreasing stature in the United States during the 1840's and 50's as a result of consumers substituting away from more expensive food toward relatively cheaper manufactured goods.[63] Evidence suggests that Egyptian peasants may have also been substituting imported goods for domestic food: for example, tea and sugar consumption exploded in the countryside during the early 20^{th} century.[64]

Perennial irrigation affected living standards by increasing the Egyptian rural population's exposure to water-borne illnesses. This was because the summer canals necessary for irrigation were also ideal breeding grounds for water-borne parasites and mosquitoes, increasing the rural population's exposure to diseases like malaria, yellow fever, and bilharzia or schistosomiasis.[65] Of these diseases, schistosomiasis is most closely associated with perennial irrigation in Egypt and disproportionately affected men working in and around canals. Schistosomiasis is caused by a parasitic snail and spread by bathing or working in contaminated water. Its symptoms include anemia, chronic pain, diarrhea, under-nutrition, and chronic fatigue.[66] A 1937 study found that over 60 percent of men in perennially irrigated areas were infected with the disease compared with only around 5 percent of men in flood basin areas.[67] By the early 20^{th} century schistosomiasis had become endemic in many parts

[62] CEDEJ (2003). Numbers calculated using all Egyptian villages under 8,000 people.
[63] Komlos (1987)
[64] Hansen (1979)
[65] Richards (1982) p. 98
[66] Gray et al. (2011)
[67] Scott (1937)

of rural Egypt to the point where passing blood in the urine was considered a sign of male sexual maturity, akin to female menstruation.[68]

The evidence for increased disease morbidity in perennially irrigated areas, especially regarding schistosomiasis, is overwhelming. However, it's unclear whether heightened disease exposure translated into higher overall mortality rates. Although schistosomiasis has a number of awful symptoms, few people die from it. Despite currently infecting over 200 million people world-wide, it is directly responsible for less than 10,000 deaths each year. However, schistosomiasis may have played an indirect role in increasing mortality from other causes by weakening the immune system.[69] Therefore, it is still an open question as to whether the worse disease environment in perennially irrigated areas translated into heightened mortality rates for either sex. It's possible that higher incomes resulting from cotton agriculture or offsetting investments in public health in cotton-producing areas may have mitigated these dangers.

3.3. Data Description

All township-level data on population characteristics used in this chapter are collected from the 1897 - 1947 Egyptian censuses. Digitized versions of every Egyptian census collected between 1882 and 1996 are available on CD-ROM.[70] The 1882 census was conducted during the 'Urabi Rebellion and is believed to be unreliable, so I exclude it from my main analysis.[71] No census was conducted in 1957, and the next census was not conducted until 1966. However, it only contains population counts by gender. For this reason, I stop my analysis in 1947.

[68]Kloos and David (2002)
[69]Kloos and David (2002), GBD 2015 Mortality and Causes of Death Collaborators (2015)
[70]CEDEJ (2003)
[71]Owen (1996)

The Egyptian censuses collected between 1897 and 1947 were professionally conducted according to modern standards, and they compare favorably to contemporaneous European censuses in information quality.[72] Although some individual and household records from earlier Egyptian censuses have been digitized, scholars have yet to uncover household records from censuses conducted during the period of British colonization.[73] To my knowledge, no individual or household level records of these censuses have been made publicly available or whether they still exist at all. In particular, the 1907 and 1917 census forms were destroyed following aggregation in order to convince skeptical Egyptians that the government was not spying on them through the census.[74]

The sample used in the analyses in this chapter consists of all rural townships in the provinces of Asyut, Minya, Beni Suef, and Giza. The township or *nahiya* is the smallest level of observation in the Egyptian censuses. Egyptian townships contained several population centers, and the most typical configuration was one village and several outlying agricultural estates known as *izbas*. Some censuses consider large cities to be townships, while others assign a separate category. For this reason, I exclude large cities from the sample, in addition to townships with poor data quality. My identification strategy depends on irrigation technology variation within districts, so I excluded townships from the sample located in districts with no variation in irrigation technology.

I created the panel used in this chapter by manually matching townships between census years. Some townships split or merged during the period of analysis; in these cases, I aggregated these townships to the largest consistent unit of analysis. I located each township

[72]Owen (1996)
[73]Cuno and Reimer (1997)
[74]Owen (1996)

on a series of historical maps created between 1896 and 1923.[75] For more information, see the attached data appendix.

I classified the irrigation technology in use in each township using a map of irrigation technologies in Upper Egypt included in Willcocks (1913). I compared this map with other maps from the same period, as well as with maps from the 1940's, to verify classification accuracy and ensure that irrigation technologies did not change during the period of analysis.[76] Figure 3.3 replicates the map from Willcocks (1913) and shows the irrigation technologies in use in Upper Egypt. As explained above, land along the Ibrahimiya Canal had access to low-quality perennial irrigation prior to the construction of the Aswan Dam. I've plotted these areas in dark gray. Land converted from basin to perennial irrigation between 1902 and 1911 are shown in light gray. Land that retained basin irrigation throughout the entire period of analysis is depicted in white.

Perennial and basin irrigation were not only water-delivery technologies, they were also tax categories. Egyptian land taxes were based on land productivity, so perennially irrigated land was taxed at higher rates. Land was classified as perennially irrigated only if government-sponsored public works allowed summer crops to be grown. It was also possible for private landowners to convert land designated as basin-irrigated for tax purposes to year-round irrigation by protecting fields from floodwaters and using steam-powered pumps or *saqias* (ox-driven water wheels) for irrigation during the spring and summer. In this case the land would still be taxed as basin-irrigated.[77] The maps used in this chapter were created for tax purposes, and I do not have data on private investments. However, the historical

[75]Egyptian Topographic Maps
[76]Egyptian Topographic Maps, U.S. Army Map Service
[77]Willcocks (1913) p. 366

literature indicates that land designated as basin-irrigated for tax purposes was rarely converted to year-round irrigation by private landowners. In 1912, cotton produced in tracts designated as basin-irrigated for tax purposes accounted for only three percent of all cotton production in Upper Egypt, despite basin tracts accounting for over 50 percent of all arable land in that region. The presence of perennially irrigated fields in land designated as basin irrigation for tax-purposes would tend to bias results toward zero, and this should be borne in mind when interpreting results below. To my knowledge, the reverse did not occur, and perennially irrigated land was never converted to basin irrigation.

A third category of land with characteristics of both flood basin and perennial irrigation was land located directly on the elevated banks of the Nile. This land had access to a year-round water supply but was also subject to flooding in the fall. Instead of cotton, this land was typically planted in sorghum or millet during the summer.[78] However, for tax purposes, this land was most commonly categorized as basin-irrigated in Upper Egypt. To maintain a clear comparison between perennially irrigated land that grew cotton and land that retained flood-basin agriculture, I exclude all townships within a half kilometer of the banks of the Nile in the analysis that follows.

Table 3.1 lists the availability of each variable by census. Township population by sex, literacy rates by sex, and the percentage of the population that is non-Muslim are available for each year. The number of people per dwelling is only available until the 1927 census because the number of houses or dwellings in each township is not reported in the 1937 and 1947 censuses. Other variables of interest such as population by age group, employment by sector, and the rates of male and female widowhood are only reported in censuses conducted in 1917 or later.

[78]Richards (1982) p. 15, Willcocks (1913) p. 345

Table 3.1. Data Availability in each Egyptian Census

Variable	1897	1907	1917	1927	1937	1947
Population by sex	✓	✓	✓	✓	✓	✓
Literacy rates	✓	✓	✓	✓	✓	✓
People per dwelling	✓	✓	✓	✓		
Percent foreign	✓			✓	✓	✓
Percent non-Muslim	✓	✓	✓	✓	✓	✓
Population by age group				✓	✓	✓
Employment by sector				✓	✓	✓

Source: CEDEJ (2003)

Note: Table reports the availability of each variable at the township-level in Egyptian decennial censuses collected between 1897 and 1947. Literacy rates are calculated by dividing the number of literate men or women in each township by their respective population. In 1897, 1907, and 1917 literate men and women are recorded regardless of age, whereas in 1927, 1937, and 1947 only literate men and women over the age of five are recorded. People per dwelling is calculated by dividing the township's population by the number of occupied houses and shops (1897) or the number of houses (1907, 1917, 1927).

Table 3.2 compares population statistics between townships in the treated and control groups in 1897, the census prior to the construction of the Aswan Dam. The total sample size is 511 townships. There are 142 townships that retained basin irrigation throughout the period of study and 369 townships that experienced a decrease in the cost of long-staple cotton cultivation following the construction of the Aswan Dam. Treatment townships include townships in land that was perennially irrigated prior to 1902 and land that was converted to perennial irrigation between 1902 and 1911. There are statistically significant differences between groups in several measures. On average, townships in the control group were less densely populated, had more people per dwelling, were less literate, and had higher sex ratios than townships in the treated group.

Table 3.2. Comparison of Townships in Treated and Control Groups Prior to the Aswan Dam's Construction

	Control		Treatment			
	Mean	SD	Mean	SD	Difference	t
Population	1897.07	(1632.33)	2151.30	(1652.45)	-254.22	(-1.57)
Area (km^2)	8.41	(6.77)	6.94	(5.00)	1.47*	(2.36)
People/km^2	265.52	(137.26)	369.13	(270.27)	-103.61***	(-5.70)
People/dwelling	6.70	(1.77)	6.10	(0.85)	0.60***	(3.89)
Male Literacy Rate	4.32	(2.97)	5.31	(3.07)	-1.00***	(-3.36)
Female Literacy Rate	0.03	(0.13)	0.03	(0.10)	-0.00	(-0.11)
Sex Ratio	103.74	(6.15)	102.42	(5.51)	1.32*	(2.23)
% Men List Profession	61.18	(13.88)	60.75	(11.85)	0.43	(0.32)
% Women List Profession	0.21	(0.49)	0.34	(0.45)	-0.13**	(-2.76)
% non-Muslim	11.01	(19.13)	10.21	(15.77)	0.79	(0.44)
% Foreign	0.02	(0.14)	0.03	(0.18)	-0.01	(-0.44)
Townships	142		369		511	

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^* p < 0.05$ $^{**} p < 0.01$ $^{***} p < 0.001$. This table shows summary statistics as of 1897 for the treatment and control groups, the difference between sample means, and the t-statistic for the null hypothesis that the population means are identical. The control group is defined as townships which retained flood basin irrigation throughout the period of study. The treatment group are townships that experienced a decrease in the cost of summer cash crop cultivation due to the construction of the Aswan Dam. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded. Male and female literacy rates are reported as percents. The sex ratio is defined as the number of men per 100 women.

