DISSERTATION

THE IMPACT OF ARMED CONFLICT ON AGRICULTURAL PRODUCTION THE CASE OF LIBYA: 1970-2017

Submitted by

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ABSTRACT

THE IMPACT OF ARMED CONFLICT
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I examine the long-term impacts of a recent civil war on the agricultural sector within Libya. Due to the associated destruction and market disruption, armed conflict affects the agricultural sector in complex ways including reducing future growth potential by eroding physical and environmental capital. Libya, with its arid climate, low soil fertility and low agricultural productivity, represents an underdeveloped sector that minimizes the inherent complexity to investigate this impact. However, governmental interest in the agricultural sector has been inconsistent as the dominant oil revenue compensates for agricultural deficits through large subsidies. This absence of attention and oversight has resulted in a lack of quality agricultural data, making it difficult to develop beneficial policies to improve sector growth.

Based on its simplicity and ease of interpretation, a Cobb-Douglas style production function with Solow-Swan modification is used to characterize the agricultural sector. Though limited, data was collected from FAO and ILO on land, irrigation, fertilizer, machinery, and labor in Libya spanning from 1970 to 2017 covering periods of stability and conflict in order to estimate agricultural sector growth compared to the status quo.

To account for the long-term impacts of conflict on growth, inputs are divided into environmental capital, physical capital, and labor. Next, elasticity parameters are estimated through an OLS regression of the Cobb-Douglas production function before and after conflict. A Chow/QLR test is used to confirm the existence and timing of the structural break in the production function arising at the onset of the 2011 conflict. Finally, the impact of post-conflict growth rates are compared using the pre-conflict and conflict regression parameters.

Changes in the estimated parameters from the start of the conflict were significant at the 5% level for both the labor and physical inputs, while the environmental elasticity parameter change was not significant. The conflict elasticity estimates were -0.518, -0.803, and -18.9 for the Physical, Environmental and Labor inputs, compared to their pre-conflict values of 0.107, 0.146, and 1.315, respectively. The two key questions are whether the growth path can recover to pre-conflict levels and the associated production losses resulting over the period the sector takes to return to those pre-conflict rates.

A preliminary cost-analysis was applied to estimate the required investment to generate an increase in agricultural GDP. The most cost-efficient way to increase the production after conflict (under the assumption of a return to pre-conflict elasticities) is to increase the quantity/quality of fertilizer used. Increasing machinery is the least efficient way to grow the sector GDP. This may reflect two realities in Libya: weak soil quality and inefficient use of machinery, due to diseconomies of size with smaller plots.

Lessons from conflicts in other post-conflict countries suggest that a necessary but insufficient condition is the application of good agricultural policies to rebuild the sector. New policies could improve agricultural returns to surpass losses due to conflict if post-conflict productivity is improved. These policies must be combined with good management and reliable data to effect positive changes within the sector. In Libya's case, the primary post-conflict policies should include improving data collection and focusing on increased education and training to enhance the agricultural sector's rehabilitation.

I estimated 3 specific scenarios of the post-conflict future consisting of business-as-usual (BAU), a scenario with convergence between the pre-conflict and post-conflict growth paths within 50 years, and another with a convergence of 20 years. Based on the experiences of other post-conflict countries, Libya's agricultural production will likely converge back to the pre-conflict agricultural GDP trajectory within 10-15 years, so long as there is a minimal transition period and agricultural policies are consistent and well managed. The expected cost to the economy is measured by the discounted difference between the pre-conflict trajectory GDP and the estimated post-conflict GDP until the convergence point. For the likely 20 year convergence, there is an estimated opportunity cost of USD2010 25.0 billion. Should the sector return to business-as-usual, the present discounted value of the conflict is USD2010 49.0 billion. The impact of the conflict is lessened by poor productivity before the conflict. It appears that the conflict slowed business-as-usual, but did not significantly erode environmental capital, which would further cripple the recovery.

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I also wish to extend my sincere thanks to Dr. Gregory Graff for his advice and guidance, and to Professor Randy Boone and Dr. Robert Kling for their insights enriching this study as members of my committee.

In this regard, I cannot but extend my thanks and gratitude to my parents who taught me that the sources of knowledge and science are inexhaustible, and to my siblings and friends who supported me on this journey.

None more than my family truly understand the journey I have undertaken in completing this work. My deepest gratitude for my generous wife and our children for their understanding, patience and encouragement throughout my academic career.

I also cannot fail to express my sincere thanks and gratitude to the Libyan government for granting me this delegation to study abroad, elevating my education in the pursuit of science and knowledge for the betterment of my country.

DEDICATION

To those who taught me self-confidence, those whose advice led me down the paths of science and knowledge, to those who taught me that the sources of knowledge are inexhaustible, to my wife and children, to my beloved Libya, to all of them, I dedicate this humble work with pride.

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Chapter 1 Introduction

The results of agricultural production are seen everywhere including the food we eat, the clothes we wear, and materials used in our daily lives. Research into agricultural production can provide meaningful explanations of the observed output, allow policymakers and others to make crucial judgments, and improve both the level and efficiency of production. This is especially important under the existence of disruptive system shocks such as armed conflict where good policy decisions can limit the duration and magnitude of production losses as the system recovers.

The term *conflict* covers a wide range of interactions, including sanctions and disagreements on resource distribution. As a subset, armed conflict represents more volatile interactions such as international or civil war. The last few years have seen a resurgence in the number and severity of armed conflicts (Dupuy and Rustad, 2018). Furthermore, civil wars have become more protracted. Since the mid 1970s, there have been no less than 30 active civil wars, having an average duration of 16 years (Fearon, 2004). As noted by Bush (1998), protracted armed conflict distorts the economy through subsidizing inefficient socioeconomic structures, stifling production and wasting scarce resources in non-productive expenditures. Furthermore, armed conflict is implicated in reduced production across all sectors, affecting everything from initial production to distribution (Collier, 1999).

While conflict is associated with reduced agricultural production (Abiad and Meho, 2018), the structural impacts of conflict on economic production are not fully understood. This is partly due to the different conflict driven mechanisms associated with the loss of production, including conversion to war economies by the state and the mobilization of capital to support insurgent military and political activities (Le Billon, 2001; Teodosijevic, 2003). Unlike classical interstate wars, civil war economies are unlikely to contribute to economic development and production (Ballentine and Sherman, 2003; Kang and Meernik, 2005). However, understanding the impact of armed conflict on agricultural production necessitates understanding how armed conflict influences agricultural inputs, including physical capital, environmental capital and labor in both the short- and long-term.

Conflict can influence production by affecting the input factors both in present and future terms (Arias et al., 2014). However, each factor of production may be affected differently. Physical capital might suffer active or incidental destruction, such as the bombing of refining facilities or closure of transportation vectors. Environmental capital can similarly be affected by destruction, but may also experience secondary impacts. The loss of physical capital might prevent the efficient extraction of environmental capital or accelerate environmental capital's depreciation. Such secondary impacts leave the environmental capital intact but dormant until the corresponding physical resources are rebuilt. Human capital, in the form of labor, can decrease during armed conflict through transitions to other activities (having workers move to different sectors or shifting to active combatants in the conflict), abandonment, or loss of life.

The underlying reason for the lowered production is easy to associate with conflict, but how the interaction of agricultural inputs to production has changed is less clear. Is the drop in production the result only of a reduction in the available resources, or is there a structural change in the use of these inputs towards production? What does recovery look like, and how long does it take? Are there permanent losses that can never be recovered?

1.1 Problem Statement

The focus of this investigation is the impact of the current armed conflict on agricultural production in Libya. Civil war has gripped Libya since 2011, partly as a consequence of the Arab Uprising,[1] leading to civil war, foreign military intervention,[2] and the collapse of the Libyan government. Since then, the country has seen a marked drop in the value of its

[1]The series of protests in Arab countries starting in late 2010 for increased democratization affecting Tunisia, Egypt and Libya, among others. This is also commonly referred to as the Arab Spring.

[2]Early involvement included efforts by the UN, while current actors include Russia, United Arab Emirates, Egypt and Turkey (Kirkpatrick and Walsh, 2020).

agricultural production (fig. 1.1). While the first phase of conflict appeared to diminish by early 2014, by mid-2014 the country had again devolved into armed conflict, which continues through this day.

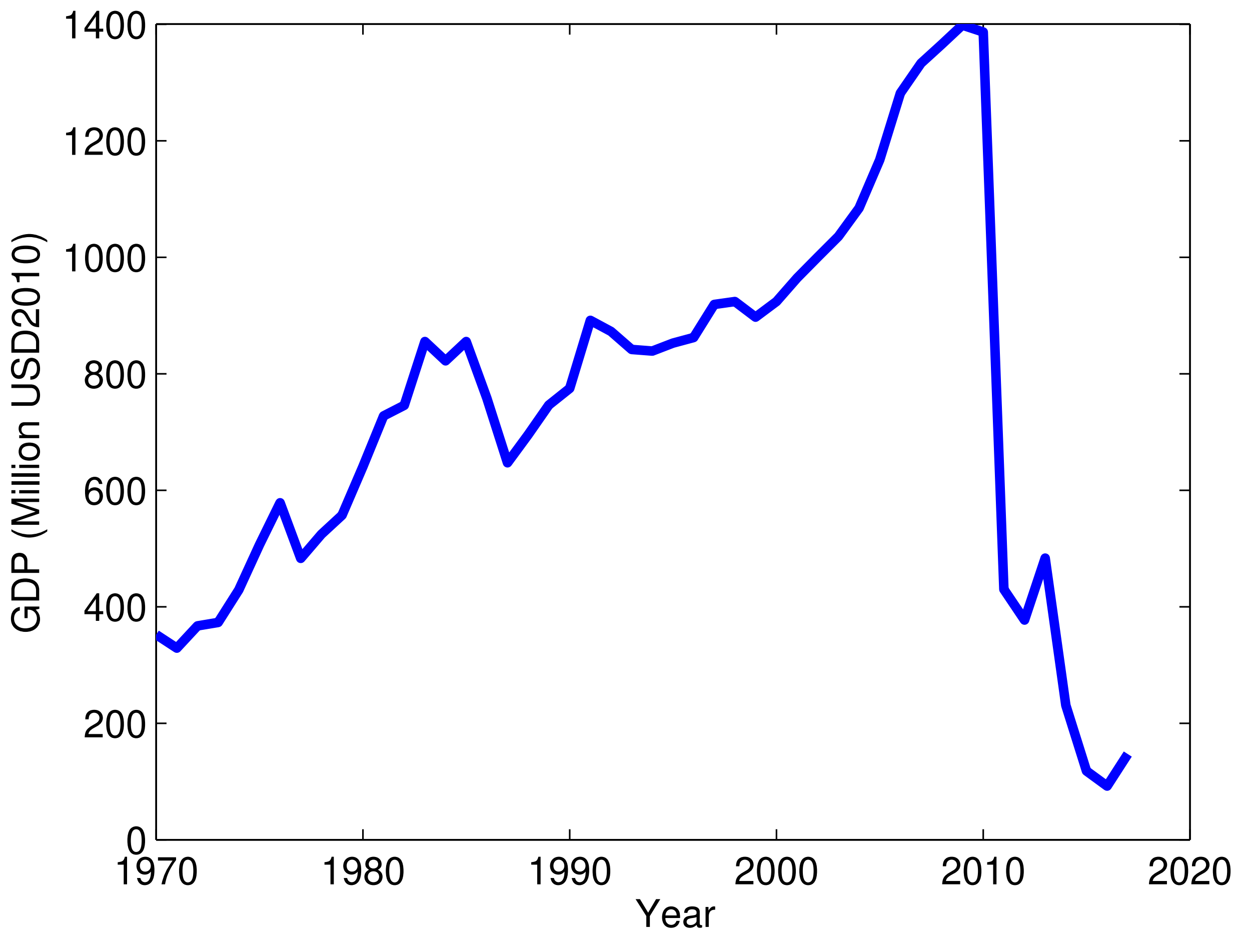

Figure 1.1: Libya's agricultural GDP since 1970

The onset of conflict has led to a destruction of infrastructure, disruption of social services, and labor shortages as the primarily foreign laborers of the agricultural sector abandon the region (FAO, 2015). Using Teodosijevic's (2003) conservative hypothesis for agricultural production, Libya's current 10-year civil war would reduce the agricultural GDP by nearly 14.5%, though from fig. 1.1, it is clear the drop is considerably larger with the agricultural GDP down nearly 90% since 2011.

1.1.1 How did Libya's Agricultural Sector get to This Stage?

The northern coastline is the most agriculturally productive land in Libya with other scattered pocket areas with access to water from shallow wells. Nearly 90% of the available land is desert, as shown in fig. 1.2 and receives less than 100 mm of rain per year as indicated in fig. 1.3. The lack of natural rainfall and surface water in Libya necessitates the development of other ways to supply enough water for both public consumption and agricultural projects. Agriculture accounts for approximately 80% of Libya's overall water use and accounted for 65-70% of the water withdrawal from the Great Man-Made River (GMMR), an artificial irrigation source, prior to the current conflict (Sanders, 2011).

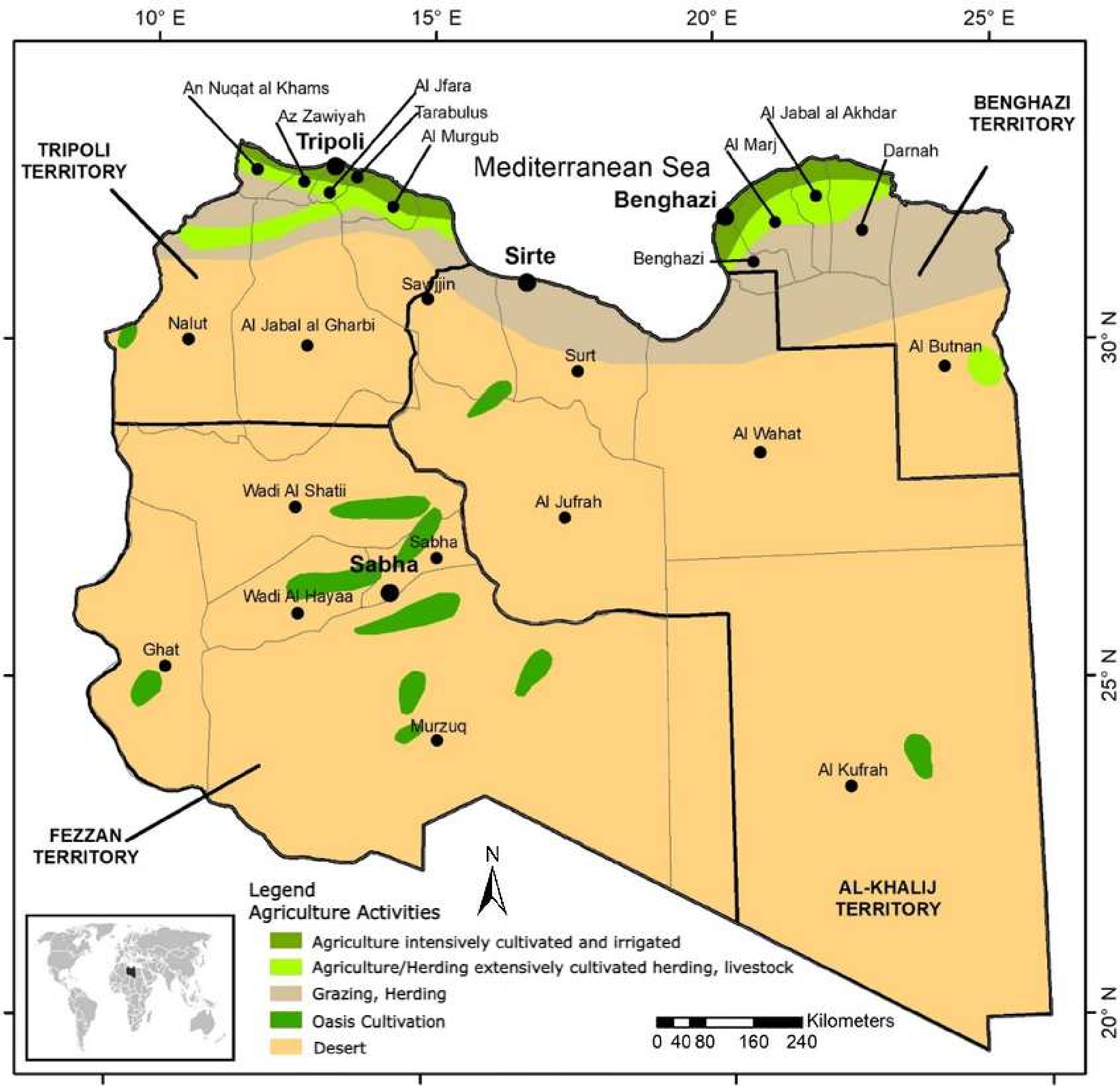

Figure 1.2: Land Type in Libya. Source: Zurqani et al., 2019

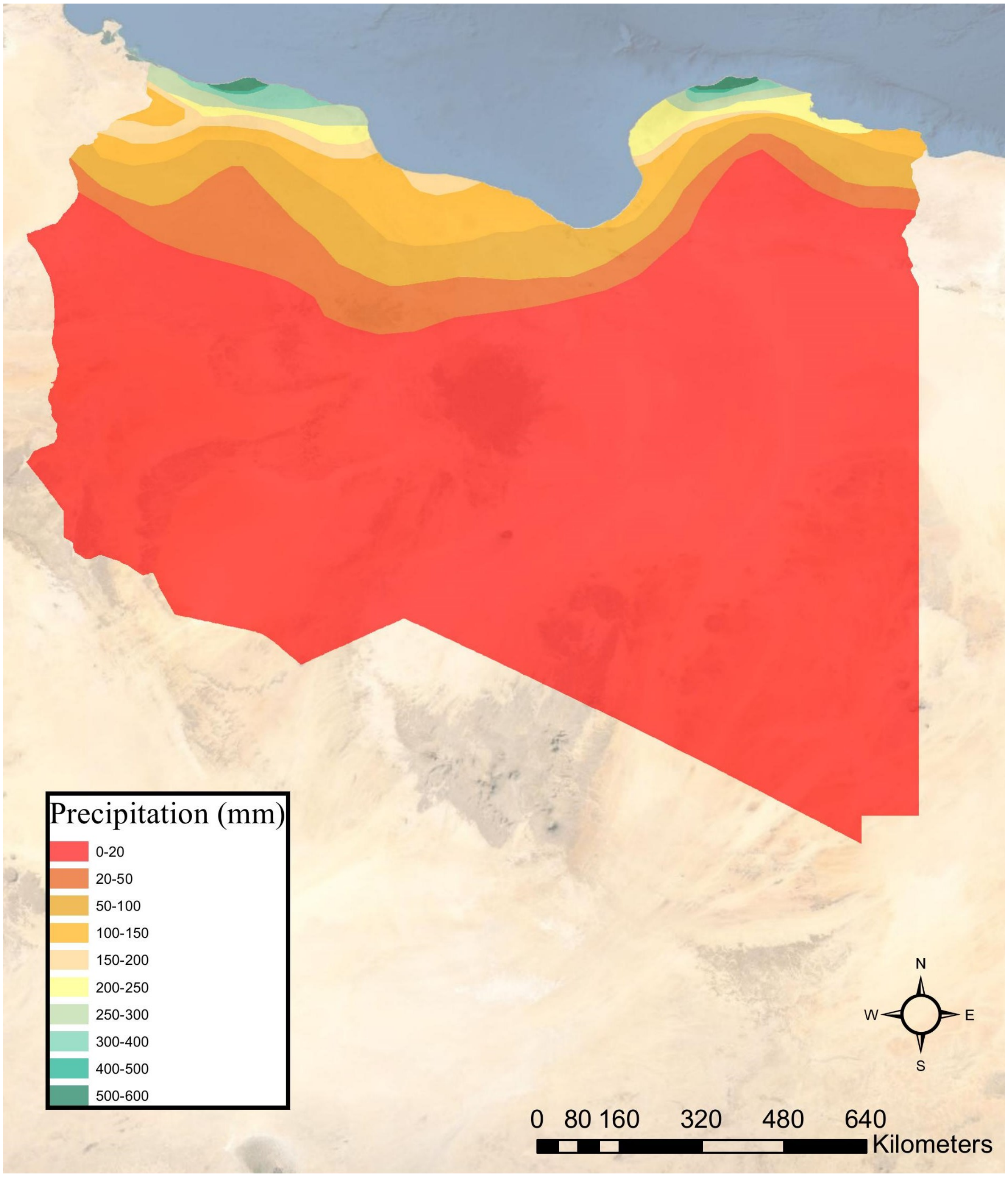

Figure 1.3: Average Annual Rainfall in Libya

Libya's agricultural sector was a national focus for much of the last half century, with heavily targeted investment through agricultural loans in the 1970s - 2000s. Though attempting to secure food independence, Libya still imports the bulk of its food resources due to poor soil fertility and minimal rainfall leading to insufficient agricultural production. Prior to the conflict, Libya imported 80% of its total food consumption, including 90% of its cereals needs (FAO, 2016a). Even so, the agricultural contribution to the GDP in absolute monetary terms continued to increase despite the decline in the national investment (fig. 1.4), perhaps indicating a chronic structural inefficiency in the agricultural planning and policy in Libya. However, the drop in investment also coincides with the sharp decline of oil revenues stemming from the oil crisis of the early 1980s. This drop was due to political conflict abroad with sanctions in 1981 and 1986 from the United States and in 1992 from the UN. Even as the sanctions were lifted, there was little incentive to continue investing in the agricultural sector as shown in fig. 1.4. The most recently available data for the investment is up through 2007, shortly before the current armed conflict.