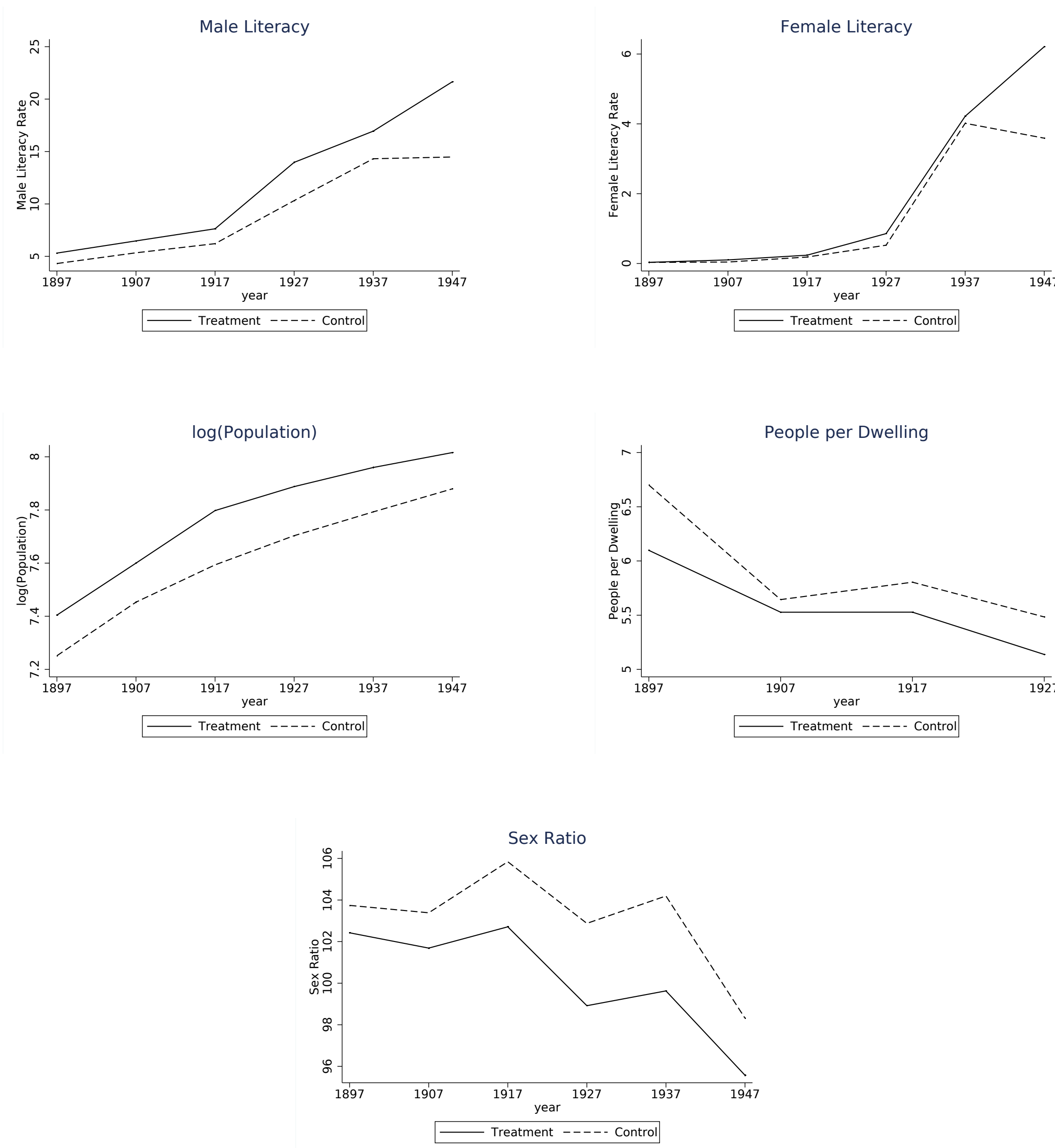
I address discrepancies in the treatment and control group by conditioning on district-year fixed effects in all difference-in-differences estimates as well as estimating pre-trends for all outcomes of interest. Systematic differences between treatment and control groups are a threat to identification only if these differences are indicative of different within-district trends over time.

3.4. Effects of Cheaper Cotton Cultivation on Population Characteristics

Figure 3.4 shows changes in mean population characteristics over time for treatment and control groups. Male and female literacy increased at about the same pace in treatment and control areas until 1917. After 1917, male and female literacy rates in the treated townships began increasing faster than for townships in the control group, and this difference increased over time. We see that literacy actually fell for women in control areas between 1937 and 1947. Log(population) in treated and control areas increased at about the same rate over the period studied. The gap between treatment and control townships in the number of people per dwelling falls in 1907 before increasing again in 1917 and 1927. Trends on people per dwelling are not shown for 1937 and 1947 due to a lack of data availability. Sex ratios in treated and control townships fell over time, and we see that the average sex ratio in treatment and control townships diverged between 1907 and 1917. This gap persists for two decades before sex ratios begin to converge in 1947. While Figure 3.4 is useful for establishing a frame of reference for interpreting a causal effect, the plots shown here fail to separate out the role of inherent township characteristics and district-wide trends that may induce bias.

I use difference-in-differences to identify the causal effect of interest: a sudden and sustained decrease in the cost of long-staple cotton cultivation in perennially irrigated areas caused by the construction of the Aswan Dam. I estimate this model on the same variables shown in Figure 3.4: male and female literacy, log(population), the number of people per dwelling, and the sex ratio. This identification strategy controls for fixed township characteristics, such as geographic location and soil quality. I incorporate district-year fixed effects to control for geographic trends or policies enacted at the district level. Thus, this analysis compares changes in the outcome of interest between townships within the same district

Figure 3.4. Changes in Mean Population Characteristics Over Time



Source: CEDEJ (2003)

Note: Figure shows changes in average male literacy, female literacy, log(population), people per dwelling, and the sex ratio in treatment and control areas over time. The sex ratio is defined as the number of men per 100 women. Male and female literacy are reported as percentages.

over time. The identifying assumption necessary for this model to uncover the causal effect of interest is that changes in outcome variables would have been the same for treated and control townships within the same district but for the construction of the Aswan Dam and the fall in the cost of cotton cultivation in perennially irrigated areas.

The timing of the treatment varies by township because some basins were converted to perennial irrigation after 1907. I assume that the treatment effect is the same for each township in a particular year: for example, the treatment effect for 1917 is the same for all townships with access to perennial irrigation following the construction of the Aswan Dam, regardless of whether the first year of the treatment was 1902 or 1911.

Let y denote an outcome of interest, i the township, d the district, and t the census year. Let D_{it} be a binary variable equal to 1 if the township is in the treated group. Let T_0^i be the baseline census – the first census year prior to the treatment taking place. For townships that were converted prior to 1907, $T_0^i = 1897$. For townships that were converted between 1907 and 1911, $T_0^i = 1907$. The estimated equation is

$$y_{it} = D_{it}\Big[\rho\mathbb{I}\{t < T_0^i\} + \beta_t\mathbb{I}\{t > T_0^i\}\Big] + \alpha_i + \gamma_{dt} + \epsilon_{it} \tag{3.1}$$

α_i is a fixed-township characteristic, γ_{dt} is a district-year fixed effect, and ϵ_{it} is a random disturbance that varies at the observation-year level. I assume that ϵ_{it} may be correlated over time but not across townships. β_t is the estimated treatment effect for year t, if $t > T_0^i$. The pretrend ρ is identified using the 1897 census because some townships have 1907 as their baseline census.

Table 3.3 shows the results of estimating the above model on the township-level sample described above for the following outcome variables: male and female literacy, log(population), and the number of people per dwelling. I examine changes in the sex ratio in a separate table below. Standard errors clustered at the township-level are reported in parentheses. For each outcome variable, I also include specifications that exclude district-year fixed effects in order to measure the bias caused by failing to control for district-year trends.

Columns (2) and (5) of Table 3.3 show that the treatment caused male and female literacy to increase by 2.041 and 0.336 percentage points in 1927, respectively, controlling for district-year fixed effects. The effect for 1937 is similar for both groups, although it is more imprecise. In 1947, average male literacy in the control group was only 14.50, implying that the treatment caused nearly a 42 percent increase in male literacy over the control group. For women, the treatment caused a 70 percent increase over the control group in 1947. There is little difference in point estimates or standard errors between specifications which include and exclude district-year fixed effects. The estimate reported for ρ finds no evidence of a pre-trend in treated areas. Finally, because changes in the educational environment are unlikely to show benefits in the short-term, the lack of a positive and significant coefficient in 1907 and 1917 can be seen as a sanity check.

Table 3.3. Effect of Treatment on Literacy Rates, Population Growth, and People per Dwelling

	Male Literacy			Female Literacy			log(Population)		People per Dwelling	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ρ	-0.427	0.276	0.266	-0.0667	0.204	0.203	-0.0428	-0.138**	0.333***	0.463**
	(0.446)	(0.651)	(0.645)	(0.136)	(0.192)	(0.191)	(0.0258)	(0.0428)	(0.0808)	(0.163)
β_{1907}	-0.0254	0.191	0.150	0.0346	0.137	0.133	-0.0225	-0.0605	0.614***	0.813***
	(0.374)	(0.404)	(0.397)	(0.0625)	(0.0751)	(0.0744)	(0.0287)	(0.0385)	(0.183)	(0.234)
β_{1917}	0.259	0.545	0.488	0.0261	0.118	0.113	0.0349	-0.0121	0.453**	0.626**
	(0.378)	(0.434)	(0.427)	(0.0585)	(0.0709)	(0.0702)	(0.0315)	(0.0417)	(0.165)	(0.218)
β_{1927}	2.490***	2.041***	1.956***	0.305**	0.336*	0.329*	0.0153	-0.0327	0.384*	0.586*
	(0.512)	(0.543)	(0.540)	(0.110)	(0.131)	(0.131)	(0.0349)	(0.0424)	(0.173)	(0.228)
β_{1937}	1.472	1.460	1.378	0.174	0.259	0.252	-0.00226	-0.0465		
	(0.761)	(0.877)	(0.876)	(0.234)	(0.237)	(0.237)	(0.0379)	(0.0458)		
β_{1947}	6.013***	6.096***	6.014***	2.593***	2.593***	2.586***	-0.0328	-0.0766		
	(0.856)	(0.942)	(0.944)	(0.440)	(0.467)	(0.466)	(0.0399)	(0.0488)		
% non-Muslim			0.0755*			0.00654				
			(0.0346)			(0.0121)				
Townships	511	511	511	511	511	511	511	511	511	511
R^2	0.765	0.784	0.784	0.669	0.696	0.696	0.958	0.961	0.636	0.668
District-Year FE		✓	✓		✓	✓		✓		✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$. Standard errors clustered at the township level are in parentheses. Table shows the effects of a decrease in the cost of cotton cultivation on male and female literacy rates, log(Population) and the number of people per dwelling. The estimated equation is described in the text. β_{1907} is the estimated treatment effect for 1907, etc. ρ is the estimated pretrend coefficient. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

Prior research has indicated that non-Muslim Egyptian minorities such as Coptic Christians tended to be better educated than the majority Muslim population during this period.[79] If ethnic minorities were more mobile in response to economic opportunities, then it's possible that changes in literacy could be caused by differential migration rates or differential fertility of Muslims and non-Muslims. In order to control for this potential source of bias, columns (3) and (6) include an additional variable in the regression: the percent of the population that is non-Muslim. Results reported in Table 3.3 indicate that point estimates change little with the addition this control variable, lending no support to the hypothesis that changes in the non-Muslim population relative to majority Muslims are responsible for the estimated positive effect of the treatment on literacy rates. We see that the estimated coefficient in columns (3) and (6) are positive, as predicted by prior research. Only the coefficient estimate for male literacy rates is statistically significant at the 5 percent level. The estimates in column (3) indicate that the magnitude of the treatment effect in 1947 on male literacy rates is around 80 times larger than increasing the non-Muslim population by a single percentage point.

Increases in literacy attainment in perennially irrigated areas may have been due to a number of factors. One explanation is that cotton agriculture may have increased incomes, thereby increasing parental willingness to invest in their children's education and forego the contribution of each child to household production while being educated. Another potential explanation is that the returns to human capital increased in cotton producing areas, due, potentially, to job opportunities in transportation and other sectors related to cotton agriculture. I explore this possibility below, but find no sustained increase in labor market opportunities outside of agriculture in cotton-producing areas.

[79] Saleh (2016)

Columns (7) and (8) report estimates for log(population). Once district-year fixed effects are controlled for, there's no evidence of a change in population in treated areas. I find a statistically-significant and negative pretrend in population for treated townships, suggesting that population grew more quickly in treated townships prior to the baseline year. Point estimates for subsequent years are negative and imprecisely estimated. On the one hand, if agricultural incomes increased in townships that were able to grow cotton more cheaply, and if the Upper Egyptian agricultural economy could be reasonably classified as Malthusian, then it is surprising that I do not find positive and statistically significant estimates for any year. One explanation may be that incomes increased but Upper Egypt did not, in fact, conform to a simple Malthusian model. Some historians have embraced this point of view.[80] On the other hand, it's possible that the increase in cotton agriculture simply did not cause an increase in agricultural incomes for most of the population aside from the wealthy. This is consistent with the views of many historians that the benefits of cotton agriculture in Egypt accrued primarily to the wealthy, as well as evidence that national per-capita income remained stagnant during the period of study despite an increase in cotton agriculture.[81]

It may have been the case that increases in income, as a result of the switch to cotton agriculture, accrued mainly to those households who were not constraining their fertility. Because they were already choosing the optimal quantity of children, additional income was invested in their children's education. On the other hand, households that were constraining their fertility as a result of lower incomes may not have experienced income increases at all. This explanation is plausible given that male literacy in sample townships was no higher than 25 percent, on average, at the end of the period of study, which suggests that most families

[80] Mitchell (1991)
[81] Owen (1969), Richards (1982), Hansen (1979)

were not educating their children. Because I lack data on land or wealth distributions within townships, it is not possible for me to empirically test this hypothesis.

Columns (9) and (10) show estimates for the number of people per dwelling in each township. Estimates are not shown for 1937 and 1947 because data on occupancy are not available in these years. Results indicate that the treatment caused the number of people per dwelling to increase by more than half of a person for each census year between 1907 and 1927. However, I also find evidence of a positive pre-trend, indicating that the number of people per dwelling was higher in treated areas, controlling for township-level and district-year fixed effects, prior to the baseline year and then fell. In the following sections, I use additional census data to test whether changes in fertility patterns or mortality rates may be behind the observed changes in log(population) and people per dwelling.

My difference-in-differences identification strategy relies on the assumption that counterfactual trends in the absence of the construction of the Aswan Dam would have been the same in treated and control areas. One potential threat to identification is that trends, unrelated to the treatment, may have differed in control and treated townships for simple geographic reasons. As I mentioned above, townships located within half a kilometer of the Nile are excluded from the analysis. However, townships in treated areas are still closer to the Nile and other means of transportation, like railroads, which tended to run adjacent to the river. Consequently, one potential source of bias is that the treatment effect may be measuring better access to transportation or market integration rather than the desired treatment effect. Note that this is a relevant concern only if the effects of better transportation or market integration changed over time.

To address these concerns, I perform a robustness check in which I restrict the sample of townships to those within short distances of the canals that divided perennially irrigated land from land that retained flood basin irrigation over the period of study. I've chosen distances of 500 meters and 1 kilometer because a moderate number of townships in several districts fall within these distances, and because these distances are not large enough to create an economically meaningful difference in transportation costs. Tables 3.4 and 3.5 report the results of these exercises for literacy rates and population changes, respectively. As with Table 3.3, I report estimates both including and excluding district-year fixed effects. For literacy rates, all estimates control for the percentage of the population that is non-Muslim.

Table 3.4 indicates that point estimates for literacy are robust to restricting the sample to townships near the dividing canals. However, estimate precision is lower. Examining specifications which consider townships within 1 kilometer of the dividing canals, columns (4) and (8) of Table 3.4 show that treatment effects for male and female literacy are both statistically significant at the 10 percent level in 1947. For specifications restricted to townships within 500 meters of the dividing canals, column (2) shows that the treatment effect for male literacy in 1947 is also significant at the 10 percent level. However, column (6) indicates this is not the case for women.

Table 3.5 shows estimates for log(population) and the number of people per dwelling on the restricted sample. For log(population), estimates are larger in magnitude than in the unrestricted sample, although they remain statistically insignificant at the 5 percent level. For the number of people per dwelling, the estimated effects are approximately double that of the unrestricted sample. On the one hand, we see that the sign of the estimates does not change after restricting the sample. On the other hand, these results suggest that estimates for the unrestricted sample may underestimate the magnitude of the treatment effect, however the level of imprecision in the estimates of Table 3.5 make it difficult to draw firm conclusions.

Table 3.4. Effect of Treatment on Literacy for Sample of Townships Near Dividing Canals

	Male Literacy				Female Literacy			
	Within 500 meters		Within 1 km		Within 500 meters		Within 1 km	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ρ	-0.700	-0.373	-0.530	0.0723	0.0551	0.273	-0.0551	0.155
	(1.150)	(2.148)	(1.048)	(1.704)	(0.368)	(0.614)	(0.324)	(0.466)
β_{1907}	-0.581	-0.682	-0.357	-0.369	-0.00574	0.0562	-0.00689	0.0366
	(0.788)	(1.063)	(0.730)	(0.985)	(0.140)	(0.231)	(0.140)	(0.207)
β_{1917}	-0.805	-0.618	-0.523	-0.397	-0.0288	0.0219	-0.00148	0.0643
	(0.840)	(1.121)	(0.749)	(1.016)	(0.141)	(0.233)	(0.142)	(0.217)
β_{1927}	1.013	1.094	0.991	1.091	0.113	0.146	0.268	0.342
	(1.090)	(1.286)	(0.970)	(1.162)	(0.286)	(0.314)	(0.263)	(0.305)
β_{1937}	1.131	1.830	0.758	1.246	0.421	0.933	0.198	0.615
	(1.747)	(2.261)	(1.475)	(1.884)	(0.559)	(0.661)	(0.466)	(0.543)
β_{1947}	4.190*	4.445	4.272*	3.979	1.882	1.792	2.168*	1.736
	(1.907)	(2.410)	(1.649)	(2.015)	(0.954)	(1.186)	(0.834)	(0.947)
Townships	103	103	132	132	103	103	132	132
R^2	0.705	0.746	0.689	0.741	0.610	0.670	0.596	0.686
District-Year FE		✓		✓		✓		✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$. Standard errors clustered at the township level are in parentheses. Table shows the effects of a decrease in the cost of cotton cultivation on male and female literacy rates for the sample of townships near the canals that divided basin irrigated land from land converted to perennial irrigation after 1902. The dividing canals are the Bahr Yusef south of the Fayum Oasis and the Lebbeini Canal north of Fayum. The estimated equation is described in the text. β_{1907} is the estimated treatment effect for 1907, etc. ρ is the estimated pretrend coefficient. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

Table 3.6 tests whether the decrease in the cost of cotton cultivation in perennially irrigated areas caused changes in male mortality relative to that of women. In the absence of sex-specific migration, additional male mortality or decreased female mortality can be seen

Table 3.5. Effect of Treatment on log(Population) and People per Dwelling for Sample of Townships Near Dividing Canals

	log(Population)				People per Dwelling			
	Within 500 meters		Within 1 km		Within 500 meters		Within 1 km	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ρ	-0.0238	-0.300*	-0.00693	-0.267**	0.338	1.255	0.426	1.304*
	(0.0656)	(0.118)	(0.0557)	(0.0977)	(0.224)	(0.723)	(0.225)	(0.613)
β_{1907}	-0.0959	-0.229*	-0.0566	-0.190*	1.108*	1.418*	0.998**	1.344*
	(0.0717)	(0.0993)	(0.0631)	(0.0918)	(0.458)	(0.654)	(0.381)	(0.565)
β_{1917}	-0.0612	-0.181	-0.0167	-0.139	0.951*	1.247*	0.735*	1.107*
	(0.0746)	(0.104)	(0.0638)	(0.0892)	(0.424)	(0.615)	(0.356)	(0.545)
β_{1927}	-0.0887	-0.186	-0.0190	-0.127	0.938*	1.301*	0.726	1.158*
	(0.0735)	(0.100)	(0.0639)	(0.0882)	(0.442)	(0.640)	(0.370)	(0.564)
β_{1937}	-0.0846	-0.167	-0.0475	-0.121				
	(0.0762)	(0.101)	(0.0687)	(0.0896)				
β_{1947}	-0.107	-0.187	-0.0665	-0.138				
	(0.0829)	(0.105)	(0.0735)	(0.0934)				
Townships	103	103	132	132	103	103	132	132
R^2	0.955	0.965	0.959	0.971	0.522	0.695	0.525	0.652
District-Year FE		✓		✓		✓		✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$. Standard errors clustered at the township level are in parentheses. Table shows the effects of a decrease in the cost of cotton cultivation on log(population) and the number of people per dwelling for the sample of townships near the canals that divided basin irrigated land from land converted to perennial irrigation after 1902. The dividing canals are the Bahr Yusef south of the Fayum Oasis and the Lebbeini Canal north of Fayum. The estimated equation is described in the text. The base year is the census prior to the decrease in the cost of cotton cultivation. β_{1907} is the estimated treatment effect for 1907, etc. ρ is the estimated pretrend coefficient. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

by a fall in the sex ratio, here defined as the number of men per hundred women. Estimates using the full sample and samples restricted to townships near the dividing canals are both shown. Column (2), which contains the preferred specification with district-year fixed effects, indicates that the sex ratio fell in treated areas relative to the control townships for several years before recovering in 1947. The treatment caused there to be 2.479 and 2.727 fewer men per 100 women in perennially irrigated areas in 1927 and 1937, respectively. Columns (4) and (6) indicate that point estimates are robust to restricting the sample to townships near the dividing canals, however standard errors are large relative to the estimated effect.

3.5. Testing for Changes in Mortality

The previous section demonstrates that a sudden decrease in the cost of cotton cultivation in perennially irrigated areas caused the sex ratio to fall. In this section, I analyze this result and attempt to determine whether this was due to differential changes in mortality for men and women. In line with the prior historical literature, the evidence I examine in this section points to an increase in male mortality in treated areas. However, I also find evidence of a decrease in female mortality, especially among the elderly. To my knowledge, no prior researcher has found a similar result or made a similar claim. I provide several pieces of evidence to support higher male mortality and lower female mortality. First, I find that age distributions for women in treated townships tend to skew older, indicating more elderly women relative to young women in treated townships, whereas distributions for men tend to skew younger. Next, I compare sex ratios by age group and find that there are significantly fewer men per hundred women in older age groups in treated townships, with little difference in younger age groups.

Taking into account data limitations, I attempt to measure differences in cohort attrition between treated and control townships. In the absence of migration, cohort attrition is the same as cohort mortality. I demonstrate that if it is assumed that age distributions are equal in treated and control townships in 1907, implied cohort attrition for women is

Table 3.6. Effect of Treatment on Sex Ratio

	Full Township Sample		Restricted to Near Dividing Canals			
			Within 500 meters		Within 1 km	
	(1)	(2)	(3)	(4)	(5)	(6)
ρ	1.416*	-0.0128	-2.447	-1.307	-1.059	-0.130
	(0.694)	(0.951)	(2.531)	(2.675)	(2.415)	(2.440)
β_{1907}	0.166	-0.375	-1.239	-0.785	-0.590	-0.333
	(0.834)	(0.877)	(1.734)	(1.847)	(1.706)	(1.809)
β_{1917}	-1.266	-1.322	0.391	1.597	1.050	1.921
	(0.861)	(0.900)	(1.881)	(1.851)	(1.811)	(1.843)
β_{1927}	-2.096*	-2.479*	-2.566	-2.105	-1.559	-1.448
	(0.908)	(0.970)	(1.873)	(1.923)	(1.861)	(1.871)
β_{1937}	-2.702**	-2.727**	-3.417	-3.149	-2.959	-2.777
	(0.940)	(1.011)	(2.001)	(2.270)	(1.920)	(2.102)
β_{1947}	-0.880	-0.513	-1.313	-0.481	-0.742	-0.144
	(0.954)	(0.974)	(2.021)	(2.201)	(1.911)	(2.031)
Townships	511	511	103	103	132	132
R^2	0.546	0.579	0.527	0.562	0.516	0.562
District-Year FE		✓		✓		✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}\, p < 0.05$ $^{**}\, p < 0.01$ $^{***}\, p < 0.001$. Standard errors clustered at the township level are in parentheses. Table shows the effects of a decrease in the cost of cotton cultivation on log(population) and the number of people per dwelling for the sample of townships near the canals that divided basin irrigated land from land converted to perennial irrigation after 1902. The dividing canals are the Bahr Yusef south of the Fayum Oasis and the Lebbeini Canal north of Fayum. The estimated equation is described in the text. The base year is the census prior to the decrease in the cost of cotton cultivation. β_{1907} is the estimated treatment effect for 1907, etc. ρ is the estimated pretrend coefficient. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

significantly lower in treated townships. I find no statistically significant difference in male cohort attrition in any age group between treated and control areas. Finally, I look at data on widows and widowers directly. I find that the treatment caused an increase in the percentage of women who identify as widows with little change for male widowers. Although the lack of an increase in cohort attrition in treated areas for males is not consistent with an increase in male mortality, the rest of the evidence suggests that male mortality increased while female mortality fell.

The major competing explanation for the fall in the sex ratio is sex-specific migration patterns. Because there are fewer men per 100 women in treated areas, this argument implies a greater out-migration of men from cotton-producing areas, perhaps to urban centers or to agricultural opportunities elsewhere. However, the data does not support this hypothesis. When I examine sex ratios by age group, I find no indication that there are fewer working age men relative to working age women in treated areas.