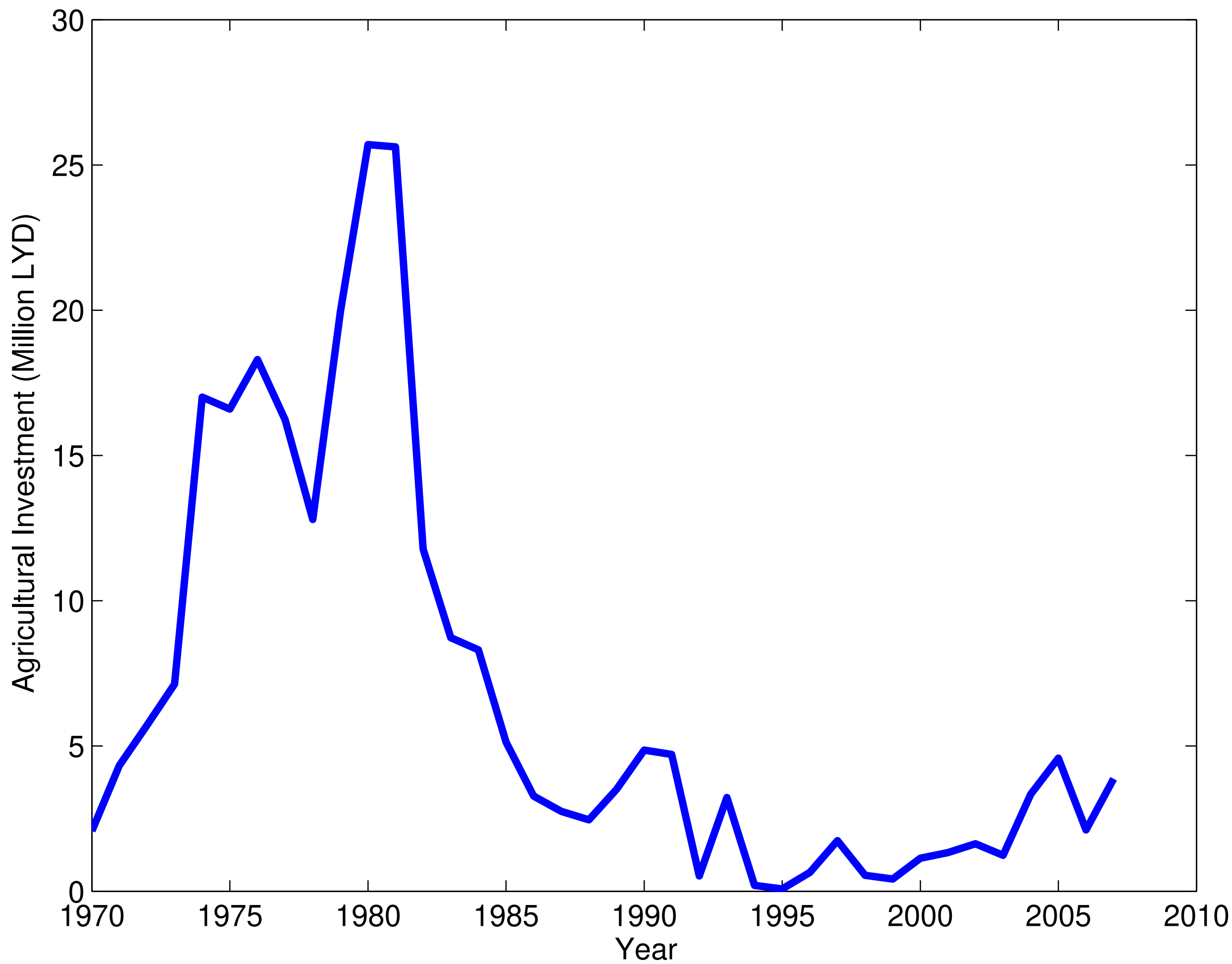

Figure 1.4: Investment into the agricultural sector in local currency

Despite Libya's massive governmental investment in the agricultural sector between 1970 and 1990 (Allan, 2014), the sector functioned inefficiently even before the ongoing armed conflict (Latruffe, 2010; Heemskerk and Koopmanschap, 2012). These inefficiencies are partially attributed to deficient environmental capital. Markou and Stavri (2006) reported that constraints of natural indicators (reduced freshwater scarcity, limited arable land, and low rainfall) have led to a weak Libyan agricultural sector.

The health of an agricultural sector also relies on the availability of physical capital resources. However, Libya is not a net producer for most agricultural inputs, nor does Libya have locally available resources in the most agriculturally productive regions. Most fertilizers are imported while water is transported across country from groundwater sources such as the Nubian Sandstone Aquifer via the pipelines of the GMMR as in fig. 1.5.

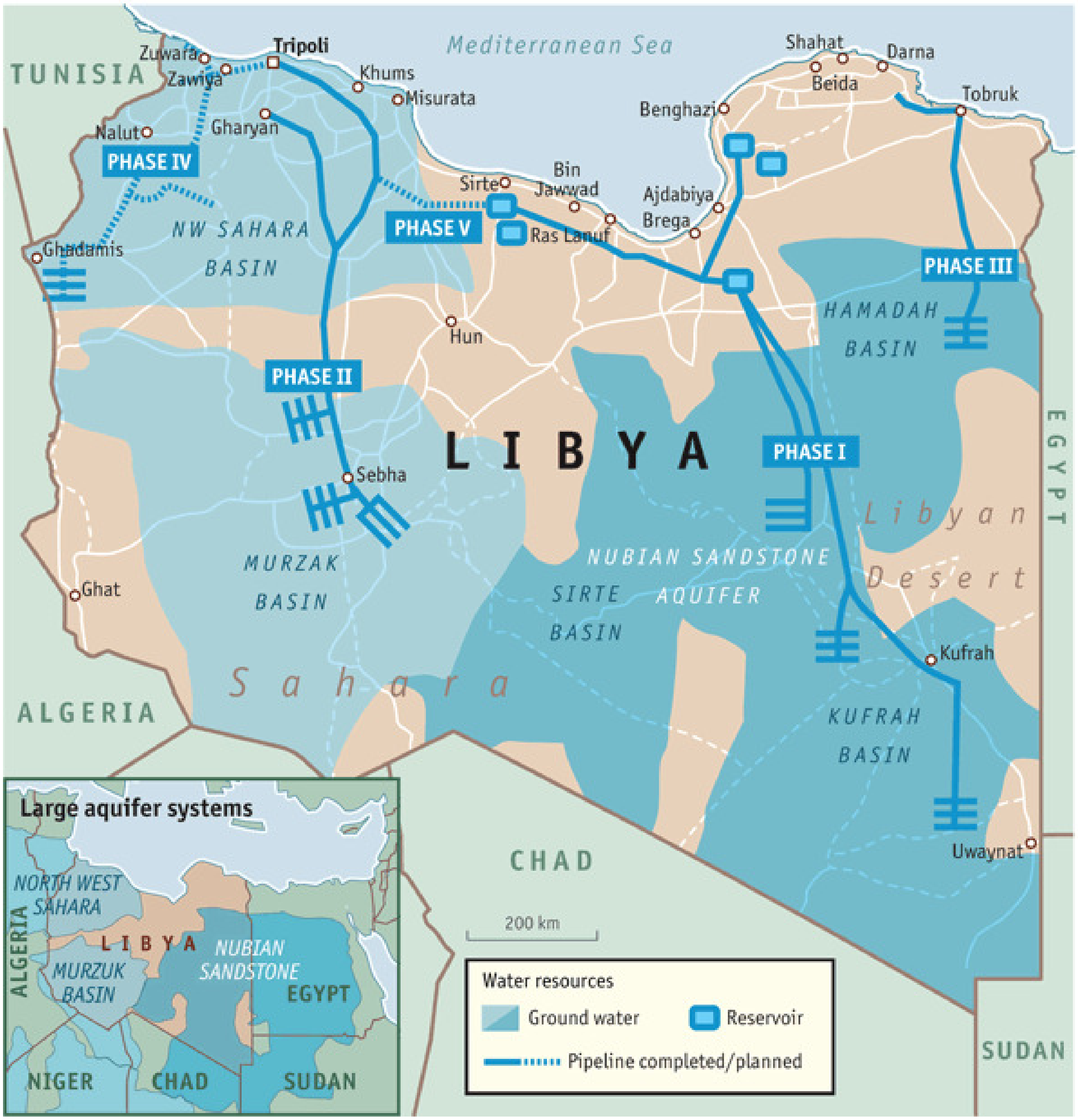

Figure 1.5: GMMR Project Phases. Phases I and II have been completed. Source: Abdudayem and Scott, 2014.

The GMMR is the largest underground network of pipes and aqueducts in the world, pumping an estimated 4.5 million cubic meters of freshwater per day from the Nubian Sandstone Aquifer System (Aqeil et al., 2012). However, the pipeline and related structures have been targeted during the conflict, including the NATO bombing of a pipe production facility in 2011 and the more recent and repeated closure of the pipeline section to Tripoli by militants (Abdulkadder, 2017). The pipeline has been attacked in some fashion at least 10 times since 2011 ("Water Conflict Chronology", 2020), leading to shortages both in residential areas as the main intent of such attacks, and to the agricultural sector as secondary impacts.

Much like the physical inputs, labor for the agricultural sector is heavily outsourced. Prior to the conflict, an estimated 50% of the *total* workforce was non-Libyan, with a larger percentage in the informal sectors including agriculture (World Bank, 2015). As such, the agricultural sector in Libya has been characteristically weak with high turnover, underlying the importance of understanding and maximizing the efficient use of the inputs in general.

Low education among Libyan farmers regarding machinery, fertilizer and irrigation use is also implicated in the low productivity of the sector (Abunnour et al., 2016; Abagandura et al., 2017). In addition, other factors including a lower rate of technological adoption have contributed to the low efficiency in Libya's agricultural sector, reflected in agriculture's low contribution to the national GDP (Azzabi, 1993).

1.1.2 Where Will it all go from Here?

While instability is expected to lead to a period of gradual decline in the production, conflict is expected to induce a sharp downward impulse to the system. Each of the inputs to production are expected to be affected by the presence of conflict such as the loss of capital availability. While a loss in labor or physical capital can be reversed, environmental capital loss is often more pernicious and irreversible. In Libya, there is little environmental capital for agriculture, making it even more precious. But as I show, the Libyan conflict seems to have had negligible effect on the environmental capital. The conversion of agricultural inputs for agricultural production may also experience structural change both in the fall and recovery phases.

While the negative impacts of conflict are difficult to avoid, policy makers and other stakeholders can affect the recovery. Once conflict subsides for example, the output of the agricultural sector may follow many possible paths as shown in fig. 1.6. In some recovery scenarios, the post conflict growth may converge to the same pre-conflict trajectory path as if conflict had not occurred. In any recovery scenario, there will be associated losses compared to the pre-conflict path (shaded regions A and B) and possible gains beyond the convergence point (shaded region C) if the post-conflict growth exceeds the pre-conflict growth.

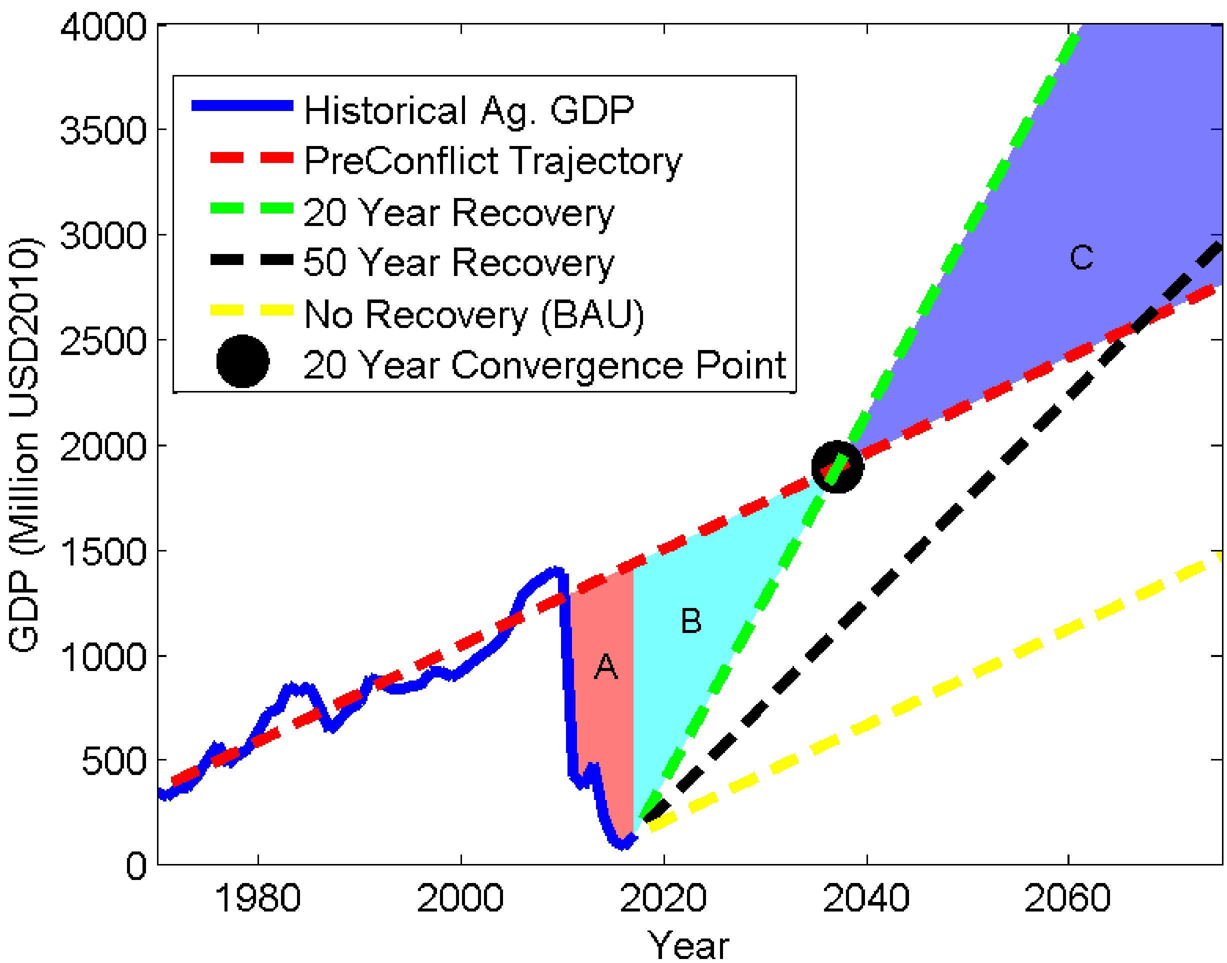

Figure 1.6: Three of several possible recovery projections for the agricultural production.

There is a distinction between production and productivity when considering the impacts of conflict. Production is the focus on total output of the agricultural sector but does not address the efficiency of input conversion. Productivity, either in focusing on partial or total factors, is the ratio of the output aggregate production to the individual or group inputs, respectively. While there is a good reason to look at the efficiency of production, this investigation only looks to explain the production aspect.

The output production under periods of stability (between 1970 and 1986), of political conflict during the period of international sanctions (1986-2004), and of armed conflict (2011-current) is shown in fig. 1.6. From the beginning of the conflict in 2011, the agricultural GDP has not kept pace with the pre-conflict trajectory. This has incurred permanent dead-weight losses (shaded region A) as the area between the pre-conflict trajectory path and the conflict period's observed GDP. As armed conflict continues in Libya, the long-term impact on the production is unknown. Total production will likely decrease as the inputs to production are affected by the conflict. For example, conflict is likely to increase the percentage of idle land and overall investments are expected to decline (Arias et al., 2014). The three future curves shown in fig. 1.6 represent a few possible trajectories of the production output GDP once the conflict has ceased, though the path is not known beforehand. The bottom (yellow) trajectory has the same growth path as before the conflict (red), but with a vertical offset, and represents a return to business-as-usual practices after the conflict. This lower path will not converge to the pre-conflict path, and will result in continued long-term losses from the conflict. The path in the middle (black) proceeds on a long-term growth path that weakly exceeds the pre-conflict rate and eventually coincides, then surpasses, the original trajectory. On this hypothesized path, the pre-conflict production level would not be reached until 2068. The uppermost post-conflict path (green) represents even higher relative long-term growth, with an earlier convergence to the pre-conflict trajectory. Each of these long-term projection models assumes a negligible transition period after the end of conflict. Economic losses are shown for the most rapid, 20-year convergence path as areas $A+B$, representing the already observed (region A) and hypothesized (region B) losses, respectively. These losses would never be recovered if production growth rate levels off back to the pre-conflict path (rather than surpassing it), but can be eliminated if production continues at the same rapid pace (region C) exceeding the pre-conflict growth rate. If growth continues at the post-conflict rate after convergence, the economic losses are $A + B - C$.

The sector growing faster than the pre-conflict rate would likely require outside intervention. Without exceeding the original growth rate, a country experiencing extended conflict will find themselves experiencing penalties of production loss from conflict inordinately. Growth exceeding the pre-conflict rate is required to catch up, and even then there are still permanent losses if the post-conflict growth rate is not maintained above the pre-conflict rate.

The impact of armed conflict in different countries is likely to result in different production models. It is not reasonable to say the way a conflict has affected the agricultural sector in another country is similar to how conflict (and the corresponding recovery) should be analyzed in a new environment such as Libya. As of yet, fig 1.6 describing the possible production futures in Libya has not been developed, nor has an adequate model that takes into account the agricultural inputs to production been developed to even generate such a figure, with or without the presence of conflict. This problem compounds the issues faced by policy makers when addressing necessary interventions during the post-conflict period to rebuild the agricultural sector.

1.2 Research Gap

Current research about the conflict in Libya focuses on addressing the nature, cause, role, and impacts of conflicts, especially on the energy sector and disruptions to oil production. Investigating the impact of conflict on other sectors, such as agriculture, has received considerably less focus. This is perhaps due to the relative importance of the other sectors or the lack of reliable quantitative data. The absence of recent data can be understood as a shift of government focus to restoring stability rather than measuring variables under duress. In addition, the mechanism of the conflict's impacts on agricultural production is not fully understood. Studies on lowered production in the agricultural sector in Libya have been generalized over the entire economy, while the role of the armed conflict on the agricultural production has not been investigated comprehensively in Libya. Most studies examining the agricultural sector of Libya have also used data before 2011, prior to the armed conflict and thereby ignore relevant developments used for improving policy. Even in the absence of conflict, many researchers have examined a singular factor affecting production. This omits important explorations and factor dependencies while also producing biased results.

Studies examining the impact of conflict on agricultural production are often limited. Most focus either on past causes, on explaining the results after the conflict ends, or on detailing the recovery period. While these inquiries are important in addressing the prevention and long-term repair of the damages induced by conflict, they also remain ambivalent in describing the impact of conflict as it occurs. Fewer studies examine the impacts during the actual conflict. Acquiring reliable primary data under periods of armed conflict may largely explain the deficiencies in critical analysis for this period. Furthermore, not all conflicts are protracted enough to reasonably infer impacts from available data.

Abundant research has examined the correlation between the appearance of conflict and possible underlying factors causing those conflicts, more often focused on conflict prevention (Collier et al., 2000; Miguel et al., 2004; Fjelde, 2015). Similarly, other studies have highlighted impacts of conflicts on the socioeconomic and political landscape as well as institutions (Hartzell et al., 2001; Blattman and Miguel, 2010; Minhas and Radford, 2017). Additional research has examined post-conflict recovery and the factors most likely to impede or promote reconstruction, often with disagreement on whether conflict spurs future growth (Barro and Sala-i-Martin, 2004; Kang and Meernik, 2005). There has been less focus, however, on the interim and long-term implications of conflict on the factors of production and productivity (Brunnschweiler and Bulte, 2009; Gates et al., 2012). Of those, few have investigated the impacts of conflict on agricultural productivity both during and after the cessation of conflict (Sambanis, 2002; Miguel et al., 2004; Ross, 2004a; Arias et al., 2014).