For all of the analyses in this section, rather than naively compare treatment and control means, I use the following OLS model to measure differences between treatment and control townships:

$$y_i = \beta D_{it} + X_i' \xi + \gamma_d + \epsilon_i \tag{3.2}$$

where y_i is a population characteristic of interest measured at the township level, X_i is a vector of population characteristics measured prior to the baseline year, and γ_d is a district-level fixed effect.

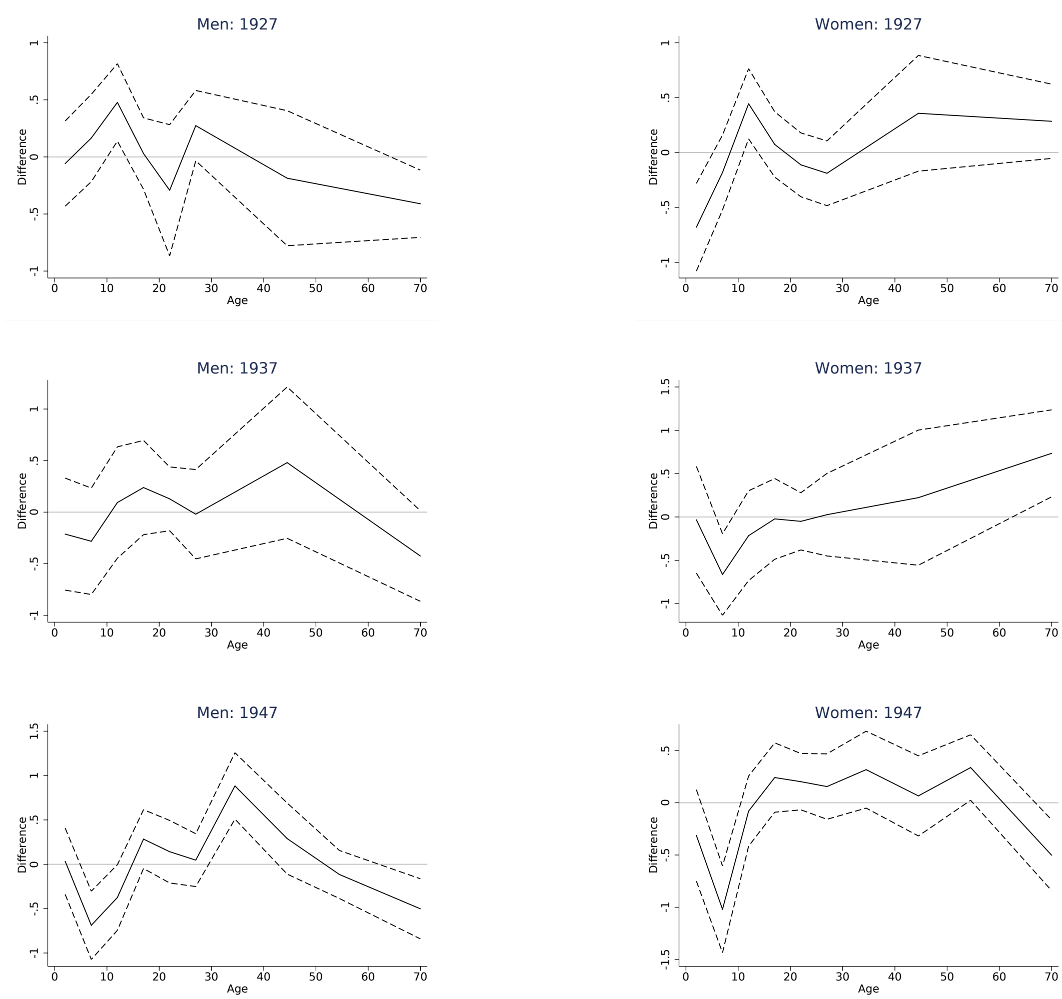
I use OLS rather than difference-in-differences because of data limitations. In order for the coefficient of interest β to have a causal interpretation, we must make stronger assumptions than those that were necessary for the difference-in-differences setting in Section 3.4. In particular, it must be assumed that the treatment is uncorrelated with omitted characteristics that affect the outcomes of interest once district-level characteristics and measured pre-baseline characteristics are controlled for.

First, I consider differences between treatment and control townships in the percentage of men and women in each age group. Figure 3.5 shows coefficient estimates for β and 95 percent confidence intervals for men and women for 1927, 1937, and 1947. Looking first at men, I find few statistically significant differences between the percentage of men in each group in treated and control areas. A notable exception is the 10-14 age group in 1927, which is larger in treated townships controlling for baseline population characteristics and district-level fixed effects. I find a similar effect for women in 1927. There is little difference between treated and control townships for men in 1937. However, for men in 1947, I find a very different pattern. There is a larger percentage of men in the 30-40 age group in treated areas, and there is also a smaller percentage in the 5-9 and over 60 age group.

Figure 3.5 shows that the age distribution for women in treated areas tends to skew older. In particular, we see that there are a greater percentage of women in the over 60 age group in treated areas in both 1927 and 1937. However, by 1947 this has reversed, and we find a smaller percentage of women in the over 60 age group in treated areas compared with control townships. This is consistent with the small coefficient estimate for 1947 shown in Table 3.6 above.

Figure 3.6 shows the same model estimated on differences in the sex ratio by age group. In all three census years, 1927, 1937, and 1947, I find that there are significantly fewer men in the over 60 age group than there are women, controlling for baseline township characteristics and district-level fixed effects. In 1927 this is also true for men in the $30-59$ age group and in 1947 for the $50-59$ age group. Estimates are smaller or close to zero for most other years and age ranges. It's unlikely that these differences in the sex ratio by age grouping can be

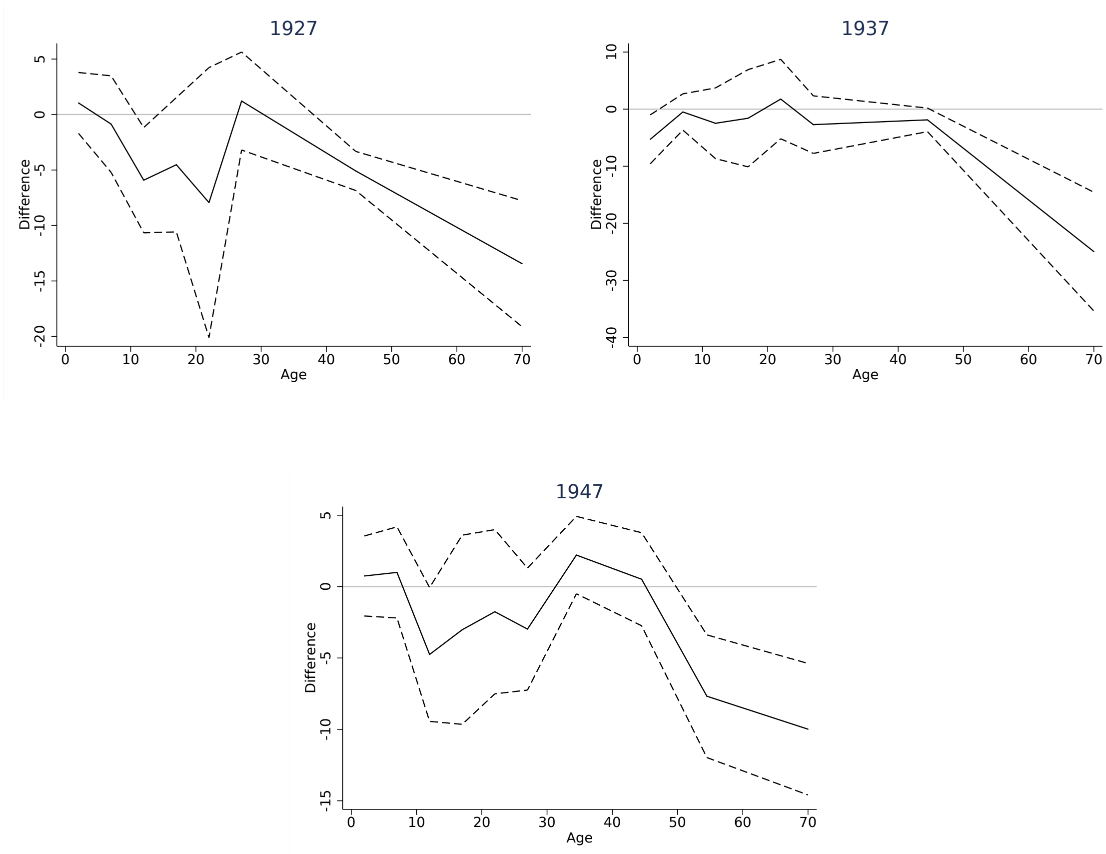
Figure 3.5. Difference Between Treatment and Control Areas in Percentage of Men and Women in Each Age Group



Source: CEDEJ (2003)

Note: Figures show the coefficient estimates and 95 percent confidence intervals for estimating the model $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$ on the percentage of men and women in each age group. Men and women with unknown ages are dropped from the analysis. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Coefficient estimates are shown by the solid line and confidence intervals are indicated by the dashed lines. Confidence intervals are constructed using heteroskedasticity robust standard errors. Age groups recorded in the 1927 and 1937 censuses are $0-4$, $5-9$, $10-14$, $15-19$, $20-24$, $25-29$, $30-59$, and over 60. The 1947 census includes age groups for $30-39$, $40-49$, and $50-59$. Estimates are plotted at the mid-point of each age group with the exception of over 60, which is plotted at 70.

Figure 3.6. Difference Between Treatment and Control Areas in Sex Ratio in Each Age Group



Source: CEDEJ (2003)

Note: Figures show the coefficient estimates and 95 percent confidence intervals for β in the model $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$. The outcome variable y_i is the sex ratio by age group in each township. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Coefficient estimates are shown by the solid line and confidence intervals are indicated by the dashed lines. Confidence intervals are constructed using heteroskedasticity robust standard errors. Age groups recorded in the 1927 and 1937 censuses are $0-4$, $5-9$, $10-14$, $15-19$, $20-24$, $25-29$, $30-59$, and over 60. The 1947 census includes age groups for $30-39$, $40-49$, and $50-59$. Estimates are plotted at the mid-point of each age group with the exception of over 60, which is plotted at 70.

explained by differential migration among men and women. This would imply that elderly men were leaving perennially-irrigated areas en-masse while elderly women were staying, or that elderly women were in-migrating in large numbers. A more plausible conclusion is that male mortality among elderly men increased in treated areas, mortality for elderly women fell, or both. The fact that age distributions for women in treated areas tend to skew older while distributions for men skew younger suggest that both factors are at play.

Table 3.7. Difference in Rates of Male and Female Widowhood in Treatment and Control Townships

	% Men are Widowers			% Women are Widows		
	1917	1937	1947	1917	1937	1947
	(1)	(2)	(3)	(4)	(5)	(6)
β	-0.162	-0.0710	-0.0560	0.834***	1.355***	0.934***
	(0.0841)	(0.0754)	(0.120)	(0.246)	(0.220)	(0.264)
Control Mean	1.323	1.716	1.780	10.651	10.841	12.918
Townships	511	511	511	511	511	511
R^2	0.145	0.128	0.0861	0.271	0.314	0.220
District FE	✓	✓	✓	✓	✓	✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.01$. Heteroskedasticity robust standard errors in parentheses. The estimated equation is $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$. The outcomes of interest are the percent of men (women) who are widowers (widows) in the 1917, 1937, and 1947 Egyptian censuses. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

Table 3.7 shows the result of regressing the percentage of men and women who are widows or widowers on the model indicated above; the year 1927 is omitted from the tables due to data availability. This table shows that the conversion to perennial irrigation had a negligible effect on rates of male widowhood, which overall was quite low. Between 1917 and 1947, no more than 1.78 percent of all men reported being widowers in a given year.

On the other hand, the treatment had a statistically significant effect on the number of women identifying as widows in all censuses that measure widowhood. In the 1937 census, for example, there is a 1.355 percentage point difference between the rates of widowhood in treated and control townships, controlling for baseline characteristics and district-level fixed effects – an approximately 12.5 percent increase over the control group.

These results should be interpreted carefully. First, the low rate of male widowhood is probably indicative of a large number of men remarrying after their wives died rather than nearly all women surviving their spouses. Secondly, the higher incidence of female widowhood in perennially irrigated areas is not, in itself, evidence of higher male mortality. It may also, at least in part, indicate a decrease in female mortality, potentially caused by higher incomes or a redistribution of household resources, that caused women to outlive their husbands at greater rates.

Age distributions are not available at the township level prior to 1927, but a national age distribution is available for 1907. I perform a simple exercise in which I impute the national age distribution in 1907 to each township in 1907 and then calculate cohort attrition between 1907 and 1927, defined as the percentage decrease in the 1907 age cohort between 1907 and 1927. For example, the cohort of men under the age of 10 in 1907 are between 20 and 29 in 1927. The idea behind this exercise is that, if we assume that treated and control areas had similar age distributions in 1907, any differences in cohort attrition between 1907 and 1927 are caused by differences in mortality rates or in-migration rates.

Table 3.8 shows the results of this exercise. As for other models in this section, I control for township characteristics measured in the baseline year and district-level fixed effects. Age cohorts from the 1907 census were chosen to match data availability in 1927. I find that cohort attrition in treated areas was lower for both men and women than in control areas,

Table 3.8. Difference in Imputed Cohort Attrition Between Treatment and Control Townships

	Men			Women		
Cohort in 1907:	Under 10	10 - 40	40 plus	Under 10	10 - 40	40 plus
	(1)	(2)	(3)	(4)	(5)	(6)
β	-1.445	-1.648	1.627	-2.878	-5.857*	-3.729**
	(2.679)	(2.195)	(1.499)	(2.280)	(2.287)	(1.275)
Control Mean	36.076	20.162	56.697	24.058	15.873	60.564
Townships	511	511	511	511	511	511
R^2	0.0456	0.0399	0.101	0.0508	0.0444	0.134
District FE	✓	✓	✓	✓	✓	✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.01$. Heteroskedasticity robust standard errors in parentheses. The estimated equation is $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$. The outcome of interest is imputed cohort attrition. The size of cohorts in 1907 is imputed using the national age distribution reported in the 1907 census. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

barring men over the age of 40. However the difference is only statistically significant for women over the age of 10. For women who were between 10 and 40 in 1907, and therefore are over 60 in 1927, their cohort size fell by 5.857 percentage points less in perennially irrigated areas, compared with a control group mean of 15.873 percent. In other words, cohort attrition was approximately one-third lower in perennially irrigated areas for women in this age group. Taking this exercise at face value requires assuming that the age distribution in each village was exactly that of the national distribution in 1907. However, assuming that the distribution in each village was close, these estimates provide additional evidence that mortality fell for women in perennially irrigated areas, especially for those women in their middle to old age.

3.6. Discussion and Conclusion

This chapter demonstrates that the sudden decrease in the cost of growing long-staple cotton in perennially irrigated areas following the construction of the Aswan Dam increased literacy rates for both men and women over the long term. Acquiring the ability to read was costly in a mostly agricultural society, and literacy may have had limited applicability in many rural occupations. The increase in literacy in perennially irrigated areas following the construction of the Aswan Dam could indicate increased job opportunities in jobs which required a literate workforce or that an increase in incomes allowed parents to bear the cost of educating their children, including the opportunity cost of their children's household production.

To test whether an increase in jobs requiring a literate workforce may have been behind the increase in literacy rates, I estimate the model used in Section 3.5 on the percent of men and women employed in non-agricultural occupations in each township. Results are shown in Table 3.9. I find that there were a greater percentage of men employed outside of agriculture in 1927 in treated townships, but the magnitude of these coefficient estimates falls over time. Estimates for women are close to zero or negative. Therefore, I find no evidence that more opportunities for work outside of agriculture was driving these changes. This analysis does not, however, rule out the possibility of greater returns to human capital in treated townships within occupations.

In Section 3.4, I found that population growth did not increase in treated townships but the number of people per dwelling did. One possible explanation for this is lower overall mortality, especially among the elderly. This would be this case if the decline in female mortality was significantly less than the corresponding increase in male mortality, and, as such,

Table 3.9. Difference in Percent of Workforce Employed Outside of Agriculture Between Treatment and Control Areas

	Men			Women		
	1927	1937	1947	1927	1937	1947
	(1)	(2)	(3)	(4)	(5)	(6)
β	1.866*	0.175	0.0735	0.123	-2.448	-0.692
	(0.877)	(0.783)	(0.925)	(0.604)	(1.349)	(0.794)
Control Mean	42.849	36.642	41.342	96.645	94.163	39.329
Townships	511	511	511	511	511	511
R^2	0.295	0.412	0.445	0.101	0.0702	0.512
District FE	✓	✓	✓	✓	✓	✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}\, p < 0.05$ $^{**}\, p < 0.01$ $^{***}\, p < 0.001$. Heteroskedasticity robust standard errors in parentheses. The estimated equation is $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$. The outcome of interest is the percentage of the workforce employed in a non-agricultural job. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

more adults were living in the same household. For this to be the case and for population to not grow faster in perennially irrigated areas, we would expect fertility to fall as well. Table 3.10 shows the differences between treated and control townships in fertility measured as the number of children under 5 per 100 women ages 15 to 60 for census years 1927 - 1947. Ages 15 to 60 are used because age blocks reported in the census do not permit an earlier cutoff for female infertility. As before, I control for observable baseline population characteristics and district-level fixed effects. For all three years, 1927, 1937, and 1947, the point estimate is negative and is statistically significant in 1927 and 1947. I find that women in treated areas had, on average, between 1.45 and 2.25 fewer surviving children in all three census years.

Table 3.10. Difference in Fertility Between Treatment and Control Areas

	1927 (1)	1937 (2)	1947 (3)
β	-2.244**	-1.454	-1.769*
	(0.756)	(1.212)	(0.818)
Control Mean	50.097	46.500	41.326
Townships	511	511	511
R^2	0.225	0.102	0.321
District FE	✓	✓	✓

Source: CEDEJ (2003)

Note: Asterisks denote significance: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$. Heteroskedasticity robust standard errors in parentheses. The estimated equation is $y_i = \beta D_{it} + X_i'\xi + \gamma_d + \epsilon_i$. The outcome of interest is fertility, defined as the number of children under 5 per 100 women age 15 to 60. X_i is a vector of baseline year controls and includes township area, population, people per dwelling, percent non-Muslim, male and female literacy rates, the sex ratio, the percent of the population that is foreign, and the percent of men and women that list professions. Townships located within 500 meters of the Nile, that are urban, and which were not reliably matched across census years are excluded from the analysis. Townships located in districts with no variation in irrigation type have also been excluded.

All but the point estimates for the 1937 census are statistically significant. Data limitations do not allow me to separate parental fertility choices from differences in infant mortality.

In this chapter, I've shown that the drop in the cost of long-staple cotton cultivation caused by the construction of the Aswan Dam caused literacy rates to increase in perennially irrigated areas. I've also argued that increased cotton cultivation led to an increase in male mortality as well as a decrease in female mortality. One plausible explanation for the differential changes in mortality rates is that men were exposed to a higher disease burden as a consequence of working in and around irrigation canals while women increased their access to resources affecting their well-being.

Egyptian women played an important role in agricultural production during this period, especially in cotton agriculture. Their labor, as well as that of their children, were essential during the cotton harvest. Islamic law also recognized women's individual ownership rights over various types of movable property, including livestock and agricultural implements. Women often owned this property as a result of inheritance or through their bride price, and they retained individual control over this property even after marriage. Their control over this property increased their barganing position within the household. [82] The higher productivity of women in cotton agriculture seems to have been consistent across different countries; for example, women working in cotton agriculture in the United States earned higher wages relative to men than did women working in wheat agriculture.[83] As a result of a greater contribution to household production, or, possibly, as a result of greater ownership of movable property in cotton-producing areas, women may have acquired increased bargaining power, allowing them greater command over household resources. This, in turn, would explain the fall in women's mortality in cotton-producing areas. Alternatively, the fall in women's mortality may be the result of increased incomes.

Composite living standards, such as the Human Development Index, frequently measure living standards as a combination of health, income, and education.[84] I've shown that two components of these indices improved for women in cotton producing areas after the construction of the Aswan Dam. Men experienced gains in education, but these gains may have been offset by decreases in their life expectancy as well as lower quality of life due to an

[82]Tucker (1991) p. 40 - 63
[83]Goldin and Sokoloff (1984)
[84]Morris (1979), United Nations Development Program (2009)

increased disease burden. Evidence of higher incomes is mixed. On the one hand, the increase in literacy in cotton-producing areas suggests that households had more income to invest in their children's education. On the other hand, the lack of a population increase contradicts the Malthusian model, which predicts that higher incomes should cause population increases. One way to explain these apparent discrepancies is that higher incomes primarily accrued to those who were not constraining their fertility. They then used this income to invest in their children's literacy.

The results provided in this chapter indicate a more nuanced interpretation of the effects of cotton agriculture on living standards for the Egyptian population than is typically presented in the literature. Studies that focus on incomes at the expense of other aspects of living standards miss important improvements, especially for women. The mechanism for the increase in literacy rates in cotton-producing areas is still uncertain, and future historical research would be useful in this area.

CHAPTER 4

Egypt's Experience Under Colonialism

The British occupation of Egypt (1882 - 1922) set the stage for the previous two chapters on Egyptian economic history. The feature distinguishing the British colonial administration's economic policy in Egypt from its predecessors was neither its liberalism nor its emphasis on agricultural commodity production. Egypt had adopted liberal economic policies during the reigns of the last two independent Khedives, Sa'id and Isma'il, and agricultural commodity production and export were central to the economic policies of every 19^{th} century Egyptian ruler. Instead, the main difference between the British colonial administration and its predecessor regime, the independent-in-all-but-name Khedivate run by the successors of Muhammad 'Ali, was its ability to execute large development projects, like the Aswan Dam, successfully and at a reasonable expense. The post-independence Egyptian government continued British economic policy, for the most part, but it placed a greater emphasis on education and industrial development.

Egypt's colonial experience was different from other colonies in Africa and Asia because its sought-after commodity, cotton, was widely produced, both in terms of geography and in terms of the percentage of the population employed in its production. As a result, infrastructure projects that increased cotton production or facilitated its export tended to benefit many Egyptians rather than just a wealthy elite. This final essay places Chapters 2 and 3 in a unified historical context. I explain how the empirical findings and historical issues discussed in those chapters contribute to our overall understanding of Egyptian economic development and the legacy of colonialism in Egypt.

The centrality of agriculture in Egyptian economic policy during the 19^{th} and early 20^{th} centuries came as a result of Egypt's comparative advantage in agriculture and its weak industrial base. Egypt has some of the most productive agricultural land in the world, capable of growing multiple crops each year without the need for a long fallow. By virtue of its arid climate and ample water supply, Egyptian farmers were able to cultivate sought-after agricultural commodities, like long-staple cotton, sugar, and indigo.[1] At the same time, and tabling for a moment Muhammad 'Ali's attempt to expand factory production, the vast majority of Egyptian manufacturing was restricted to small firms producing traditional handicrafts. Egypt's poorly educated population and its lack of natural resources like fuel, metals, and wood were major barriers in the way of attempting to develop a modern industrial base capable of producing substitutes for foreign imports, let alone being competitive with domestically-produced goods in other countries. Thus, it's no wonder that Egyptian rulers during this period, including Muhammad 'Ali, his successors, and the British colonial administration, sought to develop Egypt's economy along agricultural lines.[2]

Muhammad 'Ali's (1805 - 1848) most important economic innovation was the overhaul of the system of rural taxation and administration, allowing him to exercise an unprecedented degree of control over Egypt's agricultural production. To do this, he imposed state monopolies on grain and other staples, as well as on cash crops like indigo and cotton, forcing peasants to sell their harvest to government warehouses and buy back crops for personal consumption at inflated prices. 'Ali eliminated tax farming and greatly diminished the power of

[1] For a description of Egyptian agriculture in the early 19^{th} century, see Richards (1982) p. 6-19.
[2] See Issawi (1982) p. 150-154 for a description of industrial activity in Egypt and other Middle Eastern countries during the early 19^{th} century.

local sheikhs and village headmen. As a result, he made peasants directly answerable to the state and centralized power within the national government.[3] By increasing state capacity, he was able to undertake large public works projects, such as dredging summer canals in the Nile Delta. The main purpose of 'Ali's reforms was increasing government revenue in order to expand Egypt's armed forces. Because 'Ali had illegally seized power, his position as the Khedive (Viceroy) of Egypt was only accepted by the Ottoman Empire because it lacked the force to dislodge him. His policies worked: after a series of military defeats in the 1830's, the Ottoman Sultan formally recognized Muhammad 'Ali as the hereditary ruler of Egypt.[4]

Despite the success of 'Ali's agricultural policies in expanding Egyptian state capacity and freeing up funds for his military campaigns, some historians have instead emphasized 'Ali's failed attempt to industrialize Egypt using Soviet-style methods, considering it a great missed opportunity.[5] However, 'Ali's primary motivation was not economic development *per se*. Rather, it was ensuring that he had access to military supplies if Egypt was embargoed or blockaded – a realistic concern given his expansionist foreign policy and European naval superiority – or if Egypt's terms of trade became too unfavorable.[6] Factories built during his rule typically produced military equipment, like guns and powder, or goods with both military and commercial applications, like cotton textiles. Keeping these factories running required both protectionism and significant cross-subsidization from the agricultural sector. For example, raw materials, like cotton, were purchased from farmers at state-mandated

[3]Cuno (1992)

[4]Sources on Muhammad 'Ali's economic policies are Rivlin (1961), Owen (1969), and Fahmy (1998).