While most investigations covering the impact of conflict are in consensus about the overall reduction of production, the conclusions are often extremely broad or excessively pointed. For example, the work of Messer et al., (1998) concluded that conflict leads to a general destruction of both physical and environmental capital with both short and long-term impacts on the agricultural sector. In contrast, Nillesen (2016) pointed out how conflict has led to a loss of labor in Burundi's coffee bean production, possibly in response to risk aversion.

One of the defining features of agricultural research in Libya has been the dearth of investigations that compile and examine agricultural data. Researchers may not be to blame for this, as the sources for the data are often poorly catalogued, of questionable standards, or entirely missing. A large gap within the literature is a repository of reliable, aggregate data to use for analysis.

1.3 Research Objectives

To address the deficiencies in the current research on the agricultural production in Libya, the objectives are to:

1) Measure and describe agricultural production in Libya between 1970 and 2017, including periods of armed conflict, sanctions and general stability.

2) Identify the influence of the environmental, physical and human capital on the resilience of agriculture to conflict.

3) Discuss long-term impacts of armed conflict and potential for recovery on the agricultural sector in Libya.

1.4 Methods

To achieve these objectives, I will implement the following methods described briefly:

For objective 1, I will collect data on environmental, physical and human capital and model the resulting production in GDP from 1970-2017. I will then regress that data against GDP.

For objective 2, I will identify individual influences of the input capital variables on the production variable by examining changes in input associated parameters using the regression. Structural changes to the model based on armed conflict will be evaluated with the ubiquitous Chow test (Chow, 1960).

For objective 3, I will use recent and relevant publications, comparisons to other post-conflict countries, and the results of my model to deduce the most likely future trend of the production. This analysis of the future long-term prospects will include how the Libyan government and international organizations should respond through policies after the conflict to maximize recovery for the agricultural sector.

Chapter 2 Background

In this chapter, I highlight the changes in national statistics between the beginning and end of the study period (1970-2017) to provide an idea of the agricultural state of Libya. I then address Libya's relevant agricultural history by focusing on three distinct periods. This history is useful in understanding how the agricultural situation in Libya evolved over time and in explaining underlying reasons for the observations during the study period. Afterwards, I take a deeper look into the literature of production and conflict in general terms, followed by more Libya-specific investigations into those same ideas.

2.1 Libya Profile

2.1.1 Libya at a Glance

Libya presents an interesting agricultural case over the study period. By 1970, oil had already become a large component of the Libyan economy making the nation unique in many ways from its nearest neighbors[1]. The population density of Libya is also small with less than 5 inhabitants per km^2 (Goldewijk, 2005). Libya has more similarity to the Arab Gulf countries in terms of economics than to its nearest neighbors (Amrouch and Wadie, 1987). Lastly, the Great Man-Made River (GMMR) project distinguishes Libya from other regions. The GMMR is the largest underground network of pipes and aqueducts in the world, and provided approximately 3.68 million cubic meters of underground water every day in 2005 (McDiarmid, 2005). Some of the demographic and agricultural changes from 1970 to 2017 within the country are shown in table 2.1.

[1] Algeria is the only neighbor with a significant oil component to the national GDP. In 2020, oil's contribution to Algeria's GDP was 14.5%, while Libya's oil contribution had been between 45 and 65% of the GDP in the decade prior to the conflict (World Bank, 2020c)

Table 2.1: Libya Past and Present. Source: FAO, World Bank, ILO

	1970	**2017**
Population (million)	2.134	6.581
Employed in Agriculture (thousand)	127	250
Percent of total employment	>30	17.58
Agricultural GDP (million USD2021)	5.84	25.12
Contribution to Total GDP (%)	2.477	0.82
Land Size (million hectare)	176	176
Arable Land (million hectare)	1.73	1.72
Permanent Crop area (thousand hectare)	308	330
Forest Land (thousand hectare)	217	216
Agricultural Investment (million USD2010)	32.7	-
South Rainfall Average (mm)	10	10
Coastal Rainfall Average[a] (mm)	120	120
Irrigation (billion m^3)	-	4.85
Livestock (million Head)	3.792	10.418
Poultry (million)	1.255	35.782
Crop Harvest (thousand tonnes)	462.8	2141.3
Fertilizer Consumption (kg/hectare)	7.223	19.598

[a]Rainfall rates can exceed 300 mm over limited areas.

While various components of the agricultural sector have increased over the period such as the livestock count, crop harvest and fertilizer use, the sector has lost ground for the past 50 years in its contribution to the national GDP. Unsurprisingly, the waning importance of the agricultural sector of the economy stems from the dominance of the oil sector, even with the gains in overall agricultural GDP and production over the period.

Some of the characteristics of Libya's agricultural production are listed in table 2.2, listing the important features of production within the sector. The agricultural sector focuses on cereal crops such as wheat and barley. Livestock is also important, though the sector relies heavily on imported animal feed (Azzabi, 1993).

Table 2.2: Primary Components of Libyan Agriculture

Main Crops	Wheat Barley Olives Dates
Primary Livestock	Sheep/Goat Cattle Chicken
Water Sources	98% Groundwater

Many other areas of Libyan agriculture are underdeveloped or untenable for production. For example, fishing stocks from the Mediterranean Sea have been underutilized with a total capture of 12.8 tonnes in 1980, to a peak catch of 50 tonnes of fish in 2009 (FAO, 2020), and remains one of the lowest fishing captures of the countries harvesting from the Mediterranean Sea.

Agriculture in Libya is also highly fragmented. Approximately 40% of farm holders work as full-time farmers. In 2015, 45% percent of the nearly 170,000 farms were smaller than 10 hectares (ha), with around 1% larger than 100 ha (AQUASTAT, 2020).

2.2 Libyan Agricultural History

Libyan agricultural history can be broken down into three periods, the first before 1970 where Libya shifted from Italian colony to independence as a constitutional monarchy after World

War II and the subsequent discovery of Libyan oil. The second period is between 1970 and 2011 and marks the bloodless revolution[2] ushering in the Libyan government under Gaddafi, which included the development of the GMMR for the large scale distribution of water. The last period occurs after 2011, where the aftermath of deposing the Gaddafi-led government built the turmoil that continues to this day. This study focuses on the last two time periods (1970-present) where the events of the early agricultural history (before 1970) provide necessary context for the current state of Libya. The conditions of conflict that characterize the last period are the motivation for this study examining the impact of conflict on the agricultural sector.

2.2.1 Pre-Revolution (Before 1970)

The period of Italian colonization[3] of Libya saw the more arable and fertile lands on the northern coast progressively confiscated from indigenous owners. The influx of tens of thousands of unemployed, poor Italian families culminated with a near complete take-over of the country's most productive agricultural resources up through the middle of the second world war (Fowler, 1973). Italian oversight of the region included the formation of branches of the *Banco di Roma*, which invested in local agriculture, among other light industrial sectors (Raza, 2012).

This started a long period where productive land was run by foreign investment. The importing of agricultural skills and capital would largely lead to increases in land equipped for irrigation. While this benefited the overall sector productivity, it also led to a loss of local agricultural knowledge and increased local resentment for the apparent exploitation of the best lands within Libya (Bertazzini et al., 2018).

The end of the North African campaign of World War II replaced Italian control of Libya with joint British and French administration, though Italian colonists remained with their

[2] The revolution started in September, 1969.

[3] The colonization started in 1911 as a result of the war between the Kingdom of Italy and the Ottoman Empire. Italian settlers migrated to Libya up until World War II. In 1934, the modern state of Libya was created with the unification of Tripolitania, Cirenaica and Fezzan.

prior land contracts still honored (Labanca, 2010). Interest in maintaining those lands was not high though; the mostly productive agricultural regions along the Mediterranean coast were still in recovery from the North African war (Sullam, 1944). Even with the declaration of independence in 1951 leading to the formation of the Libyan monarchy under Idris Al-Sanussi, it was not until the 1956 Italo-Libyan accord that Libyans started to reclaim the areas held by the Italian colonists.

This shift in ownership of agricultural land carried some problems for the state. First, the newly landed Libyans were less experienced at farming crops (they were primarily pastoralists) (Bertazzini et al., 2018). Second, the national administration was reliant on foreign development aid. Hampered by the underdeveloped management experience to shift from pastoralism on a large scale and Libya's continued reliance on outside expertise, there was no indigenous replacement for the agricultural tasks once overseen by the Italian authority. High illiteracy and a complete dependence on foreign aid made for lower overall productivity of those same farms from a decade before the colonist expulsion (Fowler, 1973). Additional problems for the local agricultural sector were physical,[4] social,[5] and cultural[6] (Heemskerk and Koopmanschap, 2012).

A complete transformation of the economy occurred with the discovery of oil deposits in 1958. In 1960, agriculture still contributed 25% of the total GDP; by 1969, the share of agriculture's contribution to the GDP had shrunk to less than 5% (Vandewalle, 1986). As in other similar situations, this sudden growth from the oil sector led to the development of a dual economy. In 1956, 80% of the population was rural. Within 10 years, the demographic shifted to being 80% urban, mirroring the shift of indigenous labor leaving the agricultural sector for other employment. No doubt this was partially in response to the overflow of foreign capital in the form of food aid reducing the the ability of Libyan farmers to compete

[4] E.g., sparse and irregular rainfall, arid and over-used land, and poor transportation vectors.

[5] Few Libyans were educated for success in planning and administration.

[6] The rules of inheritance in The Holy Quran can lead to strong fragmentation of land. There are known cases, for example, where a single olive tree is owned by multiple family members (Nyrop, 1973). Such fragmentation can drive down the useful efficiency.

in the market (World Bank, 1960). It also meant several farms were "abandoned" as their owners left for more profitable positions in the oil and other sectors, with the gaps in labor starting to be filled by an increasing contingent of foreign workers.

The Libyan government designed three separate development plans between 1952 and 1969 with varying focus on the agricultural sector. Only the first plan (from 1952-1957) was implementable, largely due to the unforeseen flow of oil revenue, rather than "the foresight of the planners or proper implementation of the development plans" (Allan, 1981). While the nascent Libyan government would start to financially encourage movement back into the agricultural sector, these efforts were hampered by the expanding oil companies siphoning off the most active workers from the agricultural sector (Rissanen et al., 2011). The government's attempt at providing long-term loans in the early 1960s to purchase agricultural land from the Italians backfired. Such loans were taken by the new urban dwellers to purchase the land for recreational rather than agricultural use, leading to inflation of land prices and contributing to lower agricultural productivity (Metz, 1987).

By 1964, Libyans had controlled the vast majority of former Italian holdings, with only 40,000 ha (about 2% of the total agricultural land) still under direct Italian control (Labanca, 2010). Even so, the production of the land could not keep up with the food need. Between 1962 and 1967, the value of food imports had increased by nearly three-fold (Vandewalle, 1986).

Misgivings about the past colonial exploitation, along with dissatisfaction with an increasingly haphazard governmental administration, paved the way for the 1969 revolution that developed into the Gaddafi-led government. Unlike the present-day conflict, this successful revolution was short-lived and did not have a strong impact on the agricultural sector for the few months in the transition from the monarchy to the new Libyan government.

2.2.2 Gaddafi-led Government (1970 - 2010)

The Gaddafi administration, in a major overhaul to promote self-sufficiency and remove foreign exploitation, expelled the remaining colonists in 1970 and redistributed agricultural lands to the Libyans who previously worked on these farms. This can be seen, for example, in the prevailing decrees of land redistribution[7] to more equitable plots to each family sufficient to sustain a family without the need to employ outside workers, rather than the concentration of fields in the hands of fewer owners as it had been during the Italian occupation (Oliveri, 2013). This redistribution of land included holdovers not just from Italian colonists, but also from those politically connected during the time of the monarchy. The impacts of this political decision were both short and long term; both the immediate influx of largely unskilled, inexperienced labor on plots designed for subsistence and the more recent swell of real property disputes in the post-Gaddafi era where ownership remains unclear will likely lead to weaker production (Ibrahim and Otto, 2017). Furthermore, by expanding the number of landholders, the plot sizes were also reduced leading to underutilized machinery and general inefficiency.

After the expulsion of the Italian colonists freed up agricultural land for the native Libyans, developmental problems started appearing within the sector (World Bank, 1960). The newly-minted Libyan farmers lacked the experience, technology and capital to make successful farmers on a wide scale. This lack of experience in the management of agricultural land is a recurring theme throughout the early Gaddafi era, as it takes years to build up the experience needed to be self-sustaining. Furthermore, there was little development in large agricultural areas beyond what had survived from World War II, likely due to the absence of local capital. The growing dependence on oil revenues led national authorities to take steps to mitigate problems stemming from relying on a single commodity by diversifying the economy. This included increased focus on the agricultural sector, where massive investments totaling nearly 20% of the national expenditure were devoted to the agricultural sector. Much of this

[7]See Laws 123 and 142 of 1970 and Law 4 of 1978 (Ibrahim and Otto, 2017).

investment focused on large-scale land reclamation, water resource development projects, and construction of large animal production complexes, all to expand Libyan agricultural production (NEPAD, 2006).

In the mid-seventies and early eighties, the Gaddafi-led government prepared and implemented five-year plans for Libyan development. Improving the agricultural sector had been the focus of the 1973-75 and the 1981-85 development plans, with the former leading to increased agricultural research and loan funding, and the latter providing funding for large scale irrigation projects. Credit was provided by the Agricultural Bank of Libya, which in 1981 provided nearly 15 million Libyan Dinar (LYD) spread over 10,000 loans and is likely the reason nearly 20% of the indigenous workforce reamined in the agricultural sector (Metz, 1987). The government also gave incentives to absentee landlords to encourage productive use of their land and instituted higher farm wage policies to stem the flow of employment from the countryside to the cities (Metz, 1987). These policies met with some success. Production levels began to rise slightly, though most workers attracted to the agricultural sector were non-Libyan, further increasing the sector's foreign labor dependence. Even with this push by the Libyan government, the Libyan economy was becoming more entrenched and dependent on oil revenues and foreign intervention for both expertise and raw agricultural labor. The agricultural sector (and Libya in general) increasingly became more prone to the impacts of the global market, and particularly to the issues of sanctions and embargoes against the nation which became prevalent in the early 1990s.

The Gaddafi-led government was intensely focused on making Libya self-sufficient agriculturally, but also in transforming the desert into a green paradise with one of the world's largest untapped groundwater resources in the southeast region of Libya.

The 1981-95 development plan gave high priority to financing of the GMMR project[8] to tap into this resource, and is currently responsible for supplying between 65 and 70% of the daily 1.4 million cubic meters of the current water need for agriculture (Sanders, 2011).

[8]The GMMR project started in 1984 is the world's largest collection of underground pipes and aqueducts supplying freshwater from the Nubian Sandstone Aquifer System, and was completely funded by Libya.

Among the "largest civil engineering projects in the world," the GMMR at the time of creation was estimated to provide water at one-fifth of any other alternative supply option at a cost to the agricultural sector of $0.033 per cubic meter (Brika, 2018). The GMMR has many positive impacts, including stemming further desertification, tempering of weather through additional land cover, and an increase in agricultural production. However, the pipeline is quickly consuming a non-renewable water supply and stores some water in open pools which contribute to higher salinity through evaporation (Moutaz, 2017).

Wastewater treatment is a second method of water capture used in Libya for agriculture, with estimated daily water flows of about 150,000 cubic meters (Brika, 2018). There are 36 known wastewater plants, with the bulk of them constructed between 1970 and 1990. As late as 2018, nearly three quarters of the wastewater treatment plants were inoperable (Alsadey and Mansour, 2020). While the Nubian Sandstone Aquifer is far away from the coast, other groundwater sources are becoming brackish with the evident seawater intrusion, requiring more wastewater treatment for use.

Desalination technology represents the third major contribution to the water supply in Libya. As of 2018, there were 21 operating desalination plants, capable of a throughput of near 530,000 cubic meters of water daily (Brika, 2018). While this technology has been used in Libya since the early 1960s, it is expected to play a larger role within Libya, given the uncertain future of the GMMR and possible over-extraction of the groundwater sources. Desalination, on the other hand, is both decreasing in cost and widely accessible near the northern population centers by the coast of the Mediterranean (Brika, 2018).

The gap between food production and need had only expanded since the 1960s. On average, about 70 percent of Libya's food needs were met through imports during the mid-1980s (Metz, 1987). From 1980 to 1999, production in Libya remained unchanged while imports grew rapidly. By the end of the 1990s, imported cereal grains in Libya accounted for 70-95% of their domestic supply (Yang and Zehnder, 2002). Successful efforts by the government to close this gap had remained elusive, providing pressure to invest more in the agricultural sector to ensure Libyan food independence.

Libya's economic dependence on oil is best seen in the oil sector's 80% contribution to the Libyan economy and generation of over 90% of the Libyan government's revenue (Ali and Harvie, 2013). Shifting from the highly agrarian economy to becoming one of the world's top oil exporters, Libya benefited greatly from international events such as the Organization of the Petroleum Exporting Countries (OPEC) oil embargo of 1973, which drastically raised the price of oil by nearly four-fold. This led to large gains in the total Libyan GDP (over 20% from 1973 to 1974 alone) to fund large projects within the domestic sectors such as agriculture (Aimer, 2019). When the OPEC embargo ended, the high prices of oil remained, leaving Libya in a strong economic position domestically. This included a surge in non-Libyan labor within the country, where work by Yahia and Saleh (2008) determined during the boom that a percentage increase in oil GDP was associated with a near 30% increase in the total foreign labor (including agricultural labor). This same study also found a positive relationship between the boom years and Libyan labor, though with less impact.

Much of this benefit from oil revenues served to cement Libya as a rentier state which has only contributed to the weak development seen in the non-oil sectors in Libya (El Kamouni-Janssen et al., 2019). At the same time, these oil revenues have been the Libyan government's driver to pursue political goals, including the expansion of the agricultural sector–in line with the goal to become a more self-reliant country.

Though Libya's large reserves improved the country's financial independence during the periods of high oil prices, Libya's focus on the oil sector for revenue made the nation highly prone to economic downturns as well. Coupled with Libya's harsher climate and lack of many other natural resources, the country remained dependent on outside imports. Foreign relations of the Libyan government were largely marked by antagonism with the West, though normalisation started in the final years before the 2011 uprising (Solomon and Swart, 2005). This, combined with the dependence on outside materials and heavy reliance on oil revenues would leave Libya vulnerable to outside pressures caused by international tensions including sanctions. While the underlying reasons for sanctions are well beyond the scope of this investigation, their impacts on the agricultural sector are relevant. Table 2.3 summarizes the sanctions levied against Libya along with the intended impacts.

Table 2.3: Sanctions imposed on Libya during Gaddafi-led government period (Arms Control Association, 2018)

Origin	Date Enacted Date Ended[a]	Intent
USA	Dec-79 Jul-06	Ban on US arms exports, economic assistance
USA	Jan-86 Sep-04	Bans most imports and all US exports
UN	Mar-92 Sep-03	Arms embargo and air travel restrictions
UN	Nov-93 Sep-03	Freezing of assets and ban imports of oil equipment
USA	Aug-96 Sep-04	Sanctions on foreign firms investing in Libyan oil

[a]Some sanctions are not fully ended, the end date refers to a judgement when the main intent of the original sanction is over.

During the later sanctions (1986-2004) affecting imports, air travel, and oil revenues, the consumer price index (CPI) increased at a faster rate than before the sanctions, consistent with higher rates of inflation ("Country Profile : Libya", 2005). This may have had profound effects on the agricultural sector as a secondary impact to the stated goals of the sanctions. As a highly import reliant country, such sanctions are particularly damaging to Libya. Nearly all agricultural inputs (e.g. seeds, fertilizer, pesticides and livestock feed) were subsidized through direct governmental intervention through reselling at a loss. However, this stifled development of local agribusiness to serve local agricultural needs. This had a compounded impact on agriculture. Once the sanctions took effect, many agricultural input subsidies were also pared down, leaving many farmers with limited options and costs rising quickly.

The impact of the sanctions were quickly noticed within Libya. As a result of the UN sanctions, Libya claimed a loss to the agricultural sector of $5.9 billion, nearly a third of the total estimated GDP losses between 1993 and 1996 (Hufbauer et al., 2008). The loss of oil revenue would likewise be tied to a decline in investment within the agricultural sector at a time when there would be increased difficulties in securing agricultural imports that Libya relied so heavily on.