[5]Quote is from Allen (2014). Issawi (1961) compares 'Ali's industrial policy to that of the Soviet Union. Works that treat 'Ali's economic policies in a sympathetic light are Batou (1990), Allen (2014), and Williamson and Panza (2015).

[6]Dunn (1997)

prices and supplied to factories at a discount. Rather than pay market wages to staff his factories, 'Ali resorted to kidnapping peasants and using them as forced labor.[7]

Given enough time, it's possible that productivity improvements could have allowed these factories to become efficient enough to operate without state subsidization and forced labor, but the system collapsed before this happened. By the mid 1830's, state monopolies on agricultural products and high taxes had impoverished peasants, causing them to reduce output or flee their homes for cities and towns. This reduced government revenue from agriculture at the same time that international cotton prices collapsed, forcing 'Ali to close down a number of factories in order to remain solvent. One positive economic spillover from 'Ali's 'industrial experiment' was increased demand for skilled technical workers and engineers. State-run technical schools were established, and some Egyptians studied engineering and other technical subjects at European universities. While these spillover effects helped create a native Egyptian professional class, most of the Egyptian population remained poorly educated.[8]

The Egyptian economy began liberalizing under 'Ali's successors as a result of domestic and international pressures. The Turko-Circassian rural elite, which had been imported to Egypt by 'Ali in order to maintain control over the native Egyptian population, demanded freedom from state monopolies and more direct control over peasants under their administration. At the same time, treaties concluded between the Ottoman Empire and European powers forbade state monopolies on agricultural products and permitted European merchants to deal directly with producers. Egypt was legally a part of the Ottoman Empire and therefore subject to these treaties, despite having achieved *de facto* independence. Although

[7]See Panza and Williamson (2015) for a succinct overview of 'Ali's factory system, written from an economist's perspective.
[8]Fahmy (1998)

'Ali and his successors sometimes circumvented these treaties, they ultimately complied in order to retain good relations with Istanbul and the European powers. Finally, this period witnessed the creation of free markets in land and greater commercial penetration of the countryside.[9]

The Egyptian government embarked on a number of ambitious development projects prior to British colonization, but many of these projects achieved only limited success. I've discussed the largest of these failed projects, the ill-fated Delta Barrage, in previous chapters. Construction of the dam began under Muhammad 'Ali and finished in 1861 after a series of starts and stops. It was immediately condemned, and it functioned, basically, as a very expensive bridge for more than twenty years until it was repaired by British engineers shortly after the 1882 occupation.[10] The economic motivation underlying the Delta Barrage was sound: cotton production in the Nile Delta nearly tripled after the dam's repair, speeding Egypt's financial recovery. Had the Delta Barrage started working in 1861 rather than in the late 1880's, Egypt's financial position in the 1870's would have been significantly improved.

The Delta Barrage is but one example of an ambitious and sensible project that was botched by poor execution. The Ibrahimiya Canal, built during the 1870's, was intended to spread perennial irrigation into the Nile Valley. However, the canal failed to achieve its goal because it lacked an intake weir and had an insufficient supply of water during the summertime until the Aswan Dam was constructed in 1902.[11] In part because of the failure of these development projects, Egypt's debt grew significantly during the 1860's and 1870's, increasing borrowing costs and forcing it to sell important assets at a bargain. The Egyptian government contributed a significant amount to the financing of the Suez Canal, and supplied

[9]Owen (1969), Hunter (1998)
[10]See Brown (1896) for a history of the Delta Barrage and its repair.
[11]See discussion in Chapter 3

the forced labor used in its construction, but indebtedness during the late 1870's forced the government to sell its shares in the canal at well below their actual value.[12] As a result, British and French shareholders benefited financially from the Canal's construction, while the Egyptian government did not.[13]

This series of failed development projects, especially in contrast with later British successes, raises the question of why the Khedivate spent large amounts of money on overly ambitious projects despite lacking the skill to implement them. I am not able to give a complete answer, but part of the reason seems to have been that the Khedivate depended on foreign experts to implement these projects. The European engineers and financiers, and later, European bureaucrats in the Egyptian administration, who marketed these projects to the Khedives were less interested in Egyptian development than they were in making a profit and extending European influence. Eager to develop Egypt quickly, the Khedives were ready to believe their claims.[14] The British colonial administration, on the other hand, had access to world-class in-house experts, many of whom had years of practical experience in India.[15] As a result, there were few conflicts of interest between administrators and the engineers in charge of designing and implementing development projects.

After occupying Egypt and taking moral, if not legal, responsibility for Egypt's repayment of international debts, the British colonial administration needed to increase government revenues quickly and sustainably. Increasing cotton cultivation was an obvious solution because it played into a British strength, irrigation engineering, and raised government

[12]Farnie (1969)

[13]Hansen and Tourk (1978)

[14]Owen (1969) p. 56 - 57. Also see Landes (1958) for a biography of one of these financiers, Edouard Dervieu, who became the personal banker of the Khedive.

[15]For example, both Lord Cromer (Evelyn Baring) and the engineer William Willcocks, who designed many Egyptian irrigation projects, including the Aswan Dam, had spent their early careers in India. See Tignor (1963a) and Owen (1965).

revenue through higher land taxes and export tariffs.[16] Cotton was widely cultivated in Egypt, so most farmers in the Nile Delta and, after 1902, in much of the Nile Valley benefited from British efforts to increase cotton cultivation. Likewise, transportation improvements, like the agricultural railroads discussed in Chapter 2 as well as the more than 2,000 kilometers of agricultural roads built during British rule, benefited most of the population rather than just a narrow group of elites. Agricultural production grew as a result of these successful projects, raising living standards for most Egyptians between 1882 and 1907.[17] Part of the reason that individual infrastructure projects, like the Delta Barrage and the Aswan Dam, were so important in raising Egyptian output is because of Egypt's unique geography. The Nile is Egypt's only water source, and more than 99 percent of the population lived within thirty kilometers of the Nile or in the Nile Delta during the period of study. As a result, a single irrigation project that changed how the Nile functioned could have a massive impact and affect a significant proportion of the population.

In spite of early successes, Egypt's economic history in the early 20^{th} century demonstrates the limitations of an export-oriented development strategy. Because new land was constrained on the extensive margin by the desert, and because most land could not be farmed more intensively without soil deterioration, Egyptian agricultural output growth increased but slowly, just keeping ahead of population growth.[18]

Industrial growth during British occupation was limited, but it's unclear to what extent this was hampered by British policy as opposed to structural constraints within Egypt. By maintaining the rule of law and credibly assuring entrepreneurs their investments would not be expropriated, the British colonial government attracted foreign investment. Capital

[16] Tignor (1963b)
[17] Hansen (1979), Daly (1998)
[18] Hansen and Wattleworth (1978)

investments in Egyptian firms increased substantially during this period, and the value of fixed capital in the Egyptian manufacturing sector is estimated to have more than doubled.[19] Nevertheless, Egypt's manufacturing sector remained underdeveloped into the 1930's and Britain's role in this stagnant growth is controversial.[20] Although Britain was willing to support certain industries, such as the bailout of sugar refineries in the first decade of the 1900's, it failed to lend support to, and may have actively hindered, other industries that were in competition with British imports. For example, cotton textile producers in Egypt were forced to pay a countervailing duty on their finished products so that they would not have an 'advantage' over imported textiles. The countervailing duty was cited as an immediate cause of one textile factory's collapse in 1907, and it's likely that another factory would have shut down if it had not been granted a reprieve from the duty by the government.[21]

In Chapter 2, I demonstrated that colonial-era transportation improvements encouraged technological adoption in Egypt's agricultural sector, but I also argued that competition from foreign imports impeded technological adoption in local manufacturing by offsetting the effects of lower transportation costs. The lack of technological adoption among local manufacturers and the failure or tepid performance of large manufacturers during the early 20^{th} century imply a low-level of productivity growth in Egyptian manufacturing. This is in line with previous research that shows that infant industries in developing nations increase in productivity very slowly without direct and continuous support from the government.[22]

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[19] Owen (1993), p. 233 - 240

[20] Owen (1993) p. 239 describes the controversy and cites Rothstein (1910) as an example of a critical work. Owen is less critical of British industrial policy, and sites the numerous structural hurdles in place of establishing industry at the time. Also see Owen (1966).

[21] Owen (1993) p. 237

[22] See Bell, Ross-Larson, and Westphal (1984). Sauré (2007) formalizes some of the observations made by Bell et al. (1984) and argues that when domestic producers have access to an alternative 'traditional' production technology that is initially cheaper but which lacks potential for productivity growth, firms using the traditional technology will out-compete firms using the advanced technology because firms do not

Britain's support for free trade may have been self-interested, but concerns that industry protection would raise prices without off-setting benefits as a result of productivity growth may have been well-founded.[23]

British education efforts were lackluster and have received considerable scrutiny from historians.[24] The British colonial administration reduced overall education funding, especially for technical and higher education. This was partly as a result of parsimony – Egypt's debt required the government to make extensive budget cuts – and partly due to the fear that university graduates could become a force for nationalism in Egypt, like they had in India. Those Egyptians who sought modern educations typically avoided technical fields, and instead studied the humanities and law. This was most likely because non-technical fields opened the door to higher salary occupations in the Egyptian bureaucracy, but cultural prejudices against manual labor may have also played a role.[25] Lord Cromer summed up British education policy in Egypt as promoting "the three r's in the vernacular, nothing more," and literacy growth was modestly positive during the British occupation.[26] However, data from Egyptian decennial censuses indicate that literacy increased significantly faster after Egyptian independence in 1922 than in the previous decades.[27]

In Chapter 3, I used the construction of the Aswan Dam in Upper Egypt as a natural experiment to evaluate the long-term impacts of increased cotton cultivation. I found that cotton cultivation caused literacy to increase at a faster rate relative to nearby areas that lacked access to year-round irrigation. Thus, it's possible that the British occupation of

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internalize dynamic productivity gains. As a result, firms do not use the more advanced technology and, in the long run, no productivity growth will occur.

[23]Lord Cromer supported free trade policies in Egypt for this reason, see Owen (1966)

[24]Headrick (1988), Daly (1998)

[25]Headrick (1988) p. 309 - 312

[26]Headrick (1988) p. 310

[27]CEDEJ (2003)

Egypt increased literacy attainment indirectly by spreading perennial irrigation. In addition, my study found that increased cotton cultivation tended to lower women's mortality. I argued this may have been due to a more equitable distribution of household resources as a result of women's higher productivity in cotton agriculture. An indirect effect of British occupation may, therefore, have been increasing gender equity in health outcomes.