Agencies of the UN noted that the aviation ban compromised the import of agricultural inputs and veterinary supplies, reducing the availability of food from both animal sources and agriculture (Gordon, 2011). Even in the rare case of exemptions to the aviation bans, the prohibition of parts and services relating to aircraft maintenance prevented the certification of airworthiness of planes. This would impact the ability of farmers to use crop dusting techniques and the transportation of perishable goods (Gordon, 2011).

The sanctions also impacted the market within Libya, resulting in labor shortages and increased wages. As a result, many farmers reduced cultivation areas based on insufficient labor to harvest crops, leading to reduced agricultural production. One estimate of the effects on the foreign labor within Libya using a multiple regression model and cointegration procedure analysis determined 65% of the fluctuation in the non-native labor were explained by the economic sanctions and corresponding oil prices (Yahia and Saleh, 2008).

2.2.3 Post-Gaddafi Era (2011 - Present)

By early 2011, continued protests evolved into a larger uprising against the Gaddafi-led government. These uprisings focused on human rights abuses, social program mismanagement, political corruption and a desire to end Gaddafi's leadership (Bhardwaj, 2012). Unlike some other nearby countries where uprisings were a direct result of food supply issues, Libya's uprising was not sparked by direct concerns with agriculture. However, the impact of the uprisings held consequences for agricultural sector regardless.

The period after the Libyan government's collapse has been described as having two major parts. Libya's civil war beginning in 2011 had originally seemed to be short-lived. This period had seen the unrest shift to the formation of an interim government, the National Transition Council (NTC), which both held Libya together and advanced the political process leading to a constitutional democracy. However, this transitional government also was beset on all sides with armed challenges from militants seeking to secure their own interests (M. Eriksson, 2015). The first formally held elections formally shifted power from the NTC to the General National Congress in mid 2012. This gave the outward appearance of control in Libya. However, the political stability was continually deteriorating especially in the wake of leadership challenges within the newly formed government in early 2014 leading to the development of two rival parliaments (For a deeper look, consult M. Eriksson, 2015). This situation degraded further, into a complete relapse into civil war in 2014 after about a year of apparent stability, where by 2015, there were five major warring sides to the conflict (M. Eriksson, 2015). To its credit, Libya has not collapsed into complete social anarchy, with government services still being able to provide a limited amount of welfare and subsidies for consumption goods. While the conflict has continued, the needs of the agricultural sector have taken a backseat to more pressing concerns of ensuring the government's survival.

The impacts to the agricultural sector with the weakened governmental state are quick to observe. Like the production in many other sectors, agricultural production dropped significantly during the relapse into conflict in 2014. Cereal crops, for example, had dropped in 2015 almost 10% below average production levels, further increasing the needs for imported food. Imports in 2015 increased by 7% to an estimated 3.7 million tons over previous years (Zurqani et al., 2019). A report by FAO established that many agricultural productive inputs such as seeds and machinery became scarce and expensive during the uprising, leading to lost production and wages tied with higher food prices in Libya ("Countries in Emergency : Libya", 2012).

The effects of conflict on the land generally consist of either changes in resource usage or in the physical destruction of ecological capital (Mitri et al., 2014). The changing use of physical capital can refer to those induced by displacement of populations (both human and animal), shifts to more secure (but likely less productive) land, and restricted access based on transportation or physical barriers. More commonly, there is a destruction (intentional or otherwise) of ecological capital. This can include militia groups razing areas to prevent it being used by competitors, expanded pollution from war efforts leeching into the soils and available local water sources, and the loss of local biodiversity (Lawrence et al., 2015).

One common impact of conflict affecting the land is the usage of ordnance. Libya has suggested as recently as 2003 that up to 27% of its agricultural land has been affected by unexploded ordnance from prior conflicts[9] though there is scant corroborating supporting data (Killers, 1998; Borrie, 2003). While there has been reports of newly added unexploded ordnance, these have been located near more populated areas of Libya (UN-News, 2020). Much of the available agricultural land is likewise situated in the same areas as the larger population centers, raising concerns that there will be long-lasting impacts once the conflict subsides. While no accurate estimate of the ordnance affected area exists due to inability to survey during the conflict. A report from the Landmine and Cluster Munition Monitor program (2020) indicates at least 27,000 ha of land is considered "suspected hazardous area", including some agricultural land.

The onset of conflict has led to labor shortages with the departure of foreign workers making up the majority of the total agricultural labor force (FAO and ITPS, 2015). These impacts are both seen and felt, where an initiative supported by FAO surveyed Libyan agricultural producers to investigate perceived reasons for the reduced harvest, concluding the armed conflict led to a lack of agricultural labor.

[9] World War II, Egypt (1977), and Chad (1980-1987).

Infrastructure delivering critical goods can be a focus of conflict, being both a desirable resource to use and as a targeted resource to prevent other factions from using. Since the outbreak of the civil war in Libya in 2011, the Libyan GMMR has been vandalized and attacked by militants from the conflicting parties, strongly affecting both residential and agricultural use (Laessing and Elumami, 2019). This includes the NATO led airstrikes against the pipe-building facility that was assumed to have hidden military assets, with the damage expected to greatly postpone future GMMR construction even after the conflict ends (Larson, 2020). In several separate instances, the water supply to major cities has been cut off by militants making demands to use as a bargaining chip (Laessing and Elumami, 2019). The results of this conflict driven damage have affected the water supply both directly through violence and lack of maintenance, and indirectly through blackouts and fuel shortages, leading to a drop in the flow rate 33% from 1.2 million cubic meters daily (Divakar, 2020).

2.2.4 Summary

With its arid climate, poor soil quality and low amounts of natural water resources, Libya represents a non-ideal agricultural producer. Libya had been a colony of Italy for 30 years prior to World War II and Libya's best agricultural land was primarily owned and managed by Italian colonists. Libya itself was resource poor and lacked the funding to develop the agricultural sector beyond the investments made from abroad by the Italians. At the close of World War II, control of Libya had shifted from Italian to British and French oversight though Italian colonists were still in control of the agricultural sector. However, these countries had limited interest in directly overseeing Libya, instead pushing for Libya's change into a constitutional monarchy by 1951. Still resource poor and heavily dependent on foreign aid, the discovery of oil in the late 1950s changed the dynamic of Libya's dependence on foreign interests. With the sudden increase in revenue, Libya was now able to fund domestic goals, including achieving greater food security. However, Libya has remained a heavy net importer of its cereal needs for much of the last fifty years, partly owing to a population increase spurred on by the discovery of oil. The late 1960s saw the rise of the Gaddafi-led government initiated by a bloodless revolution that replaced the inefficiencies of the monarchy but kept the same driven desire for self-sufficiency. This included the expulsion of the Italian colonists to reclaim the agricultural land for native Libyans. However, the disappearance of the colonists took out both local capital and local technical knowledge for working those farms that many native Libyans did not have. While the most productive lands were now back in Libyan control, the Libyan government segmented the agricultural plots to achieve the political goal of each Libyan family having enough to provide for itself at the subsistence level. This political goal did not align with the agricultural realities of Libya leading to highly inefficient farming. Furthermore, the fast development of the oil sector pulled more Libyans towards this lucrative sector, creating an agricultural labor gap that started to be filled with a large contingent of foreign laborers that has expanded for much of the last half-century.

Flush with revenue from the dramatic rise in oil prices from the 1973 oil embargo, the Gaddafi administration brought with it renewed interest in food security and heavily invested in the agricultural sector to make up for the weak productivity. This included the development of the world's largest civil engineering project, the GMMR, capable of providing over 90% of the country's total water need, much of it for agriculture. While agriculturally positive events were occurring within the country, external problems for Libya were starting to ramp up. The Libyan government's international relations with the West were often antagonistic and confrontational. Libya's repeated involvement with international incidents lead to the sanctioning of the country both by the US and the UN at various times of the 1980s and 90s. Coupled with the loss of revenue to support domestic policy from the sanctions against Libyan oil exports, the international efforts against Libya lead to a weakening of the agricultural sector including loss of foreign labor, increased cost of agricultural inputs and rising wages. Despite the great attention that the state has paid to the agricultural sector from the large investments since the beginning of the 1970s, Libya has suffered from poor agricultural production.

Domestic issues lead to protests culminating in full uprising against the Gaddafi-led government in 2011, starting the Libyan civil war conflict that continues to today. While early indications seemed to suggest Libya was on a path toward stability in 2014, the situation devolved back into full scale conflict without a single, clear governmental authority in place. During this conflict, Libya has seen a remarkable drop in the agricultural production, damage to agricultural inputs and infrastructure, and a majority of foreign labor leaving due to security concerns.

2.3 Review of Agricultural Production

Libya's history and the inconsistent focus on agriculture[10] have resulted in the development of a hobbled agricultural sector. Yes, the conditions for agriculture in the region are weak due to natural conditions and geography, but the Gaddafi government's efforts to improve agricultural production were also sub-optimal.[11]

When the current conflict ends, Libya will have a strong opportunity to redefine how the country operates the non-oil sectors of the economy. The primary goal for the newly formed government is to restore security and minimize the resurgence of conflict in the short-term before any other considerations. Restoration of the oil sector is naturally expected to remain at the forefront of this recovery process, but other concerns for stabilization will also be present, including support for agriculture. In the post-conflict period, Erskine and Nesbitt (2009) argue both the private and public sector are often inadequate to serve the needs of local agricultural efforts for development. This is expected to be especially pronounced for

[10]Consider, for example, Libya's enormous investment into providing nationwide irrigation through the GMMR and well-funded agricultural loans, contrasted with periods of investment neglect, minimal labor education, and promotion of inefficient practices (such as dividing land into smaller farms capable only for subsistence).

[11]Much of this government driven inefficiency can be traced to misunderstanding the agricultural sector and applying haphazard funding with little involvement to ensure efficient use.

Libya, where the public sector is hampered by extensive bloat and inefficiency carried over from before the conflict, and the weak private sector development induced by public sector's misuse for employment (Shernanna et al., 2013). This is problematic since agriculture's role in post-war reconstruction is considered vital (Cox, 2005), underscored by an estimated 22% of Libyans being engaged in some form of agriculture production (WFP, 2020). A stagnating agricultural sector post-conflict is expected to inhibit a country's overall recovery and development, particularly in bolstering food security, absorbing former combatants while improving livelihoods, and reducing the likelihood of renewed conflict (Lautze et al., 2012).

To investigate the impacts of conflict on Libya's agricultural sector, I first dive into the relevant literature discussing what variables are usually considered in agricultural production models. I continue with a look at the use of economic models describing agricultural production at the national aggregate level. This is followed by examination of the literature involving conflict pertaining to agricultural production. Minimal scholarly agricultural production studies are available that focus on Libya, and the use of models to examine the immediate impacts of conflict on the agricultural sector (as well as other non-oil sectors) remain large gaps in the literature.

2.3.1 Measuring Agricultural Variables

In this section, I address how data is measured for use within agricultural production functions. This information is useful in determining which inputs should be included in my model under the general headings of environmental capital, physical capital and labor.

Measuring agricultural production has some key differences from similar measurements in other sectors. Agricultural firms usually include many small businesses, making use of unpaid owner and family supplied labor generally associated with higher productivity (Thapa, 2007). Furthermore, natural characteristics such as weather and soil composition affect agriculture more than other industries and need to be accounted for within the production function. Agriculture is also self-sourcing in many ways, as a significant number of the inputs to production may originate from the sector itself as outputs from an earlier stage (Gollin et al., 2014).

Production functions rely on well-defined measurements of variables leading to the conversion of input factors to the output observed value. In agricultural investigations, the output variable depends on the scope of the production function, whether it covers firm level data, or more aggregated regional information. When the production function considers the national aggregate agricultural production, it is common to describe the output as the value of the agricultural GDP in terms of some constant reference value. This is due to the components of the agricultural output having dissimilar and non-comparable relationships; aggregating the components would be meaningless without a standard basis of comparison by value as opposed to quantity.

The measurement and collection of data related to the inputs of production for agricultural studies also requires specification. In the absence of system shocks, studies are often interested in the direct impact of production inputs on the output. A majority of the research has given attention to the function of conventional inputs such as land, physical capital and labor in explaining agricultural production and productivity growth (Lachaal, 1994; Mozumdar, 2012). Beginning with Hayami and Ruttan (1970), production functions investigating the agricultural sectors have also included intermediate inputs such as fertilizers, pesticides and seed. Mozumdar (2012), for example, also concluded how production factors such as land, water, labor, chemicals, fertilizers, and other physical capital all influence agricultural production. However, in another study, the same author found non-conventional production factors such as labor development have significant importance in improving productivity, especially in developing countries (Mozumdar, 2012). In Libya however, human capital development has been minimal and is unlikely to contribute to productivity changes (Gewider, 2012).

Environmental Capital

When discussing the factors of production used in an economic model, the goal is to create a relationship capturing the most important factors that play a role in the production process. One factor of production that exists for agricultural production functions that is not present in many other disciplines is the existence of natural resources.[12] Natural resources represent inputs that are not derived from human labor explicitly (FAO and ITPS, 2015), where the most common form of natural capital used in production models is land. As described by Echevarria (1998), non-agricultural production functions are capable of aggregating land directly into capital since the land contribution to production is usually negligible. This is clearly not the case in agriculture, where neglecting the land in agricultural production functions overestimates shares of capital and labor, while underestimating the growth rate of total factor productivity (Echevarria, 1998).

Other natural capital contributions that have been included in agricultural production models include water, soil quality, forests, air quality, livestock, seedstock, biodiversity and other factors that serve as an ecological contribution to the total agricultural product (FAO and ITPS, 2015). One critique about the inclusion of natural capital in the production process in most economic models is the correct valuation[13] of these natural inputs (see, for example, Toman, 1998).

Land is a conventional input for agricultural production function measurements commonly expressed in hectares (Kawagoe et al., 1985). The amount of cultivated land is strongly correlated with the yield, though the efficiency of the production is highly dependent on numerous features including the use of other inputs to production (Garibaldi et al., 2011). For example, there are differences in land use for different regions. This includes how

[12] Alternative designations can include ecological capital or environmental capital.

[13] Conversions from standard units of measurement into financial terms for natural resources is complicated by spatiotemporal dynamics that have interactions with other natural capital. Land near a river is generally more agriculturally valuable than that same land when the river dries up, or compared to land located centrally within a desert, for example. Assigning a meaningful value to natural capital will also need to incorporate both direct benefits and secondary impacts. Some natural capital (such as quality measures) are resistant to valuation and are more likely to be expressed as indicator (or dummy) variables.

often the land is under cultivation. For example, Boserup (2017) notes that tropical regions have long fallow periods, but in many parts of Libya land is cultivated twice in a given year, which may be associated with a land-augmenting technical change (Bustos et al., 2016). As such, cross-country comparisons that do not take into account different cultivation periods can be misleading when considering production.

A second conventional environmental capital input is water. Irrigation measurements typically include rainwater, surface water and ground water sources (FAO, 2016a), and these water-sourced contributions to agricultural production have been examined in detail by Vrachioli and Stefanou (2018). In an investigation of the agricultural production in Nigeria, Eboh et al. (2012) incorporate rainfall[14] and irrigated land into the production function and determine rain is one of the more important factors influencing the output production.

It is clear that water is an important aspect in Libya's agricultural output as sufficient water is needed throughout the growing period to sustain crop cultivation. Libya's primary crops are wheat and barley, which need between 450 and 650 mm of water per total growing period (FAO and ITPS, 2015). A very limited area in Libya experiences enough rainfall to support even those two drought resistant crops as shown in fig. 1.3. Surface water sources in Libya are non-existent, requiring the bulk of water used in production to come from underground sources such as the Nubian Sandstone Aquifer.

Other forms of natural capital likewise have their place in agricultural production economics. Many studies have incorporated the use of livestock (Hayami and Ruttan, 1970; Kawagoe et al., 1985; O'Donnell, 2010), seeds (Cornia, 1985; for farm level data - Ajibefun, 2002; McArthur and McCord, 2017), and soil (Fulginiti et al., 2004; Abdul-Rahim et al., 2018; Liu et al., 2018) in measuring agricultural production.[15] Other models have included

[14] Rainfall in this study was modelled as a quadratic function to account for the seasonal flows.

[15] In a large number of investigations, measuring or characterizing productivity was the often the goal. However, this goal is underpinned by the need to develop a production function to use to establish productivity changes on either a cross-country or temporal basis. In Libya, there is little literature available that incorporates sufficient detail in the factors of production at the national level to establish a usable production function which this investigation seeks to rectify.

factors that work against production, such as the effects of pollution and erosion (Ojimba, 2012; Panagos et al., 2018).

A main issue in Libya's agricultural output is the poor suitability of the region's environmental capital, making the factor important to include in any generated agricultural production function. The productive arable land in Libya constitutes only about 1% of the total land area of the country, mainly located on the northern coastline (Azzabi, 1993). In addition, low rainwater, poor soil quality and fertility–combined with desertification and unfavorable weather conditions–reduce the productivity of the agricultural sector in Libya.

Recent literature within Libya has focused on the inclusion of seeds. The work of Lariel (2015) highlights the need for Libya to improve its seed system to close the yield gap, though the absence of a responsible government agency within Libya means there has been little adoption of more efficient seed varietals. However, McArthur and McCord (2017) determined fertilizers and seed quality are correlated variables owing to their complementary nature, suggesting little need to incorporate both measures in production analysis.

Abagandura and Park (2016) address prominent and secondary challenges like the ever-increasing merger of seawater with groundwater, soil degradation and the scarcity of quality irrigation water sources within Libya. Abdudayem and Scott (2014) reach similar conclusions regarding the state of water institutional frameworks, infrastructure and policies as they pertain to large inefficiencies in the agricultural sector. Each of these issues is not captured by only considering the area of land as the sole source of environmental capital in the production function.

Physical Capital

The second major contributing factor to production for agricultural models consists of physical capital. Unlike natural capital, physical capital is a standard component included in economic production models and represents inputs to production that are the products of human labor which may or may not be consumed in the agricultural process expressed through the categories of tangibility, durability, mobility and reproducibility (Kataria et al., 2012). In the agricultural sector, physical capital includes machinery, fertilizers, pesticides, transportation, buildings and infrastructure.

Machinery in agriculture consists of all "labor-saving" tools used in the extraction of agricultural output, including milking machines, egg incubators, combines, and threshers. Debertin (2012) indicates that machinery such as farm tractors can substitute for labor, particularly in aggregate measurements. However, the use of machinery is not uniform over the different subsectors of agriculture, with many studies involving machinery invoking the number of tractors or tractors/ha as a proxy for machinery input data (Fuglie, 2010).

Fertilizer includes all nitrogen, phosphorous, and potash sources (FAO and ITPS, 2015). The loss of soil fertility through agriculture has been countered by the addition of natural fertilizers, while the move to higher intensity agriculture has focused on a dependence on chemical fertilizers, particularly nitrogen varieties that now exceed 70 mega-tonnes per year worldwide (Tilman, 1998). Where land/labor ratios tended to be smaller, there was increased emphasis on the benefit of fertilizer on agricultural productivity as compared to the increase in mechanization (Kawagoe et al., 1985; Woodhouse, 2010).

Pesticides are also an important component of agricultural systems and have led to increased crop yields through reduction of crop losses (Alexandratos and Bruinsma, 2012), while at the same time being partially responsible for soil degradation and pollution reducing future effective yields and compromising other food sources including fisheries and aquaculture (Carvalho, 2017). This impact noted by Guo et al. (2010) illustrates how intensive fertilizer usage can change the soil composition and can be responsible for decreased productivity over the long-term through acidification. El-Barasi et al. (2010) concluded less than 7% of Libyan farmers were aware of the environmental effects associated with pesticide and fertilizer use while even a smaller fraction of less than 1% of those farmers have the knowledge of accurate use of pesticides and fertilizer. These widespread practices reflect farmers' lack of understanding of the adverse effects of intensive use of fertilizers and pesticides. Compounding these problems are the lack of knowledge of the role irrigation plays in optimizing production.

Labor

A third major factor in the agricultural economic model is labor. Labor represents the used human capital or effort used in contributing to the overall agricultural production. Unlike the two capital contributions, labor cannot be accumulated.[16]

While the labor comprises both family farmers and hired labor, the majority consists of foreign workers (Allafi, 2014). Nearly all of Libya's labor problems existed before the current conflict[17] and reflect the economy with stronger focus on the oil sector (Vandewalle, 2012). However, the formal employment in the oil sector is small–around 40,000 people–and is insufficient in justifying the large labor gap in the agricultural sector filled by foreign labor. Instead, the higher wages supplied by the public sector (funded from oil revenues) in Libya are the more likely culprit[18] contributing to the need to employ mostly foreign labor in the lower wage agricultural sector. This development has become entrenched as there are noted unrealistically high wage expectations and negative attitudes to manual work for native Libyans (Abuhadra and Ajaali, 2014).

The dominance of the foreign labor contingent has had two profound impacts on the Libyan economy. First, it has hindered non-oil sector private sector development which makes post-conflict recovery more reliant on external interventions. Second, non-oil sectors are highly dependent on migrant labor just to function (El Kamouni-Janssen et al., 2019). Geheder (2007), for example, examines the cereal crop production from 1991 to 2004 and discusses the role of labor in measuring agricultural productivity in Libya, concluding that

[16]Some forms of capital also cannot be accumulated (such as soil quality) and are used as modifiers of other input factors.

[17]The Confiscation Law No 4 of 1978 was particularly damaging to the economic and social structure, where the public sector-funded by oil revenues-developed into the primary job creation institution (Abuhadra and Ajaali, 2014).

[18]The public sector employs 51% (and has been as high as 85% (El Kamouni-Janssen et al., 2019)) of the workforce, but contributes only 9% of the GDP. Compare this to oil or agriculture, which actively employs 2% and 6% of the workforce and contribute nearly 50% and 6% to the GDP, respectively.

the dwindling native labor force is a culmination of the transition of workers to more secure labor sectors, the lower wages within agriculture, and lower returns on investment. Unlike other countries where the share of labor present in the agricultural sector decreases as the efficiency of the labor increases (Dorward, 2013), the labor force of Libya still has low efficiency while experiencing a loss of labor share (Abidar and Laytimi, 2005).

After 2011, the absence of security in the region and increased violence against migrants who have little support system within Libya has caused a massive shift of foreign labor out of the country. The labor force in Libya prior to the conflict included nearly 2 million non-Libyans in 2005, of which only 600,000 were present legally (Baldwin-Edwards, 2006), with an estimated 15% employed in the agricultural sector (Abuarosha, 2013). In 2011, the International Organization for Migration reported over 750,000 migrant workers had fled the impending violence in Libya, causing strain on various sectors through the mass exodus. By August 2020, the number of remaining migrants was estimated under 600,000 (IOM, 2020), leaving many sectors barely functional.

In 2015, Jarad discussed the problem of agricultural productivity reduction in Libya, focusing on agricultural employment and its effect on agricultural production without addressing other variables. Jarad's contribution defined agricultural regions based on the impact of labor within various geographical limits. However, the conclusions remain difficult to apply in a broader scheme at the national level while including more than labor as a factor of agricultural production.

One consideration that appears to impact each of the factors of production (natural capital, physical capital and labor) relates to the technical expertise within Libya. In another investigation of agricultural labor, El-Barasi et al. (2010) found a high proportion of Libyan farmers lack extensive knowledge of agricultural operations such as fertilizers, pesticides and machinery partly due to the lack of agricultural education and training. The issue is compounded where illiteracy (53% literacy rate of farmers compared to the national average of 90%) is prevalent among farmers (El-Barasi et al., 2010), as is the 87.7% proportion of farmers with minimal education reported by Omar et al. (2012). The educational aspect of farmers is a detriment to other components of production. For example, nearly a third of farmers were described as having limited knowledge of fertilizer and pesticide practices (El-Barasi et al., 2010). Instead, farmers are relying on local knowledge learned from other farmers.

Under the assumption that farmers are looking to maximize their crop production, mismanagement and poor agricultural practices present an obstacle. This poor management includes over-irrigation, over-fertilization, excessive use of pesticides and poor maintenance of machinery, all of which could lead to low level of resource efficiency (Lariel, 2015). This has been a continual problem over Libyan history. For example, Brolo (1979) noted that Libyan farmers do not apply crop rotation and lack official control roles in the sector.

Labor is important to the production process as the driving force in the use of all other inputs to production. Unlike some physical inputs and augmenting technology, the absence of labor prevents all useful production. Because of this, labor's inclusion in a production model is standard. However, cross-sectional studies often conclude wide differences between developed and less-developed countries when examining the productivity associated with labor, especially in agriculture where the former experience a 71-fold increase in productivity compared to the latter (Restuccia et al., 2008). This means that it is inappropriate to compare results between different countries with dissimilar levels of economic development.

Of the inputs to production, labor may represent the best chance to improve the agricultural productivity as Dorward (2013) concludes that agricultural revolutions of increased labor productivity are foundational for both the agricultural sector and the wider national economy. Therefore, examination of labor's impact on the production is necessary when looking at the best ways to improve a stagnant or conflict-depressed agricultural sector.

2.3.2 Agricultural Production Models

One of the primary goals of this investigation is to develop a production model of Libya's agricultural sector. In this section, I detail characterizations of agricultural production functions and provide an overview of the models used in agricultural production literature.

Measurement of production and the inputs leading to production has fundamental importance in the field of economics. While production functions express mathematically a conversion of agricultural inputs into output production, the production function really represents the relation between combinations of inputs and the *maximal potential* output (Miller, 2008). The production function is used in quantifying productivity, determining a misallocation of inputs, and establishing gains from trade and market power (Demirer, 2020). Characterizing this conversion also offers insight and justification for policy decisions to improve either efficiency or the total production.

To be clear, when the discussion of agricultural production revolves around the efficiency of the conversion from the inputs to the output, it refers to *productivity*. However, this investigation is focused on *production* (and conflict's impact on production). The reason for this is two-fold. First, Libya's overall agricultural productivity is comparatively poor ("Country Profile: Libya", 2005; Galanopoulos et al., 2006) and getting progressively weaker[19] due to domestic environmental conditions (Abagandura, 2016). However, various components of agricultural productivity have seen some increase. Labor productivity within Libya, for example, has increased due to the rise of new technologies within the sector (Geheder, 2007). There remains little uncertainty regarding Libya's overall agricultural productivity, making it a poor candidate for a productivity study. In the context of conflict, the productivity is expected to decrease (Belloumi and Matoussi, 2009), but such changes in minimal productivity are likely to be statistically insignificant.

Second, a firm's productivity is measured either parametrically (with a specified production function form) or in comparisons with other firms through non-parametric methods.

[19] The increased weakness largely comes from environmental and ecological degradation.

A review of the literature on agricultural production in Libya shows many investigations focused on farm-level production functions or about disaggregated output (such as individual crop harvests), but no investigations on developing a national production function that incorporates the full agricultural sector that evaluate the suitability of the model for Libya.[20] Productivity estimations using non-parametric methods evaluate the comparative efficiency against the production frontier (Toma et al., 2015), which assumes the comparability between decision making units. This further implies that countries can push towards the efficiency frontier. However, conflict induced economic shocks are hypothesized to alter the underlying production function and make Libya unsuitable for comparison against countries not experiencing conflict.

In the literature, agricultural economists have used many models to represent agricultural production, often incorporating more than 3 factors of production. Production functions can be categorized based on the function's flexibility regarding the elasticity of substitution. Broadly speaking, production functions can either exhibit constant elasticities (such as the Constant Elasticity of Substitution (CES), Leontief, and Cobb-Douglas models), or allow for variable elasticities (such as the quadratic, translog, and transcendental models) (Sickles and Zelenyuk, 2019). Naturally, the constant elasticity models are a specific subset of the variable forms. In agricultural production economics, the CES and translog models are common; I will examine the features of these two modalities here, while a resource covering the functional forms of these and other production functions is found in Sickles and Zelenyuk (2019).

To avoid model specification issues, some investigations consider non-parametric approaches such as using Malmquist indices and Data Envelopment Analysis (Odhiambo et al., 2003). However, the most widely used approaches in the analysis of production include the use of CD and CES production functions. The former has the benefits of being linearizable, with the latter requiring more intensive analysis (Odhiambo et al., 2003).

[20]Some cross-country studies include Libya and specify a common form of production function, for example Headey et al., 2010.

The CES production function provides two primary features for the elasticity of substitution. First, the elasticity of substitution is non-negative and second, that the elasticity of substitution is constant on a given isoquant for a given set of parameters (Debertin, 2012). A drawback to using the CES production model is the limited ability to represent only one stage of production.[21]

A limiting case of the CES production function is the Cobb-Douglas (CD) function, where the elasticity of substitution is 1. The CD model is commonly used to estimate production and remains simple in application (Felipe and Adams, 2005). This standard specification has an assumed constant factor share (Gollin, 2002), but the presence of system shocks may violate that assumption (Bond and Söderbom, 2005). In practice, the CD production function is often modified through the inclusion of an exogeneous technology factor as in the Solow-Swan specification (Solow, 1956). While the CD specification is regarded as a simple tool, it has also been regarded as crude. Nevertheless, various econometric estimation problems such as serial correlation heteroscedasticity and multicollinearity are dealt with easily in the model (Bhanumurthy, 2002).

In an investigation considering the general use of the more flexible CES function compared to the CD model, Miller (2008) finds little evidence within the literature suggesting CES is preferable to CD when forecasting GDP and income shares. However, Miller also notes that aggregation issues (see Felipe and Fisher, 2003) can present a theoretical challenge to both forms, where the investigator should avoid making strong inferences without consideration of the theoretical issues. A further concern of general (non CD form) CES production functions is the difficulty in obtaining estimates of the elasticity of substitution across studies (Miller, 2008). Another criticism of the CES production function is the inability to handle more than two inputs of production with simultaneous constant elasticities, as no functional form with an arbitrary number of constant elasticities is viable with more than two inputs (Mishra, 2007).

[21] Normally, the CES models represent the rational stage, where the production is characterized by positive but decreasing marginal returns (Debertin, 2012).

Uses within the literature of CES production functions (and the corresponding nested functions such as CD) are both ubiquitous and varied in scope (dealing with national gross output to farm-level data) and focus.[22] Studies that use aggregate national data for the full agricultural sector are most often done as cross-country comparisons were largely renewed with the work of Hayami and Ruttan (1970) which considered 38 countries to share a common meta-production function of the CD type to establish a development strategy for less developed countries. The choice of the CD model was based on the ease of manipulation and interpretation. This study incorporated 7 input variables (including nonconventional education and research) and while additional inputs were considered, Hayami and Ruttan (1970) concluded the parameters measured were not viable due to either being negative or lacking statistical significance.[23] One difficult consideration in cross-country studies such as this is the underlying belief that all countries produce along a common production function. Mundlak and Hellinghausen (1982) argues that while all countries may have access to the same latest technologies, adoption of these technologies is limited by both local environmental and economic factors. Even amongst lower developed countries, the production function may not be structurally similar.

Jiménez et al.'s more recent investigation using a CD and a nested CES model examined whether Colombia's weak agricultural sector stemmed from low productivity growth or input accumulation using the inputs of capital stock (land, livestock and machinery), labor, fertilizer and animal feed (2018). At the aggregate level, the authors concluded a significant ($p<0.05$) marginal effect only with labor and animal feed, where the productivity gains measured were likely driven by improvement in technology use and input quality enhancements for poultry and non-ruminant producers. When using a CD model, Jiménez et al. determined factor shares of the significant fertilizer and animal feed components at 0.30 and 0.41, respectively (2018). For the CES model, the distribution parameters of individual

[22] Some consider only subsectors within agriculture such as water supply, major crops and availability of credit.

[23] The authors attribute this to the crudeness of the data, a feature similarly expected in Libya's data, rather than suggesting these other variables have no influence.

production inputs were not reported, though the elasticity of substitution was reported at 1.259 and 0.942 for an imposed condition of Hicks-Neutral technical change and bias technical change, respectively. The authors instead used the CES results to show the presence of biased technical change within the sector between 1975 and 2013, while estimating the elasticity of substitution without deep consideration of distribution parameters related to the input factor shares.

Unlike the CES and CD model, the translog production function allows the elasticity of substitution to vary[24] along the isoquant (Debertin, 2012). One view of the translog function is as a second-order Taylor series approximation of a CES production function (Boisvert, 1982). As such, it is unsurprising that the CD production function is again a specific case of the translog model (removing the variable elasticity).

The work of Ortega and Lederman (2004) revisited the idea of agricultural productivity measurement in cross-country comparison studies using the translog production function for the period 1961-2000 across 86 countries with sizeable agricultural labor forces. The authors considered the relationship between 6 direct inputs and with the inclusion of both a time trend and a dummy variable specifying the development of the observed country. In this study, marginal products for the inputs were largely dominated by the labor input, regardless of the country's development. However, Ortega and Lederman further explain that estimates should be used with caution, with some results having "implausible coefficients" over some of the key variables (2004).

There are further criticisms of the translog production function. First, increasing the number of factors of production rapidly expands the number of parameters that need to be estimated (it increases at a rate on the order of the square of the number of inputs). This increases the likelihood of introducing multicollinearity within the model due to the inclusion of squared and cross product terms (Boisvert, 1982). While one strategy to reduce multicollinearity is to remove terms with that have low statistical significance, doing so inhibits

[24] This can be accomplished in a similar fashion to including an interaction term within a standard log-linearized CD production function.

the flexibility that was the major reason for the departure from the CES model. A second issue with the translog production function is that it is not invariant to different measurement units (Mishra, 2007), which can lead to competing interpretations of results based on biased unit measurement specification. Regardless of the form of production function, endogeneity is a concern where input decisions made by firms are unobservable by economists possibly producing regressors correlated with the error term (Ackerberg et al., 2015). Yet, the problem of endogeneity could be resolved by using the instrumental variables approach, where an instrument is correlated with the endogenous variable rather than the error term (Angrist and Krueger, 2001).

2.3.3 Review of Conflict in Agricultural Production

A subset of the literature on agricultural production focuses on understanding the role conflict plays. In this section, I examine how armed conflict functions as a production shock both during and after the conflict period. This further is used to understand the likely effects of conflict and how conflict can be addressed within a given production model.

In measuring production, certain assumptions are common. One of these is the assumption that the model parameters are time-invariant. Even for the translog model where the elasticity of substitution is not constant in time, the change is only due to the variation within the input quantities themselves rather than explicit time dependence in parameters. As such, measuring production during periods of stability is more common in the literature than during periods of instability. The addition of conflict is disruptive to stability, and the assumptions of time invariance are no longer inherently valid.

Regardless of the methodology, the quality of data measurement for use is of concern. The less reliable the collected data, the weaker the inferences that can be drawn using that data. During stable periods where no production shocks are present, accurate measurement of production variables is more likely. Even then, measurement during stable periods may still be compromised due to changing definitions and methods of measurement, or from misreporting errors from every stage between the farm and national level (Abay, 2020). Conflict adds another layer of uncertainty where several conflict-driven factors inhibit accurate collection including weaker oversight and shifts in organizational priorities.

Measuring agricultural production is widely used and applied to many regions around the world, especially during production shocks. For example, several studies examined output growth in China between 1978 and 1984, where the output of the agricultural sector had increased over 61% due to deep agricultural policy reforms (McMillan et al., 1989). These studies include production function approaches, supply-response estimations, and Dennison-Solow type growth accounting to understand the impact of major reforms imposed by the Chinese central government in its attempt to move from communal to incentivized ownership (Lin, 1992).

Widespread conflict contributes to high costs and reprioritization of government funding leading to an economic slowdown of between 2-3% (Collier, 2007). By way of explanation, the cause of economic slowdown is attributed to the depletion of domestic capital stock. However, in Collier and Hoeffler's study (1998), the dependent variable was the decade average per capita GDP growth rate, which reduces the problem of endogeneity at the expense of short-term dynamics analysis. Furthermore, Collier finds arable subsistence agriculture is among the least affected sectors during civil conflicts, due to the agriculture being transactions and capital extensive, while producing output that is neither transactions nor capital (1998). Collier then supports the hypothesis of agricultural sector expansion relative to the GDP by looking at the long-running (15-year) Ugandan civil conflict. Collier's conclusions, however, do not establish the change in any sector, instead opting to investigate the relative factor shares, leaving open the question of how individual sectors are affected.

Numerous studies have investigated conflict (see Sambanis, 2002), with some involving agriculture (Miguel et al., 2004; Ross, 2004a; Ross, 2004b; Arias et al., 2014). However, most of the research on conflict focused on the factors predicting the appearance of conflict (Collier et al., 2000; Ross, 2004a; Dixon, 2009) and the severity and duration of conflict (Collier et al., 2004; Cunningham et al., 2009). Other research has investigated post-conflict recovery, though most do not focus on the agricultural sector alone (Cerra and Saxena, 2008; Fearon et al., 2009; Özerdem and Roberts, 2016). An early attempt to investigate the impacts of present and post-war on economic performance and productivity argued that civil war could reduce national GDP and slow the economic growth rate (Collier and Hoeffler, 1998). While the study of post-conflict is more helpful in understanding the immediate impact of conflict, countries that successfully navigate post-conflict rebuilding also are more likely to collect reliable data, introducing selection bias (Blattman and Miguel, 2010). Despite research on conflict's impact on productivity, quantitative measurement of an ongoing conflict's impact on agricultural productivity needs more investigation (Collier et al., 2009). The absence of this kind of investigation in the literature is primarily due to difficulty in obtaining reliable data while the conflict is taking place (Cederman et al., 2011). Furthermore, the use of models to examine the immediate impacts of conflict on the agricultural sector GDP, as well as other independent sectors is still a remaining gap in the knowledge.

Establishing the interrelation of conflict and agriculture has led to innovative theoretical and empirical methods to examine production and productivity. For example, Eklund et al. (2017), used satellite images to estimate crop size in ISIS[25] controlled regions in an effort to measure conflict's impact on production, while Miguel et al. (2004) employed an Instrumental Variables econometric approach to examine variation in rainfall to estimate the impact of economic growth leading to conflict. The econometric approach is based on estimation of the production technology in order to quantify the marginal contribution of each input to the aggregate production (Antle and Capalbo, 1988).

The output production is impacted by conflict through different mechanisms. First, conflict is responsible for disruption of production by preventing normal operations, especially for those whose primary source of income is through agricultural efforts. This is partly due to risk-averse producers in conflict areas avoiding systemic loss due to looting, destruction

[25] Islamic State of Iraq and Syria.

and lack of safety (Simmons, 2013). Secondly, conflict affects transportation. Destruction of transportation vectors and the diminishing number of available vendors in the region reduce the overall available supply (Simmons, 2013). Many other aspects of agricultural production are affected by the destruction associated with armed conflict, including infrastructure (Anand, 2005), markets for distribution (Özerdem and Roberts, 2016), and capital investment (Murdoch and Sandler, 2002).

While growth is stagnated, other effects also play a role. The impacts on human, physical and environmental capital during prolonged conflict also inhibit future development. Messer and Cohen (2007) postulate that civil conflicts in developing countries effectively cause food shortages, decreasing food production and affecting both import and export markets.Erskine and Nesbitt (2009) similarly cite conflict and economic problems as the main cause of more than 35% of food emergencies between 1992 and 2003, highly implicating the downturn of the agricultural sector during conflict. While it is apparent that conflict drives changes to the output production directly, there are also impacts to the inputs of production.

The effects of conflict to the inputs of production are noticeable, even at the primary level by the producers. Data collected by REACH (2016), an initiative supported by FAO, surveyed Libyan agricultural producers to investigate perceived reasons for the reduced harvest, with responses focusing on water shortages, a lack of labor, a lack of agricultural inputs, lack of irrigation, pest control and agricultural tools.

Damage is the most apparent impact caused by conflict in relation to agricultural production. To reduce morale and weaken resistance, the destruction of both physical and environmental capital is common during conflict (Messer, Cohen and D'Costa 1998; Unruh, 1995). Such damage can include pollution of the water resources used for irrigation, destruction of equipment, storage facilities and growing crops, and reduction of land fertility to prevent further production (Cohen, 1999). Each of these problems presents an issue in restoring economic livelihoods and preventing agricultural food shortages and low productivity after the damage to the arable land during post-conflict reconstruction (Machlis and Hanson, 2011; Von Braun, 2008).

Of the inputs affected by civil conflict, the impact on the environmental capital is the most pronounced long-term, especially damage to arable land, surface water, groundwater resources, natural reserves and environmental assets. This is partially due to conflict's associated displacement and land abandonment, as well as loss of agricultural production suitability (Clover, 2003). For instance, chemical warfare contaminates the soil and water, threatening human life and affecting sustainable agricultural practices both during and post-conflict (Ozerdem & Roberts, 2016). Research conducted on the Syrian Basin demonstrated how irrigated agricultural production dropped between 15% and 30% using a remote sensing approach which proved effective in locating losses in agricultural productivity due to conflict rather than drought (Jaafar et al., 2015).