Egypt's experience under colonialism differed in many ways from other countries in Africa and Asia that were colonized during the 19^{th} and early 20^{th} centuries. In some colonies, like the Belgian Congo and the Dutch East Indies, sought-after commodities were produced in a limited geographic area and production was often controlled directly by European firms.[28] Many of these countries had poor climates or adverse disease environments which discouraged settlement, and research has shown that this has tended to promote the adoption of extractive institutions.[29] This was not the case in Egypt, where cotton was widely produced and most cotton farms were owned by native Egyptians or non-Western proprietors. Egypt's dry climate and proximity to Europe attracted a sizeable ex-patriot community.[30]

One historical parallel to the Egyptian experience is British India, especially after the Crown took control from the East India Company in 1858. The British colonial administration maintained a liberal economic policy in both countries and did much to improve their agriculture and transportation infrastructure.[31] Because India's main value to the British Empire lay in agriculture, the colonial administration invested in genuine public goods, especially railroads and irrigation infrastructure. National income is difficult to estimate for the 19^{th} century with a high degree of accuracy, nevertheless available statistics suggest that

[28]See Booth (2015) for a comparison of the colonial experiences of the Democratic Republic of the Congo and Indonesia.
[29]Acemoglu, Johnson, and Robinson (2001)
[30]Tignor (1980)
[31]Whitcombe (1983)

total agricultural output in India grew substantially between 1860 and 1920 and kept well ahead of population, as it did in Egypt.[32] Despite these similarities, there were important differences between Egypt and India. Like Egypt, India was a major cotton exporter, but it had a more diversified agricultural sector and exported manufactured products made from locally produced materials, especially cotton and jute textiles.[33] The post-colonial decline of manufacturing in India was more pronounced than in Egypt, which had very little industry at all prior to the 19^{th} century, and India's manufacturing sector also recovered faster in the early 20^{th} century.[34] Additionally, water scarcity played a much greater role in India than it did in Egypt. India periodically experienced famines that killed millions of people well into the 20^{th} century, and an important goal of British irrigation projects in India was mitigating this loss of life.[35] Although Egypt had historically experienced famines, management of the Nile's water level prevented catastrophic fluctuations in Egyptian harvests by the end of the 19^{th} century.[36]

Recently, interest in the economic history of Egypt and other non-western countries has increased, but research by economic historians on non-western countries still lags behind research on those countries in Western Europe and North America that became advanced economies during the 19^{th} and 20^{th} centuries.[37] One reason behind the slow progress of research on non-Western countries is data availability. Western governments began collecting systematic economic data and Western firms began systematizing and archiving their business records before this became standard procedure in most parts of the world. However, as

[32]Heston (1983)
[33]Blattman, Hwang, and Williamson (2007)
[34]Morris (1983)
[35]Roy (2019)
[36]Richards (1982)
[37]Schirmer et al. (2010)

recent research by economic historians has been making clear, and as Chapters 2 and 3 of this dissertation demonstrate in the case of Egypt, colonial administrations often undertook similar data collection exercises in nations under their control.

There is still much we do not understand about the effects of colonialism on Egypt and other countries. The questions explored in Chapters 2 and 3 of this dissertation – the effect of transportation infrastructure on technology adoption and the effect of cash crops on living standards – are still relevant to understanding the economics of developing countries today. Given the global nature of colonialism in the 19^{th} and early 20^{th} centuries, most countries in the developing world were introduced to new cash crops and new ways of moving goods and people that substantially lowered trade costs with the West. Future research that builds on the answers provided here by bringing in new datasets, from Egypt or other former colonies, as well as new theoretical or empirical approaches would help improve our understanding of these issues.

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APPENDIX

Appendix to Chapter 1

In this appendix, I report coefficient estimates for two alternative samples. The first includes Western states and territories. The second sample excludes the Western census region but includes both movers, those men who lived in different counties in 1850 and 1860, and non-movers, those who lived in the same county in 1850 and 1860.

Tables A1 and Tables A2 show multinomial logit coefficient estimates for the sample that includes Western states and territories. Table A1 shows estimates for whites and non-whites. Table A2 shows estimates for foreign-born whites, native-born whites, white farmers, and white non-farmers. All estimates include destination-specific fixed effects.

Tables A3 and Tables A4 show multinomial logit coefficient estimates for the sample that includes both movers and non-movers. Western states and territories are not included in this sample. Table A3 shows estimates for whites and non-whites. Table A4 shows estimates for foreign-born whites, native-born whites, white farmers, and white non-farmers. As with the previous tables, all estimates show include destination-specific fixed effects. Figure A1 shows a map of the geographic distribution of fixed effects for native-born whites, again for the sample that includes movers and non-movers, and Figure A2 shows likewise for foreign-born whites.

Table A1. Multinomial Logit Coefficient Estimates for Whites and Nonwhites; Sample Includes Western States and Territories

	Whites (1)		Non-whites (2)	
Variable	Coeff.	SE	Coeff.	SE
Distance E-W	-0.220	(0.002)	-0.456	(0.020)
Distance E-W^2	0.008	(0.000)	0.016	(0.001)
Distance N-S	-0.910	(0.006)	-0.942	(0.045)
Distance N-S^2	0.073	(0.001)	0.084	(0.010)
Own State	1.546	(0.007)	1.430	(0.059)
Out-of-State Network	0.883	(0.008)	0.644	(0.067)
Δ Ag. Commodity Mix	-0.023	(0.000)	-0.026	(0.002)
Origin Counties	614		403	
Destination Counties	1578		1578	
Number of People	196460		3516	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for whites and nonwhites. All models are estimated with destination-specific fixed effects. Variable definitions are described in Table 1.3.

Table A2. Multinomial Logit Coefficient Estimates for Foreign Born, Native Born, Farmers, and Non-farmers; Sample Includes Western States and Territories

	Native Born (1)		Foreign Born (2)		Farmers (3)		Non-farmers (4)	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Distance E-W	-0.281	(0.003)	-0.116	(0.004)	-0.185	(0.004)	-0.227	(0.003)
Distance E-W^2	0.011	(0.000)	0.003	(0.000)	0.006	(0.000)	0.009	(0.000)
Distance N-S	-1.090	(0.007)	-0.393	(0.011)	-1.050	(0.010)	-0.831	(0.007)
Distance N-S^2	0.089	(0.001)	0.025	(0.002)	0.084	(0.002)	0.068	(0.001)
Own State	1.690	(0.009)	0.681	(0.017)	1.574	(0.013)	1.539	(0.009)
Out-of-State Network	1.006	(0.009)	0.372	(0.018)	0.976	(0.013)	0.832	(0.009)
Δ Ag. Commodity Mix	-0.023	(0.000)	-0.009	(0.001)	-0.025	(0.000)	-0.020	(0.000)
Origin Counties	614		599		610		611	
Destination Counties	1578		1578		1578		1578	
Number of People	160163		36297		71929		124531	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for native-born whites, foreign-born whites, white farmers, and white non-farmers. All models are estimated with destination-specific fixed effects. Variable definitions are described in Table 1.3.

Table A3. Multinomial Logit Coefficient Estimates for Whites and Nonwhites for Sample Including Non-movers

	Whites (1)		Non-whites (2)	
Variable	Coeff.	SE	Coeff.	SE
Distance E-W	-0.441	(0.003)	-0.646	(0.028)
Distance E-W^2	0.034	(0.000)	0.042	(0.003)
Distance N-S	-0.955	(0.006)	-1.028	(0.047)
Distance N-S^2	0.070	(0.001)	0.087	(0.011)
Origin County	4.257	(0.006)	3.689	(0.052)
Own State	1.347	(0.007)	1.334	(0.059)
Out-of-State Network	0.826	(0.007)	0.621	(0.066)
Δ Ag. Commodity Mix	-0.015	(0.000)	-0.011	(0.002)
Origin Counties	592		391	
Destination Counties	1548		1548	
Number of People	588398		8751	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for whites and nonwhites. All models are estimated with destination-specific fixed effects. Variable definitions are described in Table 1.3. Sample includes migrants as well as those men who resided in the same county in both 1850 and 1860.

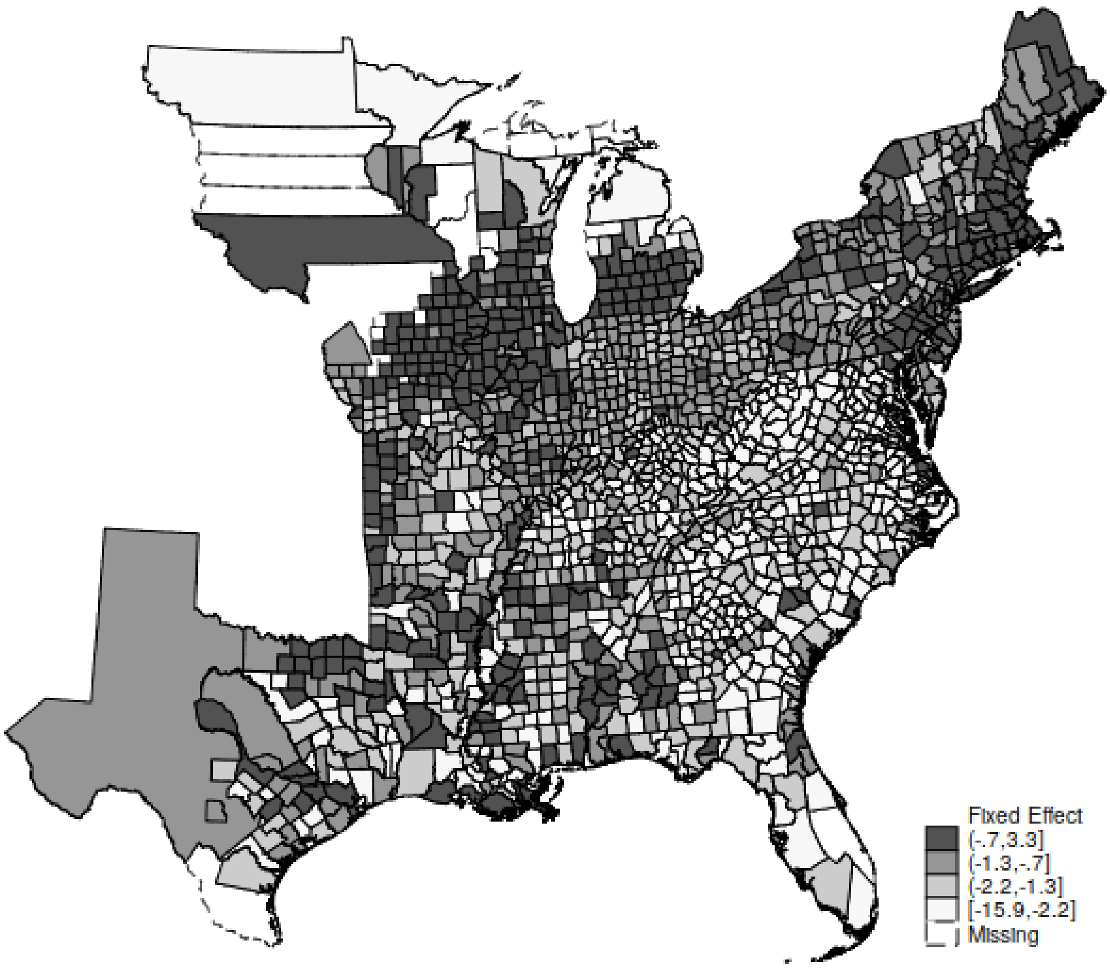
Table A4. Multinomial Logit Coefficient Estimates for Foreign Born, Native Born, Farmers, and Non-farmers for Sample Including Non-movers

	Native Born (1)		Foreign Born (2)		Farmers (3)		Non-farmers (4)	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Distance E-W	-0.503	(0.004)	-0.344	(0.007)	-0.385	(0.006)	-0.462	(0.004)
Distance E-W^2	0.037	(0.000)	0.029	(0.001)	0.030	(0.001)	0.035	(0.000)
Distance N-S	-1.142	(0.007)	-0.455	(0.011)	-1.069	(0.010)	-0.877	(0.007)
Distance N-S^2	0.085	(0.002)	0.018	(0.002)	0.077	(0.002)	0.065	(0.002)
Origin County	4.147	(0.006)	4.028	(0.017)	4.616	(0.009)	3.904	(0.007)
Own State	1.486	(0.008)	0.524	(0.017)	1.441	(0.012)	1.352	(0.009)
Out-of-State Network	0.977	(0.009)	0.202	(0.017)	0.959	(0.013)	0.770	(0.009)
Δ Ag. Commodity Mix	-0.018	(0.000)	-0.001	(0.000)	-0.023	(0.000)	-0.011	(0.000)
Origin Counties	592		582		590		590	
Destination Counties	1548		1548		1548		1548	
Number of People	523187		65211		277506		310892	

Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: Standard errors are in parentheses. This table shows the coefficient estimates for the multinomial logit model described in the text for native-born whites, foreign-born whites, white farmers, and white non-farmers. All models are estimated with destination-specific fixed effects. Variable definitions are described in Table 1.3. Sample includes migrants as well as those men who resided in the same county in both 1850 and 1860.

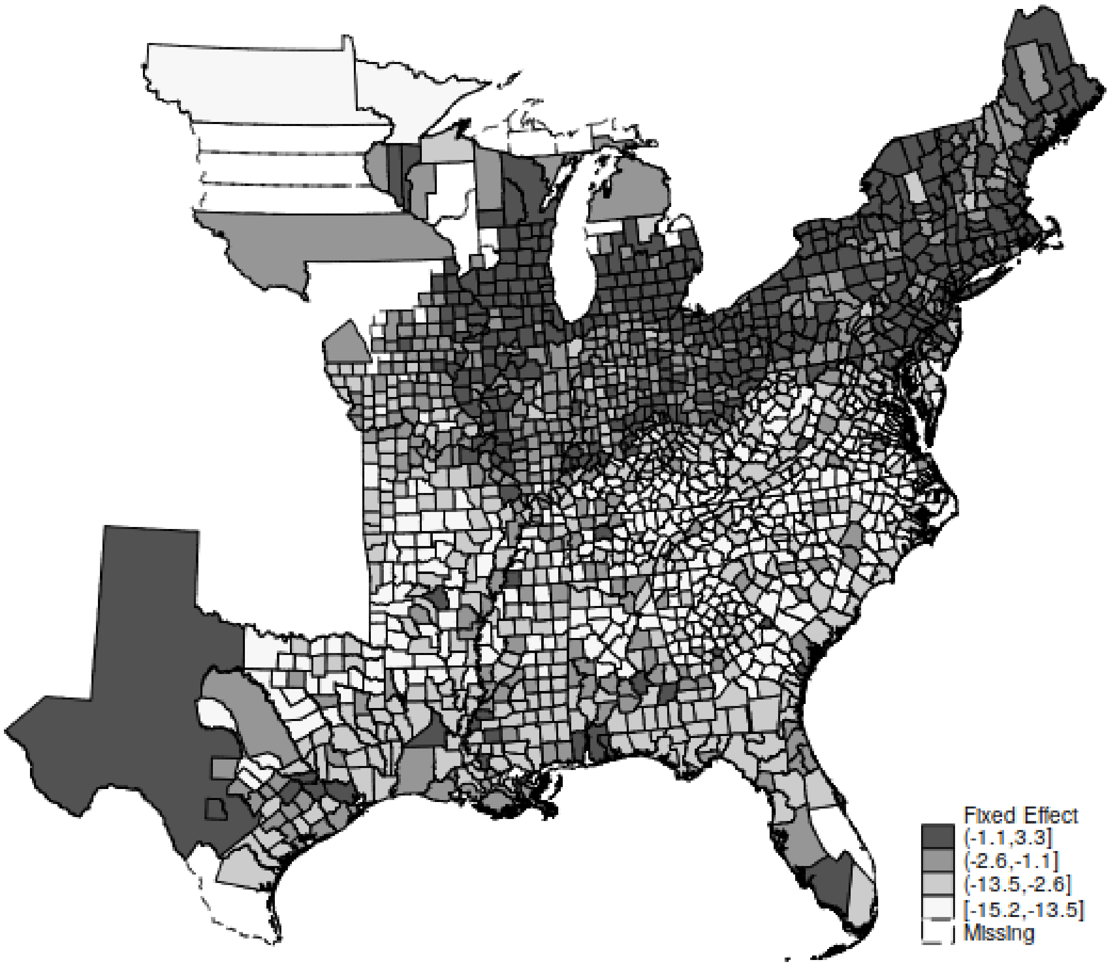
Figure A1. Geographic Distribution of Fixed Effects for Native-Born Whites for Sample Including Non-movers



Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: This figure shows estimated destination-specific fixed effects for each destination county. Counties depicted in white are missing data and were not included in the choice set of the estimated model.

Figure A2. Geographic Distribution of Fixed Effects for Foreign-Born Whites for Sample Including Non-movers



Source: Ferrie (2016), Haines (2018), Manson (2019), Ruggles (2019)

Note: This figure shows estimated destination-specific fixed effects for each destination county. Counties depicted in white are missing data and were not included in the choice set of the estimated model.

APPENDIX

Appendix to Chapter 2

Number of Steam Pumps in the Nile Delta

There are $1,095$ steam pumps listed in Boinet (1902) for the three provinces of Daqahlia, Sharqia, and Qalyubia. A total of $416,335$ feddans of cotton was cultivated in these provinces in 1899.[1] These three provinces are located further from Alexandria than the other provinces in the Nile Delta, so they, on average, faced higher internal shipping costs of moving goods to and from Alexandria. Assuming that the number of pumps per cultivated acre is at least as high in the rest of the Nile Delta as in the three provinces with available data, which is a reasonable assumption given lower shipping costs to provinces nearer to Alexandria, this would imply that there are approximately 3000 pumps in the entire Nile Delta.[2] Consequently, $2,000$ - $3,000$ pumps for the entire delta is probably a conservative estimate; the actual number may have been higher.

Shipping Costs' Proportion of Coal Prices

Coal prices aren't observed at the township level. I infer the cost of coal by assuming that shipping costs were tacked onto coal prices and adjusted by a markup. The price of coal in Alexandria isn't directly listed for 1900; instead I have data on total tonnage imported

[1] Boinet (1902) p. xv
[2] A total of $1,143,042$ feddans of cotton were cultivated in the Nile Delta in 1899. See *Annuaire Statistique* (1909) p. 269

and the total value of those imports. The *Annuaire Statistique* reports that 858,000 tons of coal were imported in 1900 for a total value of £1,119,300.[3] Therefore coal cost, on average, £1.3 per ton in Egypt.

The average cost of transport from Alexandria to a township East of the Damietta Branch of the Nile using my transportation cost network was £0.64. Adding on a 25 percent markup for resale, a reasonable guess is that coal cost £2.66 per ton in the average Egyptian township. 0.64/2.66 = .24 implying 24 percent of coal costs in each township are from transportation. Note that the assumption of a 25 percent markup for resale decreases the percentage of coal costs due to internal shipping within Egypt.

Irrigation Pumps' Coal Use

In the text, I report that one acre of cotton required 400 kilograms of coal to irrigate by steam pump for the year. All calculations are based on using an 8-inch centrifugal pump, which was the most common pump used in the Nile Delta.[4]

Foaden and Fletcher (1908) give the following rule of thumb for calculating water discharge on a 3 meter lift: $(\text{Diameter in feet})^2 * 10 = \text{cubic meters per minute}$.[5] According to this formula, an 8 inch pump discharges 4.44 cubic meters per hour. One cubic meter of water weighs 1 metric ton. To lift 4.44 tons of water 3 meters per minute, the pump requires 3 horsepower.[6] 1 kilogram of "Good Welsh Coal" generated 1 horsepower per hour for a

[3] *Annuaire Statistique* (1914) p. 302
[4] Willcocks (1913) p. 765, Foaden and Fletcher (1908) p. 183
[5] Foaden and Fletcher (1908) p. 183
[6] British horsepower is 33,000 foot-pounds or 4,554 kilogram-meters per minute.

well-functioning pump, implying that an optimally run pump needed 3 kilograms of coal per hour.

A feddan is about 1.034 acres or approximately 4184 meters^2. Willcocks (1913) reports that it took 4400 m^3 of water to irrigate a field planted in cotton over the course of the year.[7] Assuming a discharge rate of 4.44 m^3 per minute, this implies a total of 16.5 hours of pumping per acre. Thus, it takes 50 kilograms of coal to irrigate an acre of cotton for a year using a well maintained pump.

According to Foaden and Fletcher (1913): "Coal consumption is the most important item in cost of pumping. For large pumps, makers will guarantee a coal consumption not exceeding 1 kilogram of good Welsh coal per WHP per hour. As these installations are in the hands of competent European engineers pumps will run for many years and exact coal consumption can be calculated. Small pumps in bad order, with foul boilers, badly stoked, will use 8 or 10 times the amount of coal in proportion to the word done by large pumping engines."[8] Therefore, an 8-inch pump (which is on the smaller side) that was not well-maintained would have consumed 400 - 500 kilograms of coal over a year's use.

Costs of Irrigation Using Different Devices

For simplicity, I assume that all fixed capital depreciates over 3 years. I base these calculations assuming a 3 meter lift. Willcocks (1913) reports that cotton is watered 12 times between preparing the field for planting and harvesting.[9]

[7]Willcocks (1913) p. 733
[8]Foaden and Fletcher (1908) p. 184-185
[9]p. 159

Shadufs: One shaduf worked by two men could irrigate 1/5 of an acre a day on lifts under 2.5 meters. However, if the lift was over 2.5 meters multiple shadufs were used: a lower shaduf lifted water from the canal onto a terrace and a second shaduf raised the water from the terrace onto the field. Shadufs were cheap, so fixed costs per watering were negligible: only $0.15 * 2/39 = .008$. Four laborers needed to be employed for 5 days to irrigate one acre, giving a total wage bill of £.6. Thus, for a field of X acres, irrigation by shaduf cost $X * .6 + .008$ £ per watering. Multiplying by 12 gives the cost to irrigate a field per year.

Saqias: On a lift of 3 meters, Willcocks (1913) reports that a saqia powered by 2 oxen could irrigate about .5 acres over 12 hours.[10] A pair of oxen could be hired for 12 hours for 0.195£, but usually farmers used their own rather than hiring out. For these calculations I assume that the opportunity cost of using oxen for farmers who already oxen for other purposes is equal to the rental rate. This may be overstating the opportunity cost; in which case the cost of using saqias would probably be lower than that reported here.

Unskilled workers cost £.03 per 12 hour day. Assuming two workers were hired to supervise the oxen, a field of X acres cost $X * 2 * (0.195 + 2 * .03) + .05 = X * .51 + .05$ to irrigate by saqia. Note that these numbers imply that only fields smaller than .46 acres would be watered by shadufs, underscoring their limited use across the Delta.

Because fields had to be watered approximately every 2 weeks, more saqias were used for larger fields. At this lift height, each saqia would have covered about 8 acres, so fixed costs should be adjusted accordingly.

Note that the majority of costs for watering with a saqia are capital costs. Take an 8 acre field for example. Total costs are £4.13 per watering. £3.12 (75 percent) of that is the

[10] p. 766

cost of hiring oxen and 0.96 (23 percent) is wages.

Pumps

A ton of coal cost, on average, £2.66 in the Eastern Delta. A one acre field of cotton required 32 kilograms of coal to water using a poorly-maintained 8-inch pump implying £.085 in coal costs per acre per watering. A native mechanic had to be hired to maintain the pump as well, native wages for mechanics were £.11 per day. However pumps only need about 1.3 hours to irrigate an acre, implying a wage bill of only £.012.

Pumps cost around £160. A field of X acres would have cost $X * (.085 + .012) + 4.1 = X * .097 + 4.1$ £ per watering to irrigate by steam pump. At these prices, cost advantages over saqias are achieved at around 12 acres or so.

APPENDIX

Appendix to Chapter 3

Construction of Data Set

The panel data set used in this chapter was constructed by matching townships from the 1917 Egyptian census to historical maps, denoted in the bibliography as Egyptian Topographic Maps 1896 - 1923, and then matching townships across all censuses conducted between 1897 and 1947. I manually matched townships in the 1917 census to the historical maps based on their name and district. I chose the 1917 census because it was closest to the date most of the maps making up the collection were created. Out of 870 townships listed in the 1917 census in the provinces of Asyut, Minya, Beni Suef, and Giza, I was able to locate 839 townships, or 96 percent, on the maps.

I matched townships across censuses based on their name and district. Townships sometimes split or merged together between censuses. To create consistent units across census years, I aggregated townships to the largest consistent unit of analysis. In some cases, aggregated townships consisted of individual townships that had different irrigation technologies. I discarded these townships from the dataset. I excluded townships that were larger than 8,000 people in 1897 and that had inconsistent data between censuses. I defined inconsistent data as townships with large changes in area between censuses or townships with implausibly large changes in demographic variables.