Landmines and other unexploded ordnance are another issue facing ecological resources, causing agricultural lands to become unavailable to use for years (Kingma, 1997). Compounding the issue, damage to production is normally focused on the highest yielding lands resulting in a distortion of arable land, affecting rural populations prevented from working fields, and leading to major local food insecurity (Messer et al., 2001). Long-term damage is seen in many post-conflict countries. For example, there is an alteration of crop production in Vietnam due to both the remaining unexploded landmines post-conflict and the still present chemical contamination. Some farmers and growers abandoned their businesses, seriously impacting the agricultural sector (Miguel and Roland, 2006).

Some of the loss of production is not associated with destruction, but with shifts in cultivation practices. A recent study, Eklund et al. (2017), investigated cropland abandonment during conflict in the Islamic State-seized regions of Syria and Iraq, while noting a general lack of statistical data in unsafe conflict zones, guiding the use of satellite remote sensing for measurement. The conclusions of this work include a shift in the agricultural production to less productive regions and to more long-term fallow areas. Furthermore, there is a shift from high to low-intensity farming, implicating a change in the way agricultural land is being used. In the case of Libya however, the limited amount of arable land offers little possibilities of substitution (Eklund et al., 2017).

Physical capital is also affected by conflict. Collier's initial investigation (1998) and later developments (Collier, 1999; Collier, 2003; Blattman and Miguel, 2010) all point toward the flight of domestic capital stock. The basis is that internal conflict reduces the existing stock of capital as competing militaries seek advantages in wartime. Furthermore, there is depleted investment and changes in the rate of depreciation, causing a reduction in the level of capital stock and its rate of growth (Imai and Weinstein, 2000).

The social impacts of conflict also affect the labor input to production. For example, men tend to dominate the agricultural sector but are also the most likely to participate in political violence by either joining militias or defending their assets and family, reducing the productivity of farms (Cohen, 1999). Agricultural production suffers as these men are usually working age contributors to controlled agriculture businesses in the area. The difficulties in restoring agricultural productivity post-conflict are problematic, especially as agriculture is associated with the most promising immediate source of livelihood for the majority in post-conflict regions (USAID, 2009).

Fulginiti and Perrin (1998) estimated the change in the agricultural productivity in 18 developing countries through an output-based MI and a parametric CD model applied to land, fertilizer, machinery, livestock, and labor, finding output growth is highly dependent on commercial inputs such as machinery and fertilizers. In measuring the productivity growth of less developed countries (as compared to developed ones), Fulginiti and Perrin (1998) conclude technological regression as the explanation of decreased productivity. This is in contrast to many other investigations claiming convergence (Coelli and Rao, 2005; Wiebe et al., 2003)

Chapter 3 Data

In this chapter, I review what data was collected for this investigation, how it was collected, and limitations in the data. The purpose is to clearly indicate each variable's definition, source and any adjustments made to the raw data set. For the benefit of future investigators of this topic, I include a complete version of the used data in the appendix.

3.1 Output Data

The output considered in my models is the agricultural sector's annual GDP, where the term agriculture in my study refers to agriculture, livestock, forestry and fishing for Libya. Annual agricultural GDP in millions of USD 2010 is available from FAOSTAT (2020) for the full period of interest. Output solely for agriculture (without contributions from forestry and fishing sources) was not available. The data pulled from FAOSTAT was used without adjustment and is plotted in fig. 3.1. Aside from an initial drop, the agricultural GDP did not appear dramatically affected during the later sanctions period (1986-2004). The reduced access to international markets is reflected in the increases in the rate of growth of the Consumer Price Index (CPI). The associated inflationary pressure may explain the increase in GDP during this period. However, the increases in price would contribute to the appearance of healthy growth in the GDP during the sanctions even if the production quantity does not necessarily increase. It is further clear that conflict beginning in 2011 has lead to a precipitous drop in the annual agricultural GDP that well exceeds the impacts seen during the sanctions period.

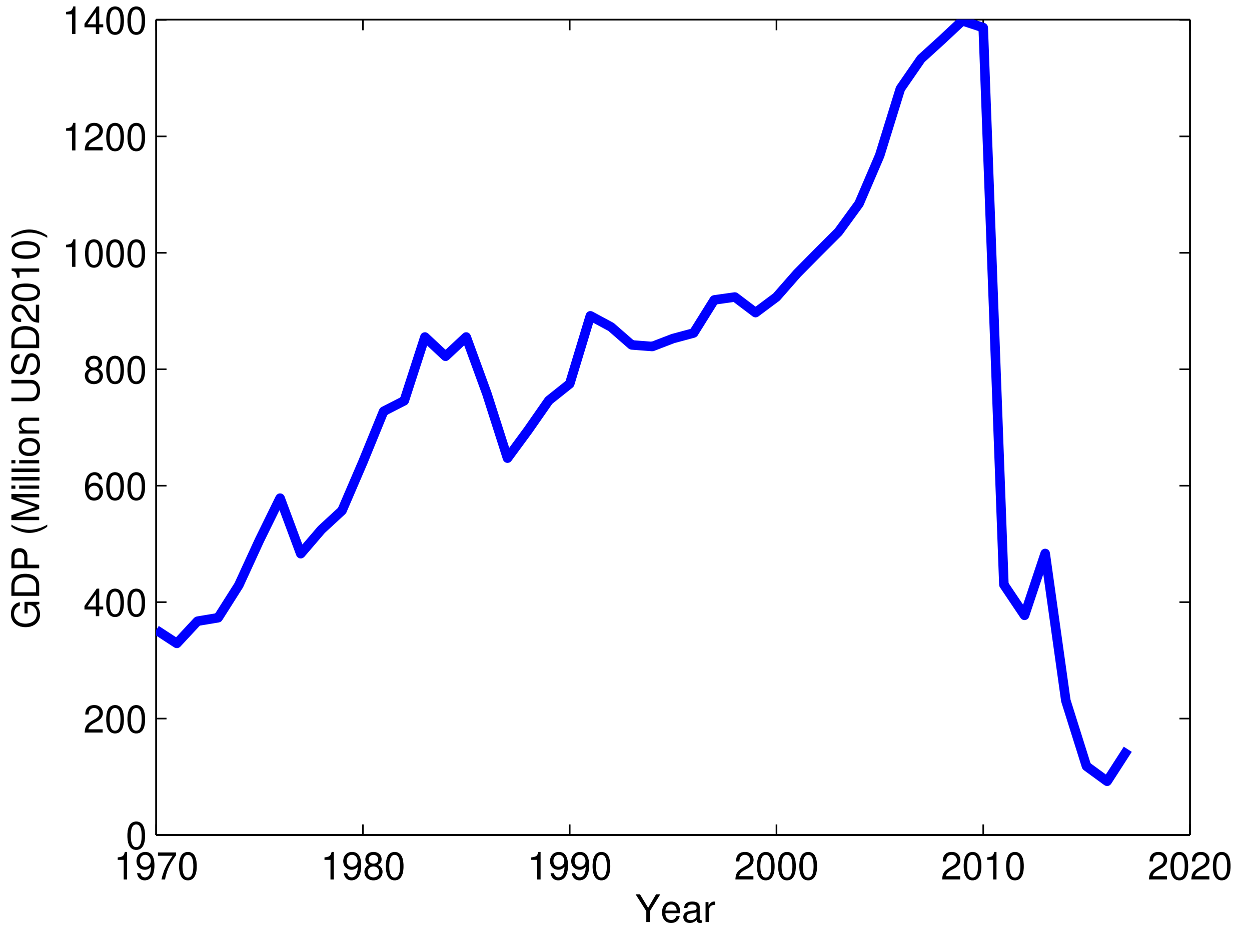

Figure 3.1: Agricultural contribution to the GDP from 1970 to 2017. The drop of GDP in the late 80s may have been the result of international sanctions. The large drop in 2011 is easily associated with the start of the current conflict. There is a small recovery up until 2014. This marks when it became clear that the Libyan civil war would continue for the foreseeable future.

3.2 Input : Natural Ecosystem Resources

Environmental (or natural) capital accounts for ecosystem resources necessary for production, such as land and irrigation. Even without the presence of conflict, the data describing environmental inputs to production are limited. Measurable environmental inputs may include land, soil type, soil productivity, nutrients, and climate among others, but the vast majority of these are either not available in the case of Libya on an aggregate country-wide basis, or of questionable accuracy with little variation that could be affected through conflict. For example, soil fertility data such as organic matter content, and nutrients stored within the soil are widely unavailable. This likely comes from the low productivity of the sector contributing to indifference for quality measurements.

For this investigation, I have relied on using the agricultural land area and total irrigation as two variables describing the environmental inputs to agricultural production. Agricultural land was chosen primarily due to the ease of collection, and the expected impact of conflict on the availability and usage of land within the study area. Irrigation was chosen to be included as there is an expectation of conflict's impact on the availability of water that is largely supplied through groundwater sources transported by large, accessible pipes. In each of these variables, conflict is expected to play a role in how the inputs are used during the crisis. Together, these two variables serve as a proxy for soil and water, which are the major ecosystem resources that are available for Libya over the observed period. Natural fertility data, such as organic matter content and soil nutrients, that would be useful in further characterizing the regional ecosystem resources is unavailable.

3.2.1 Land

Representing land as a production input requires a definition of what land is measured. From FAO, several different land measurements are available, as shown in fig. 3.2.

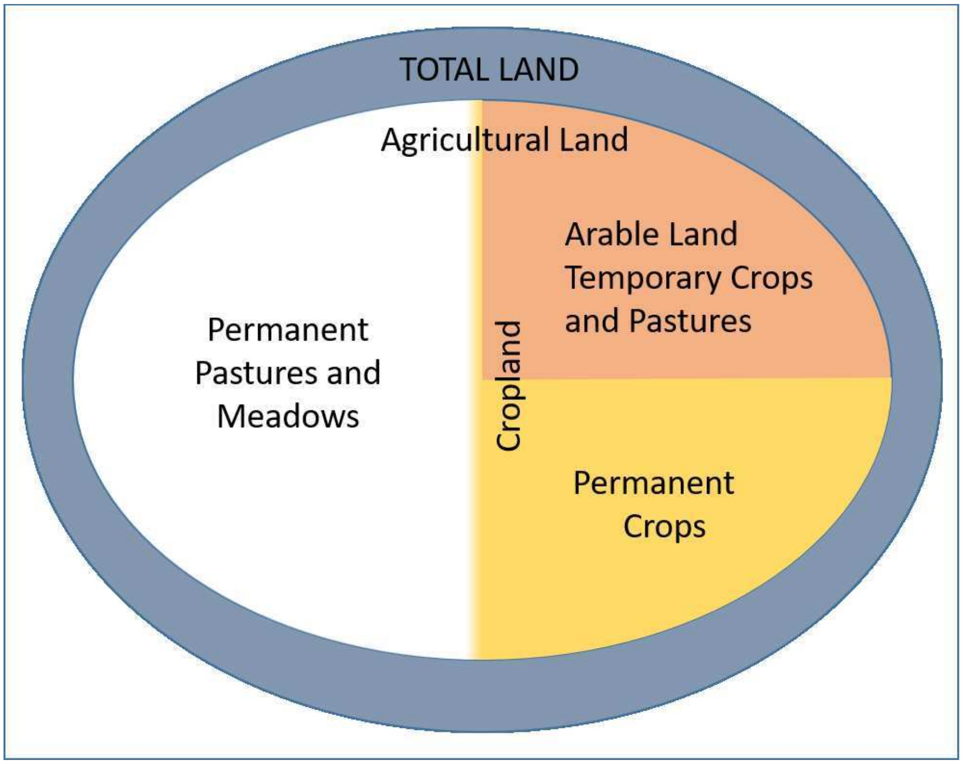

Figure 3.2: FAO Land definitions as a concentric plot

Arable land in Libya is a widely used choice for an environmental input in the literature, describing all land capable of production.[1] While Libya has nearly 2 million arable ha, this only accounts for about 0.5% of all land in the country. Furthermore, less than 35% of arable land is under active crop production in any given year. Therefore, a majority of the land value measured by arable land (or permanent pasture and agricultural land) appears to grossly overestimate the land's effective contribution to the GDP when so little of the land is actively productive. Similarly, permanent pastures overestimates the contribution of actual land use to the GDP by accounting for large swathes of grazing land that are not actively used throughout the year.

[1]Arable land refers to land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (FAO, 2020).

I have chosen to use the amount of actively used land to prevent the overestimation problem. The actively used land consists of the sum of harvested temporary and permanent crops,[2] and used fodder crop area.

Annual crop acreage data (both temporary and permanent, in harvested ha) is available from FAO (2020), broken down by crop. There are gaps in the data for some permanent crops between 1970 and 1984. It is reasonable to say the crop acreages for permanent crops vary slightly from year to year showing little change during the study period. I have estimated the value in these gaps as constant, matching the 1985 crop size data.

Fodder crops (including alfalfa, oats and vetches) are not explicitly accounted for by FAO. Instead, both fodder crops and grazing area are captured through temporary or permanent pastures and meadows. In Libya's case, only permanent pastures/meadows are recorded. However, this amount of land (between 11 and 13 million hectares (ha) over the period), does not reflect the actual land use in the agricultural process.

The largest class of livestock in Libya by far is small ruminants (of Agriculture of Libya, 2013), which I use to gauge the reasonableness of the available permanent pasture/meadow data through an estimate of stocking capacity. At a conservative estimate of 10 sheep per ha, based on neighboring Algeria's similar stocking rate (Treacher, 1993), this amount of forage land would be sufficient for 110 million sheep. Compare this to the 6.5 million sheep accounted for in 2013 (of Agriculture of Libya, 2013) and it becomes clear that much of the land is either unproductive or otherwise unused for grazing. Using the area of permanent pastures/meadows recorded by FAO could overstate the importance of the land variable, or smooth out important effects by including a large unproductive region whose impact would not vary with the presence of conflict.

An alternate attempt to estimate the used grazing land from the number of recorded livestock suffers from incomplete data captured by the local authority, where the Arab Or-

[2]Temporary crops refer to those that are harvested in the same year as planting, and will need to be planted again, such as wheat and barley. Permanent crops refer to those that can be harvested multiple times without needing to be replanted after each harvest, such as olives and dates.

ganization for Arab Development (AOAD) (2018) has livestock headcounts only between 2010 and 2017, insufficiently covering the period before conflict. Estimations using livestock data that only fall within the conflict period will likely exhibit strong biases and have therefore been disregarded for this investigation.

Fodder crops have not been regularly measured for Libya over the study period. The AOAD is the primary source of limited information regarding fodder crop size, with data spanning from 2010 to 2017 (2018). The fodder crop acreage is stable over the observational period and is unlikely affected by the conflict.[3] The AOAD estimates the crop size for Alfalfa and Oats at approximately 65,000 ha for each year since 2002, while a single year's observation from Ouchen (1997) suggests that including vetches, the total harvest area for fodder crops is closer to 85,000 ha. As the more inclusive fodder measure, I have used 85,000 ha of fodder crop as the estimate for the remaining unknown data points.

The land data variable can then be described as

$$Ld(t) = \sum_{i} A_{crop_i}(t) + F \tag{3.1}$$

where A represents the area of the i^{th} crop in ha, and F is the size of the fodder crop, held constant at 85,000 ha.

The agricultural land input variable is tabulated in the appendix, consisting of the sum of temporary and permanent crops over the full study period (1970-2017) gathered from FAO (2020), along with the expected fodder crop size of 85,000 ha (Ouchen, 1997).

3.2.2 Irrigation

Irrigation describes controlled amounts of water from groundwater and well sources contributing to agricultural production. AQUASTAT (2020), a division of FAO, collects information on water resources and agricultural water management. AQUASTAT's water

[3]Fodder crops are not desirable sources for militias to control and are unlikely to dramatically change.

withdrawal data for use in agriculture for Libya is very sparse, with only 7 observations spread during the observation period, none earlier than 1985 and spaced approximately five years apart. This is partly due to AQUASTAT's method of reporting.[4] Observation of annual variation in irrigation flow is not possible with this dearth of information.

I decided to find alternate representations of the irrigation input. The first attempt was to find the flow out of the Great Man-Made River (GMMR), where approximately 80% of the flow rate is used by the agricultural sector (Sanders, 2011). However, such measurements of the total flow rate through the GMMR were unavailable over most of the period, especially during conflict.

A second attempt was to use the amount of water necessary to support known harvested crops. By evaluating the crop water need based on the total harvested crop acreage, a rudimentary estimate of the total irrigation requirement is found, neglecting losses due to surface runoff, storage and evapotranspiration, each of which are unavailable on a large countrywide basis. I generated an accounting method based on the harvested crop area (A_i), water requirements for different crops (WR_i), and established precipitation (P). This is expressed by

$$I = \underbrace{\sum_i (A_i \cdot WR_i)}_{\text{Total Water Need}} - P \tag{3.2}$$

The harvested crop area is the same FAO data set used in the land input, while the water requirements are available from FAO.[5]

The precipitation, P, is the portion of water obtained from rainfall. Figure 1.3 indicates differing amounts of rainfall over the various locations of agricultural land. To estimate the rainfall precipitation, I have broken the survey area into three distinct rainfall regions as shown in fig. 3.3. This figure was obtained using Google Earth Pro (GEP) to isolate

[4]From AQUASTAT, the database regroups data per 5-year period and shows for each variable the value for the most recent year during that period, if available. For example, if 2003-2007 are grouped together, and data is available for 2004 and 2006, only the 2006 data is reported for the entire group period.

[5]Available at http://www.fao.org/3/s2022e/s2022e02.htm

crop locations with satellite images, where the polygon areas identify locations with recent agricultural use. The program QGIS was used to generate the final image.

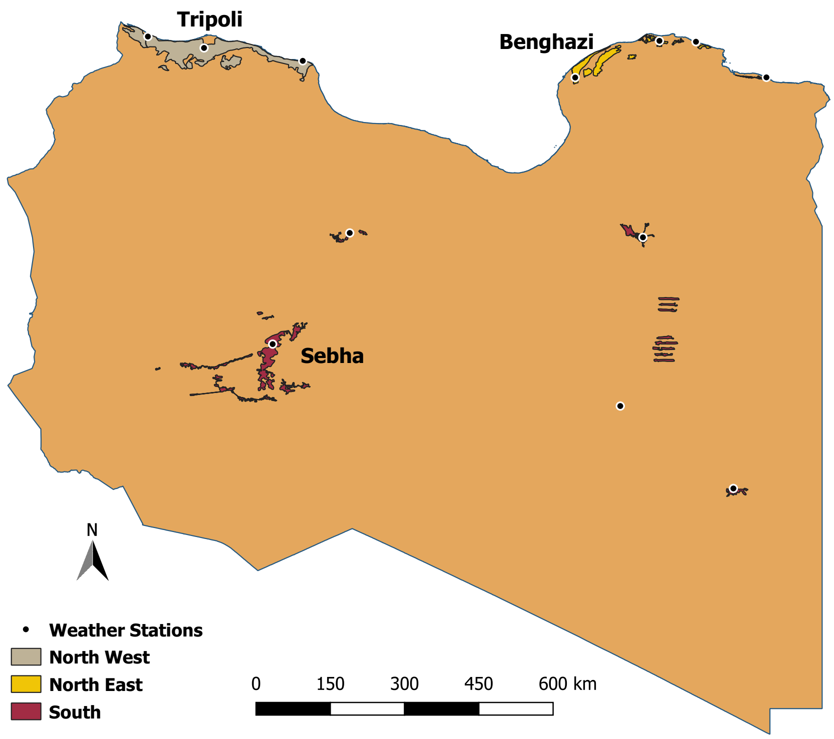

Figure 3.3: The sub-regions of similar precipitation with weather stations marked

I have also identified the locations of weather stations collecting daily rainfall data (NOAA, 2004) over the study period. Candidate stations within the sub-regions were isolated based on containment within sub-regions and being sufficiently close to regions of agricultural production. Given the low variability in rainfall events for sub-regions, I have used a simple annual average of data from the weather stations assigned to each sub-region, rather than a distance weighting method that is common (Shepard, 1968). This simple average defines the rainfall amount in the area, R_i, as summarized in table 3.1. The average yearly rainfall in table 3.1 is the arithmetic average of the measured rainfalls of each station in the corresponding group.

Table 3.1: Weather Station Profiles in Libya

Group	Station Name	Station Number	Lat.	Long.	Average Rainfall (mm/year)
North West	Zuara	620070	32.883	12.083	
	Tripoli Int'l	620100	32.664	13.159	
	Misurata	620160	32.417	15.050	229.6
North East	Benina Airport	620530	32.097	20.269	
	Shahat	620560	32.800	21.883	
	Derna	620590	32.783	22.583	
	Tobruk	620620	32.100	23.933	199.0
South	Sebha	621240	26.987	14.473	
	Hon	621310	29.117	15.950	
	Jalo	621610	29.033	21.567	
	Tazerbo	622590	25.800	21.133	
	Kufra	622710	24.179	23.314	19.7

The precipitation variable, P, represents the sum total annual precipitation over the three sub-regions identified. However, the sum total of the sub-region area does not represent the total harvested area, which is smaller. Since we are only interested in the precipitation over the actual harvested area, I use an *effective* area A_{eff_i} that represents the product of the relative proportion of the j^{th} sub-region's area (calculated from polygon size in GEP) and the total harvest area. A sub-region's precipitation is the product of the rainfall and the associated effective area, converted to cubic meters (m^3).

$$P = \sum_j R_j \cdot A_{eff_j} = \sum_j R_j \cdot \frac{A_{sub-j}}{\sum(A_{sub-j})} \cdot A_{tot} \tag{3.3}$$

The irrigation variable input is then recast as:

$$I = \underbrace{\sum_i (A_i \cdot WR_i)}_{\text{Total Water Need}} - \underbrace{\sum_j R_j \cdot A_{eff_j}}_{\text{Precipitation}} \tag{3.4}$$

This method of estimating the irrigation has drawbacks. First, it assumes the crops are distributed evenly among the available arable land in the region. Second, it assumes the precipitation occurs during the growing period of the crops. This method also does not explicitly account for efficiency, either in the total harvest area or in water losses in the irrigation process.

Annual land and irrigation results are shown in fig. 3.4. The drops in 1977, as well as 1992-1995 can be associated with the governmental efforts to extend the life of aquifers on the coast of Libya from 25 to 125 years. These efforts included a reduction in water intensive crops and the corresponding irrigation (El Asswad, 1995). The continued increase of the environmental variables during the early conflict (2011 to 2014) may indicate confidence in a return to normalcy from the newly formed government. The descent back into civil war in 2014 then describes the loss of confidence as the conflict raged on.

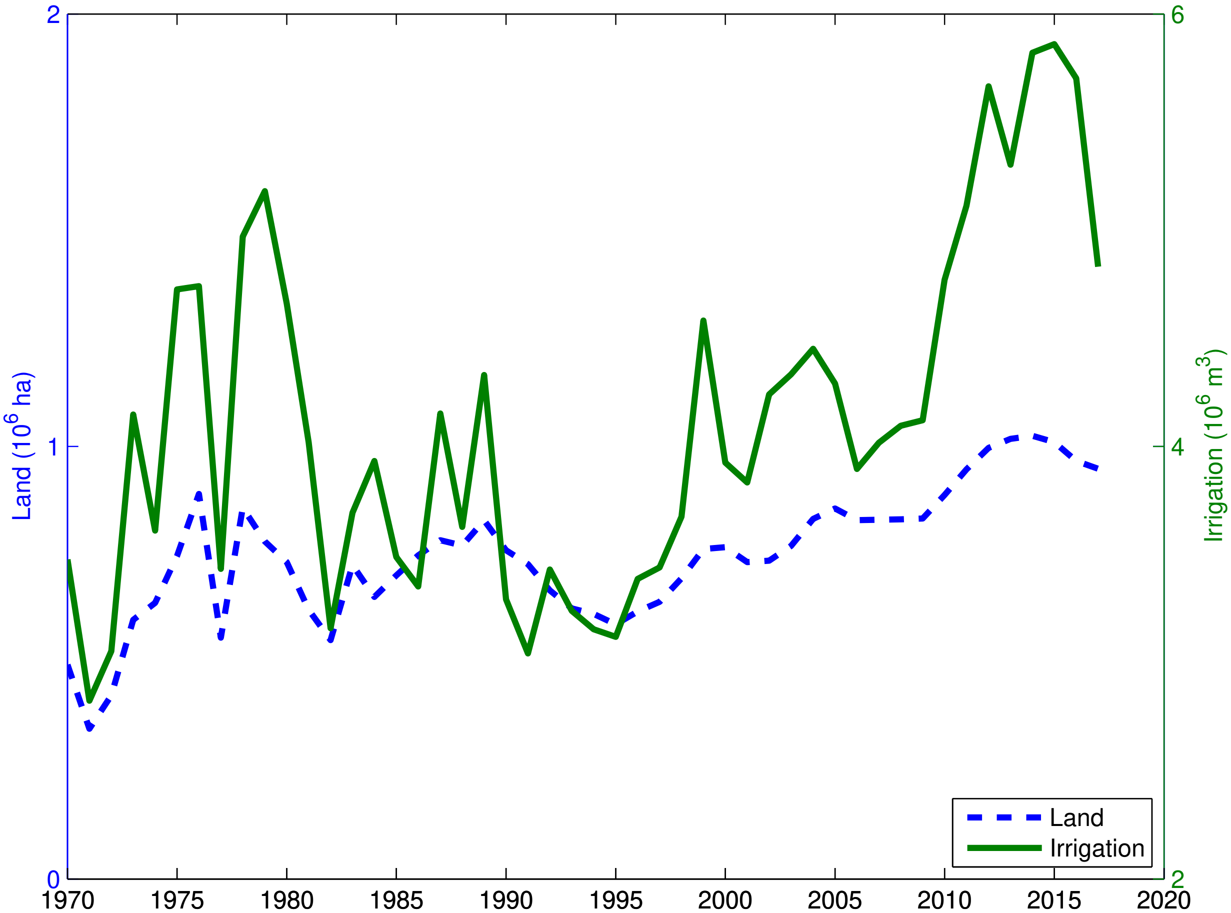

Figure 3.4: Environmental capital time series

3.3 Input : Physical/Industry

Physical capital accounts for tangible human-made inputs to production. The human-made characteristic leads to physical capital's reproducibility. Common physical capital inputs in agriculture include durable[6] inputs like machinery and buildings, and non-durable inputs such as fertilizers and pesticides.

Based on data availability, only machinery and fertilizer are examined in this study.

[6]Here, durable implies able to be used over several production periods.

3.3.1 Machinery

This input is meant to include several types of machinery. Tractors, threshers, milking machines and more are all represented as part of the machinery variable. However, individual data on most agricultural machines used is not collected in any database maintained either by Libya or international sources that I have uncovered.

The most used machine in the agricultural sector that is measured is the tractor. The FAO compiles estimates of the total number of tractors in use between 1970 and 2003 (FAO, 2020). Absent other sources, the number of tractors in use does not span the full period.

An alternative measure of the machinery variable is the energy consumption of the agricultural sector. The international energy agency (IEA) collects information on the energy consumption by sector.[7] This data set spans 1990 to 2017, measuring the energy consumption of the sector in terajoules (TJ).

A linear regression on the partial overlap of the two time series (number of tractors in use and energy use) leads to a conversion from one system to the other in the following way:

$$ENERGY = 0.0410 \cdot TRAC + 3051.36 \tag{3.5}$$

where $TRAC$ is number of tractors in use in thousands, and $ENERGY$ is the energy use of agricultural sector in TJ. This relationship displays the expected positive correlation between the number of tractors and consumed energy in the agricultural sector.

The resulting energy use for agriculture is plotted in fig. 3.5. Between 2004 and 2005, there is an over two-fold increase in the energy use of the agricultural sector. This does not coincide with an obvious change in the operation of the agricultural sector.

[7] A similar data set exists for the United Nations Statistics Division : Energy Statistics Database.

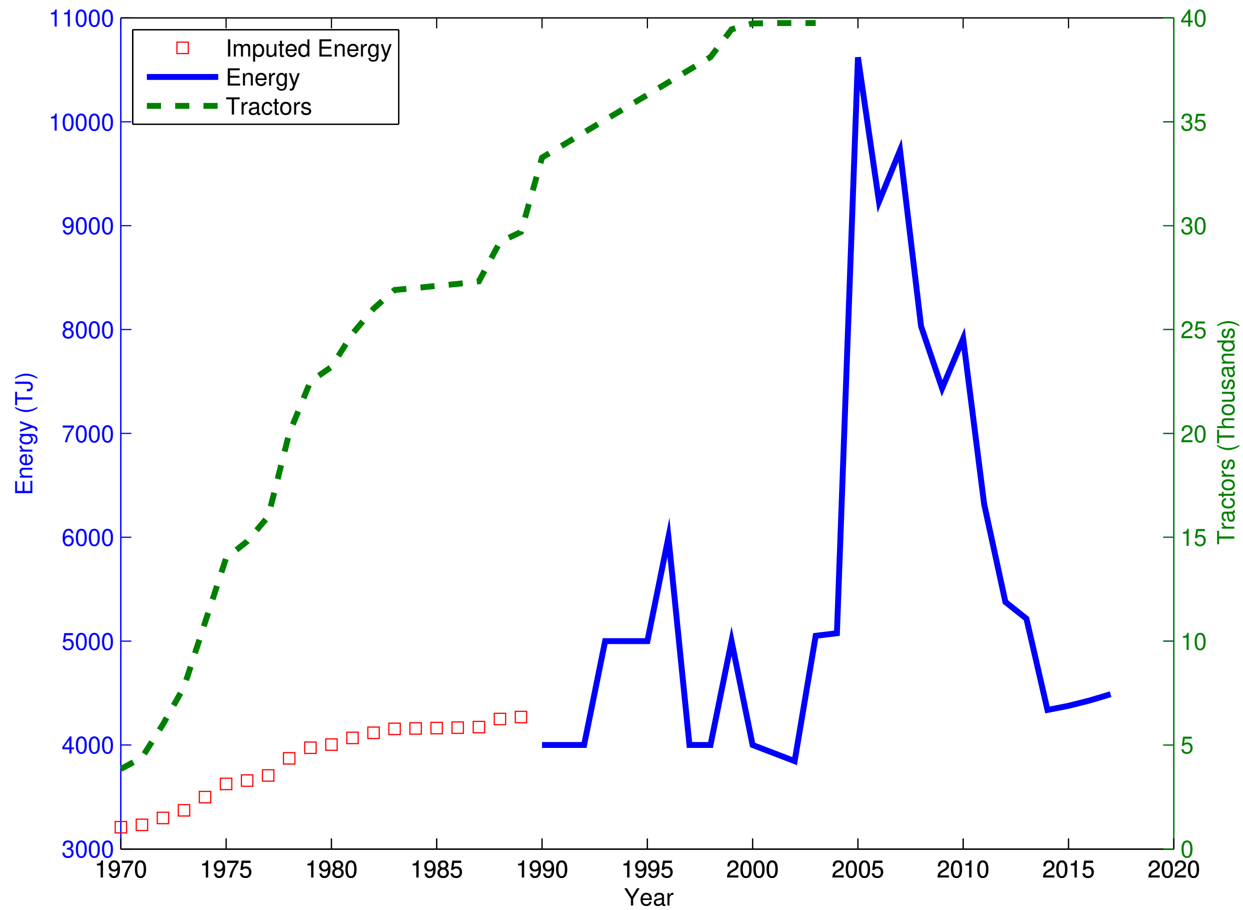

Figure 3.5: Tractor and Energy data set

Three possible explanations include a shift from a decrease in unspecified energy consumption also measured in the IEA data set, the new inclusion of domestic aviation contributions to the energy consumption beginning in 2005 suggesting previously unaccounted for agricultural transportation, or possibly 2004's widespread blackouts leading to the building of more power plants in the region to account for the surging power consumption of the country (Eklat and Sidon, 2012).

3.3.2 Fertilizer

The fertilizer input for agricultural production includes three traditional main categories based on their primary content chemical: Nitrogen, Phosphorous, and Potassium.[8] Libya has

[8]Potassium based fertilizers are often referred to as potash in many data sources.

only one major fertilizer production facility in a joint relationship with Norwegian fertilizer maker Yara, with an annual production capacity of 700 and 900 thousand tonnes of ammonia and Urea at the Marsa El Brega plant (Reuters, 2009). This plant has been active only for a few years during the study period, and up to a third of this production is used in export (FAO, 2020); the remainder is insufficient to account for the domestic agricultural sector use, and there is little historical indication of fertilizer reserves within Libya (Mwakubo, 2018). As such, fertilizer use is strongly tied to the imports to Libya, given the low production within Libya. Fertilizer import data is compiled from FAOSTAT.[9]

The aggregate time series data for both physical inputs (Machinery and Fertilizer) is shown in fig. 3.6. Early in the study period, the fertilizer used by the agricultural sector appears cyclic, with an overall upward trend lasting until the mid 1990s. During the sanctions period affecting imports (1986-2004), the CPI showed increases in line with higher rates of inflation. The losses in fertilizer use over this time may also be attributed to the rapidly increasing costs from international sanctions coupled with the losses of government backed subsidies of agricultural input. Shifts to black market goods to address the shortfall in the available fertilizer inputs and their associated increased markups can explain the lower usage of fertilizer during this sanction period. Farmers likely developed more efficient fertilizer usage habits based on the increased fertilizer costs, including coping mechanisms (e.g., shifting to local organic fertilizers away from more costly chemical fertilizers). While the sanctions were lifted around 2005 and access to international markets had returned, the government backed subsidies did not, keeping prices elevated. This may explain the behavior of stagnant growth in the fertilizer beyond 2005.

Aside from the initial drop in fertilizer use seen in 2011 at the beginning of the conflict, there does not seem to be further impacts on the fertilizer usage since then. While this may indicate fertilizing habits were not impacted, the stagnant nature of the fertilizer could

[9] There are two locations for the data within FAOSTAT. For 1970-2001, the repository is called fertilizer archive, and has aggregate import value by mass. For 2002-2017, the standard fertilizer database is used. This data set has each fertilizer broken down by nutrient, which I have aggregated.

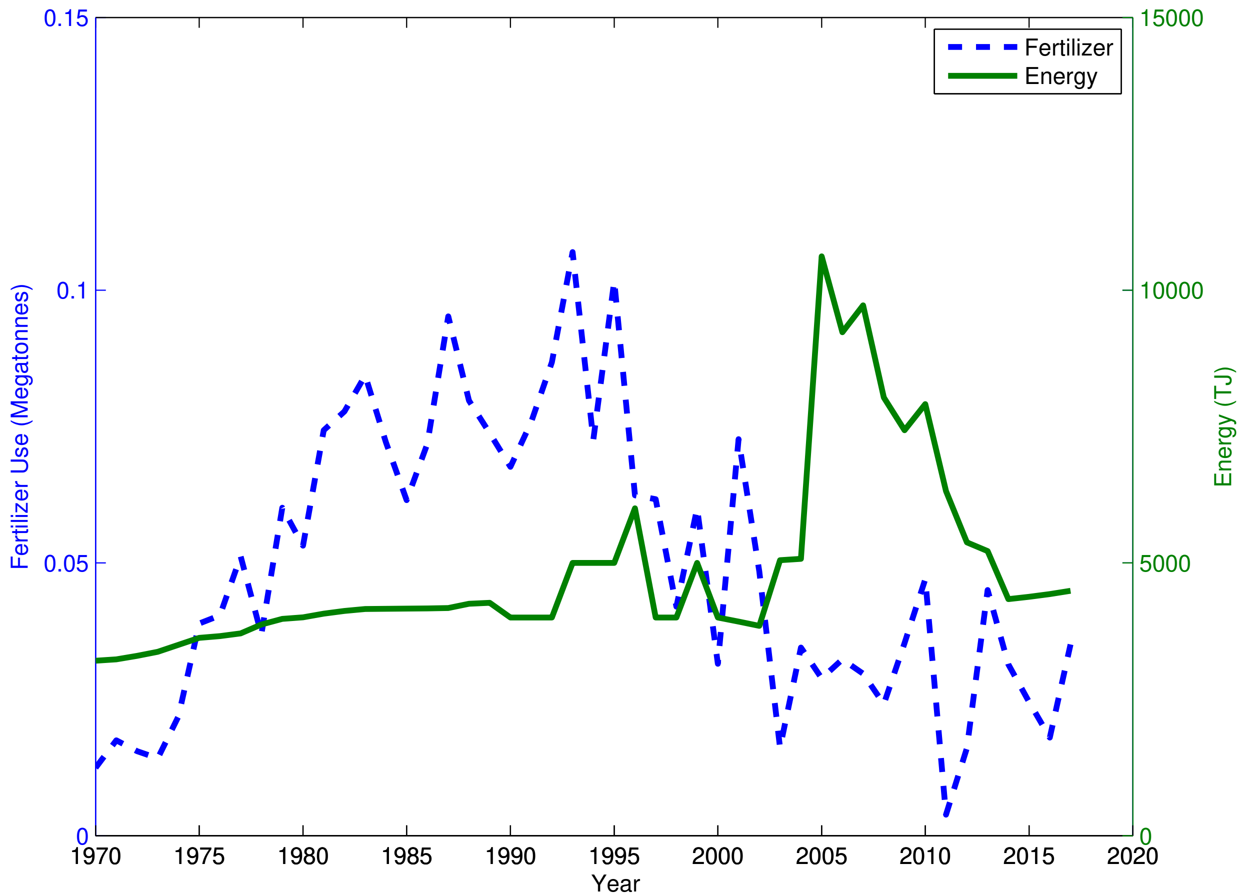

Figure 3.6: Machinery and Fertilizer time series data for full study period.

reflect more fertilizer usage in lower quality land as farmers shift to safer areas of cultivation. The impact on fertilizer may also be muted due to the lowered use of fertilizing since 2005, long before the conflict.

The machinery capital input (measured in TJ) shows a steady rise in the agricultural sector's energy use over the period until around 2005, with a decline in energy usage of the sector ever since. The appearance of conflict does not appear to be associated with a break in the energy usage for the sector as it did for fertilizer usage, and likewise does not seem to impact the sector's energy use while the conflict continues.

3.4 Input : Labor

The labor input is a measure of the number of workers employed in the agricultural sector. The employment in the agricultural sector is difficult to pin down, partly due to the informal employment of children and foreign labor. Libya also has many workers whose primary occupation is not agriculture, though many spend a significant amount of time devoted to farming.

The major source of labor data comes from the International Labour Organization (ILO) estimates, though internal data compiled by the Governmental Authority for Information (GAI) of Libya is also available (Abuarosha, 2013). Both FAO and the World Bank provide employment data, each being pulled from the ILO source.

The current ILO data set on employment in the agricultural sector spans 1991 to 2017. Rather strangely, the ILO database does not retain records of the employment estimates prior to 1991. Instead, agricultural employment from 1970 to 2000 was obtained from FAO at the beginning of this investigation. However, this resource is no longer available as of May, 2020. I have included the data set that was originally obtained from FAO in the appendix. I retain confidence in the data obtained for this early period, as it is consistent with the data source provided by GAI (Abuarosha, 2013).

The agricultural labor input time series is plotted in fig. 3.7. There is a general upward trend for the full period, with a drop during the onset of conflict. However, the drop in labor for 2011 is not significant enough to suggest that conflict was the cause; the drop may remain a fluctuation not induced by conflict. Interestingly, the labor input increases while the conflict continues. Coupled with the larger exodus of foreign agricultural labor, this could be a result of a shift back from other sectors (industry and services) but is more likely part of the small reduction in unemployment seen since 2013 (World Bank, 2015).

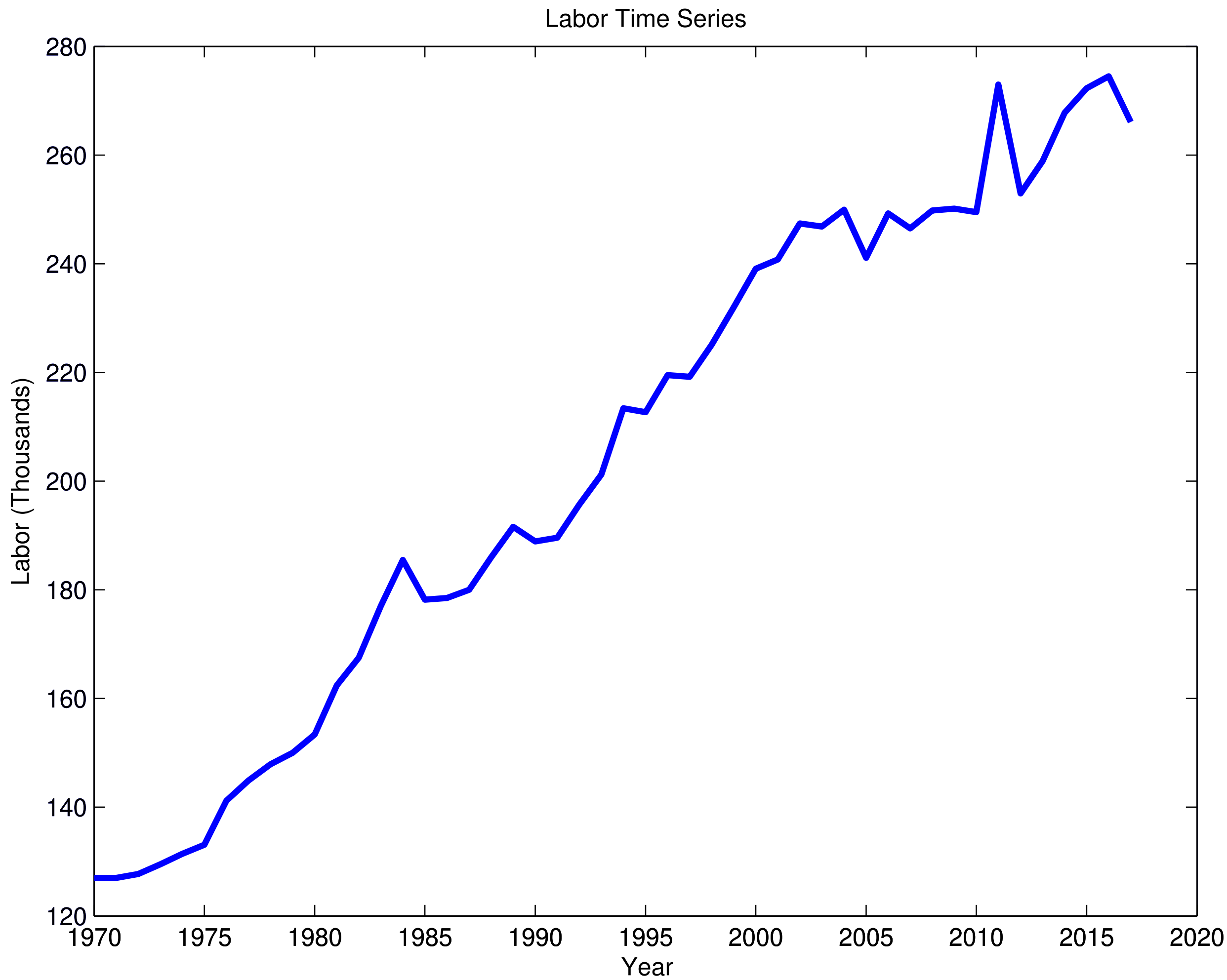

Figure 3.7: Labor time series

Chapter 4 Method

This chapter describes the methodology for achieving the investigation objectives. To meet my objectives, I first develop a model that can describe the conversion of the agricultural inputs by type (e.g. physical capital, environmental capital, labor) into agricultural GDP. To develop that model, I establish parameters with the given data collected and devise a method to test for a structural break in the timeline of Libya's agricultural GDP coinciding with political and physical conflict.

4.1 Generating the Model

An agricultural production function that describes the relationship between the output GDP and different inputs can be described in the following algebraic form (Trueblood, 1991):

$$GDP = f(K_p, K_e, L) \tag{4.1}$$

where K_p is the physical capital and is related to the material inputs of machinery, fertilizers and pesticides assisting in agricultural operations. K_e is environmental capital, and is related to land and irrigation, and L is labor. This is an adaptation of Solow's (1956) original foundational study that cast productivity as a function of both capital and labor. The adaptations dividing capital into natural and physical dimensions has a long history within the literature (Bhattacharjee, 1955), with more refined definitions of input components based on data availability (Hayami, Ruttan, et al., 1971).

The physical capital K_p is then expressed as:

$$K_p = g(Mach, Fert) \tag{4.2}$$

The environmental (natural) capital, K_e, is assumed to represent the irrigation and land used for agricultural purposes. The environmental capital can be described in the following functional form:

$$K_e = h(Irr, Land) \tag{4.3}$$

The production function can be restated equivalently as

$$GDP_t = f(Mach, Fert, Irr, Land, Labor) \tag{4.4}$$

In the above formula, the overall agricultural output can be predicted based on these inputs. However, this specification does not account for the expected decreases in efficiency generated over time. The addition of a factor of productivity, A, was first investigated by Hayami and Ruttan (1971) and leaves the function both Harrod and Hicks neutral. The production function is then

$$GDP_t = A \cdot f(Mach, Fert, Irr, Land, Labor) \tag{4.5}$$

The agricultural production function in equation 4.5 is often cast as either a Constant Elasticity of Substitution (CES) or Translog model to account for variable elasticity. The Cobb-Douglas (CD) production is a special case of CES form and is also ubiquitous within the literature. Equation 4.5 can also be cast in the form of the modified CD function, as presented by Solow-Swan (1956). This model is chosen since it represents an aggregate economy-wide production function, adapting CD with the inclusion of a total factor of productivity (TFP) as a gauge of the production inputs‘ efficiency (Cypher, 2014). The generalized CD model (where the unit elasticity restriction is lifted) provides similar flexibility to the CES model while maintaining a simpler form with ease of interpretation. While the CES model is generally described as being superior in many contexts, it often does not provide additional benefit for the increased computational overhead (Miller, 2008). The motivation to use the

CD model over the more flexible translog formulation is partly based on CD's parsimony, but also on the reality of the usable data set and the primary purpose of the investigation. The absence of high-quality agricultural data for Libya makes it difficult to justify using more complex functional forms where richer interpretations of parameters would be undercut by by the data weakness. The translog model also presents a dilemma in attempting to isolate the structural change within the agricultural sector. Since the translog model increases in parameters on the order of the square of the input variables, the seven available data points (2011-2017) for the conflict period are insufficient to have meaningful estimates of the hypothesized change. Even if the model were limited to two inputs, a total of 6 parameters would need to be estimated for the translog model.

In the CD form, the production function is expressed as:

$$GDP_t = A \left(\prod_{i}^{4} K_{i,t}^{\alpha_i} \right) L_t^{\beta} \tag{4.6}$$

where GDP_t is the measurement of economic output of Libya's agricultural sector. This output aggregates the entire agricultural GDP stemming from crops, fisheries, livestock and forestry resources. Symbol A represents the TFP variable assigned for agricultural technology used in Libya and is assumed to be slowly varying and effectively constant due to the low innovation rate in Libya compared to developed countries and the overall exogenous nature of technology (Aiyar and Feyrer, 2002). Each $K_{i,t}$ factor is representative of the time dependent natural and physical capitals. These factors are organized according to the following index:

1: Used agricultural land, Ld

2: Irrigation (excluding rainfall), Irr

3: Machinery and equipment, $Mach$

4: Fertilizers, $Fert$

L represents the non-capital time dependent labor, where both α_i and β parameters are constant output elasticities for the corresponding input factors.

Taking the logarithm of both sides yields a linearized version of the production function, allowing estimation of the coefficient elasticity parameters α_i and β, and the error term coefficient using the standard ordinary least squares (OLS) regression analysis.

$$\ln GDP_t = \ln A + \left(\sum_{i}^{4} \alpha_i \ln K_{i,t} \right) + \beta \ln L_t + \epsilon \tag{4.7}$$

Using the expanded form, this is

$$\ln Y_t = \ln A + \alpha_1 \ln Ld_t + \alpha_2 \ln Irr_t + \alpha_3 \ln Mach_t + \alpha_4 \ln Fert_t + \beta \ln L_t + \epsilon \tag{4.8}$$

where the error coefficient ϵ has a normal distribution with mean of zero and constant variances.

4.1.1 Use of Solow-Swan Model

The Cobb-Douglas production function (Cobb and Douglas, 1928) has regularly been modified to suit the needs of different investigations, including the Swan-Solow model (Solow, 1956; Swan, 1956). The assumptions underlying the use of the Swan-Solow model include constant returns to scale, diminishing marginal productivity of capital, exogeneous technical progress and substitutability between capital and labor with exogenous rates of population growth.

Swan-Solow refined the Cobb-Douglas prescription by accounting for the residual component, TFP (Durlauf et al., 2008) and is described by

$$Y(t) = f(K, L, A) = K(t)^{\alpha} \left[A(t) L(t) \right]^{1-\alpha} \tag{4.9}$$

Where $Y(t)$ is the total production (as measured by the agricultural GDP), the product $A(t)L(t)$ represents the effective labor, and alpha is the elasticity output for the capital (K). The α term is expected to be a positive fraction ($0 < \alpha < 1$) to ensure that the marginal products of each input are positive, with diminishing returns. The transient forms of both labor and augmenting technology are exogenously driven (Sesay, 2004),

$$L(t) = L_0 e^{nt}$$

$$A(t) = A_0 e^{gt}$$

In this form, the Swan-Solow modification shares the CD's defining characteristic of constant returns to scale. If the condition that $1 - \alpha$ is allowed to vary as β, while still maintaining that the exponents are positive fraction (retaining the requirement of positive diminishing marginal products), the constant returns to scale condition is then relaxed.

$$Y(t) = f(K, L, A) = K(t)^{\alpha} \left[A(t)L(t)\right]^{\beta} \tag{4.10}$$

The sum of the exponents, $\alpha+\beta$, defines the returns to scale (RTS) seen in the production function

$$\alpha + \beta = \begin{cases} \text{Decreasing RTS,} & < 1 \\ \text{Constant RTS,} & = 1 \\ \text{Increasing RTS,} & > 1 \end{cases}$$

In the more generalized form with more than two inputs to production, the sum of all exponents replaces $\alpha + \beta$ with the same conclusions for RTS. In the case of constant RTS, the elasticity parameters also represent the factor shares contributing to 100% of the total output.

This model is a growth theory that assumes limited resources, where the primary relationship shows a dependence of economic growth being a function of exogenous technology, capital and labor (Jones, 1998). In the context of agricultural development, the capital is often broken into two forms, environmental capital and physical capital (Echevarria, 1998).

The Solow-Swan model has certain limitations. One aspect of the model (as a consequence of the Cobb-Douglas production model) is that it assumes homogeneity across firms (Karabona and Koutun, 2013). Additionally, the use of reducing an economy to simple mathematical functions likely masks complex interactions of a true economy. Though, if the purpose is to offer predictions, the model can remain useful as a forecasting tool (Miller, 2008). While the model does not explicitly account for inefficiency or endogenous technology (Fagerberg, 1994), it does account for the advances of exogenous technology. The inefficiency in using the natural resources available may have internal onset causes preventing the efficient capture, such as conflict (Sesay, 2004).

Swan-Solow based investigations into conflict consider the resulting economic consequences; these studies frequently examine the impact on the GDP for the entire economy (Kugler et al., 2013). This is problematic in Libya where the economy is dominated by the oil industry, where the bulk of output is from the extraction of existing resources (Mankiw et al., 1992). The use of human capital as part of the Solow model for oil-based economies like Libya has been called into question by Bhattarai and Taloba (2017), though the investigators claim that the Solow-Swan model is still reasonable without the Mankiw-Romer-Weil (MRW) modification including the accumulation of human capital (Mankiw et al., 1992). However, the reason for not including oil-based economies in Mankiw et al.'s (1992) study was that a standard growth model is not expected to explain the extraction process that dominates an oil-based economy in the first place. However, investigation of non-extractive individual sectors of the GDP does not share this same issue. This is particularly true for agriculture where there is a conversion of inputs rather than pure extraction (as in mining economies and the oil sector). Therefore, I use the Swan-Solow model as an appropriate way to look at how conflict in Libya has affected the agricultural economy.

4.1.2 Evaluating the Input Factor Roles

An OLS analysis represents a standard method of estimating unknown coefficient parameters of a linear regression model, obtained through minimization of the sum squares of the differences between predicted and observed outputs to obtain the best linear unbiased estimator (Berry, 1993).

The OLS is ideal to measure the relationships between the explanatory variables and the GDP, as long as the basic Gauss-Markov assumptions of OLS are satisfied, including normally distributed errors and homoscedasticity of the underlying data (Nevitt and Tam, 1997). First, the model requires the dependent variable to be a linear combination of the explanatory variables and the error terms. Second, the use of OLS requires that the explanatory variables cannot be linearly dependent exhibiting multicollinearity, nor can the number of observations be less than the number of explanatory variables. Third, the explanatory variables should be independent of the error terms, such that the expected value of the error is zero under the presence of any of the explanatory variables. Fourth, the error terms themselves must have a mean of zero and constant variance, established by the absence of heteroscedasticity. This further means that there is no autocorrelation amongst the error terms (Berry, 1993). However, an OLS specification has some limitations. For example, outliers can dramatically distort the solution, which could lead to inaccurate findings (Lane, 2002; Nevitt and Tam, 1997).

While generally altering input factors in a linear regression leads to different coefficients, scaling of any input factor in the log-linearized model (equation 4.7) does not alter the elasticities determined by an OLS regression.

The driving question is how the presence of conflict influences these key variables in leading to agricultural output.

4.2 Finding a Structural Break

The existence of a structural break in time series data using linear regressions is commonly done econometrically with a Chow test (Chow, 1960; H. B. Lee, 2008). This method analyzes the same variables obtained in different data sets to determine if the coefficients in two linear regressions are the same. If the coefficients are different, it suggests a structural break in the data. The associated null hypothesis of the Chow test for the multi-linear regression model leads to

$$H0 : \alpha_1 = \alpha_2, \beta_1 = \beta_2, ... \tag{4.11}$$

Where α and β, etc., are the associated slopes, and the subscripts refer to before and after the expected break point.

The Chow test is applied when the break point (where the discontinuity exists) is explicitly known. However, other methods have been applied when such break points are not known (Kramer et al., 1989). Since the expected break point in Libya arrives with conflict in 2011, the Chow test is reasonable to use. However, an alternative to using the Chow test is the Quandt Likelihood Ratio (QLR) test, which repeatedly applies the the Chow test to all possible break points within the data set, preventing the need for a predetermined break location. The maximal QLR statistic is associated with the structural break point, so long as the associated F statistic exceeds the critical statistics tabulated by Andrews (2003).

When the structural break location is unknown, common practice is to use a symmetric trim of the data set (locations where the break point is not tested), of 15%[1] from either end of the data series, leaving the central 70% of the data to be tested for a break point Andrews, 1993. However, if a set break point is expected, other trim points can be used, where the critical values are now based on parameter λ, given by

[1]In Andrews (1993 and 2003), this value is referred to as π_0.

$$\lambda = \frac{\pi_2(1-\pi_1)}{\pi_1(1-\pi_2)} \tag{4.12}$$

where π_1 and π_2 refer to the relative percentile locations of the trim points within the data. The critical statistic are also given by Andrews (2003), broken down by number of tested break parameters (usually the number of predictor slopes and the intercept).

While the existence of a break point in 2011 is expected, which would only require the use of the Chow test, the possibility of existence of other break points within the data is not to be ignored, so the QLR test is applied to determine if other breaks of significance exist. Once the QLR test has established the location of the primary break in the data (expected in 2011), a follow up QLR is run on the period before the primary break to check for the existence of other possible break points in the data.

Once the data is segregated, alternative model formulations are applied to the first pre-break period to set a baseline for associated elasticity parameters.

4.3 Alternative Specifications

Many possible model prototypes and methodologies are available for econometric investigation. It becomes important to clarify the choice used for this study as the ideal candidate for the given study.

The simplicity of the CD model and interpretation based on simple methods such as OLS on the linearized form are attractive. Given the lack of studies on Libyan agricultural production using multiple inputs, the CD presents a reasonable, if naive, approach. More generalized formulations such as the CES[2] have difficulty when describing multiple factors of production. This stems from Uzawa's (1962) conclusions where either all elasticities between pairs of factors are identical, or that if any differ, the remaining elasticities are 1.

[2]Of which the CD model is a limited case where the substitution parameter approaches 0.

The instrumental variables method used by Miguel et al. is not appropriate in the case of Libya. Miguel et al.'s study (2004) focused on regions where there is little irrigation and the agricultural sector remains a large component of GDP, neither of which is true for Libya, where the actual area irrigated was estimated at 20% (Aquastat, 2008) and with the agricultural contribution of 2% to the overall GDP (World Bank, 2020c).

Likewise, stochastic frontier analysis, as used by Gong (2018), is not useful in the case in Libya, where the production and yields are more likely to be homogeneous than for the author's study. There was no expectation for the factor shares to change before the onset of conflict (Gollin, 2002). With conflict, structural changes will occur. While it is not usually included in a model of agricultural production, the presence of conflict in a region could reduce efficiency, stagnate growth and implicate a time-dependent response in the economic growth to reach pre-conflict levels (Bazzi and Blattman, 2014).

Chapter 5 Results

This chapter focuses on the results of this investigation. First, I use the Quandt likelihood ratio test (QLR) to establish that conflict creates a structural break within the study period using the base inputs of the model (equation 4.8). This separates the study period into "pre-conflict" and "conflict" sub-intervals where the model parameters are distinct. I then regress the data against the model to obtain estimators of the elasticity parameters for both pre-conflict and conflict periods. This is accomplished using a dummy-variable analysis to estimate the pre-conflict parameters and the change in the parameters arising from the conflict. For some inputs, my choices of which data to include may introduce selection bias. I investigate the impact of other input data selections to demonstrate the stability of the pre-conflict regression coefficients for altered input choices to understand this possible bias in my results.

5.1 Finding a Structural Break

The QLR test was applied to the full data set with the results shown in fig. 5.1. The data year with the largest value of the F-statistic from the test describes the most likely structural break point within the data, with a statistically significant break (F-critical for a 5% trim[1] in data with 6 parameters at a 1% significance level = 25.96 (Andrews, 1993)) located at year 2011 with corresponding F-statistic of 109.347. This breaks the data into two distinct periods, from 1970 to 2010 (now referred to as the "pre-conflict" period) and 2011-2017 (now referred to as the "conflict" period).

[1] It is more common in the literature to use a 15% trim in the data, however, this would exclude the expected location of the structural break. As noted by Andrews (1993), the 15% threshold is a good choice if the structural break point is entirely unknown.

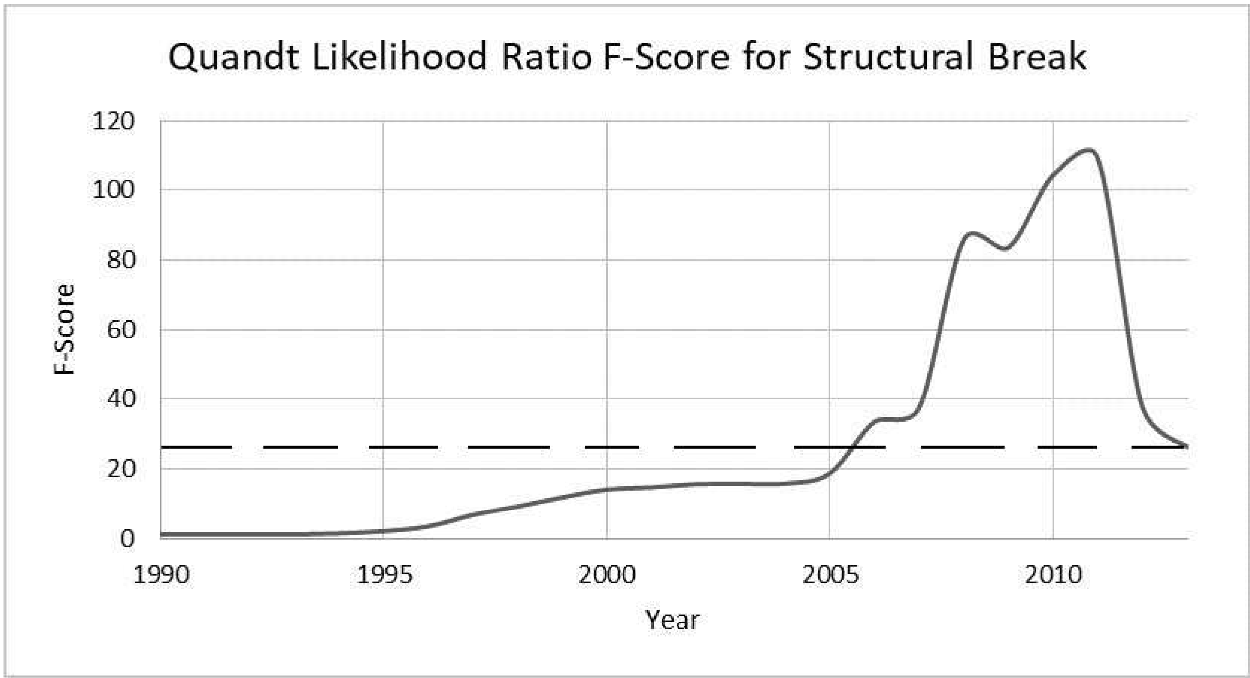

Figure 5.1: The QLR results. The location of the largest F-statistic above the 1% threshold of significance (F-crit = 25.96) indicates the presence of a structural break.

The QLR test shown in fig. 5.1 uses the full data set to establish a structural break in 2011. Other structural breaks may still exist within either sub-interval. However, the size of the sample during the conflict period (2011-2017) is too small to attach significance for another QLR test and is therefore neglected when looking for subset structural breaks. The results of a QLR test on pre-conflict (1970-2011) period are shown in fig. 5.2.

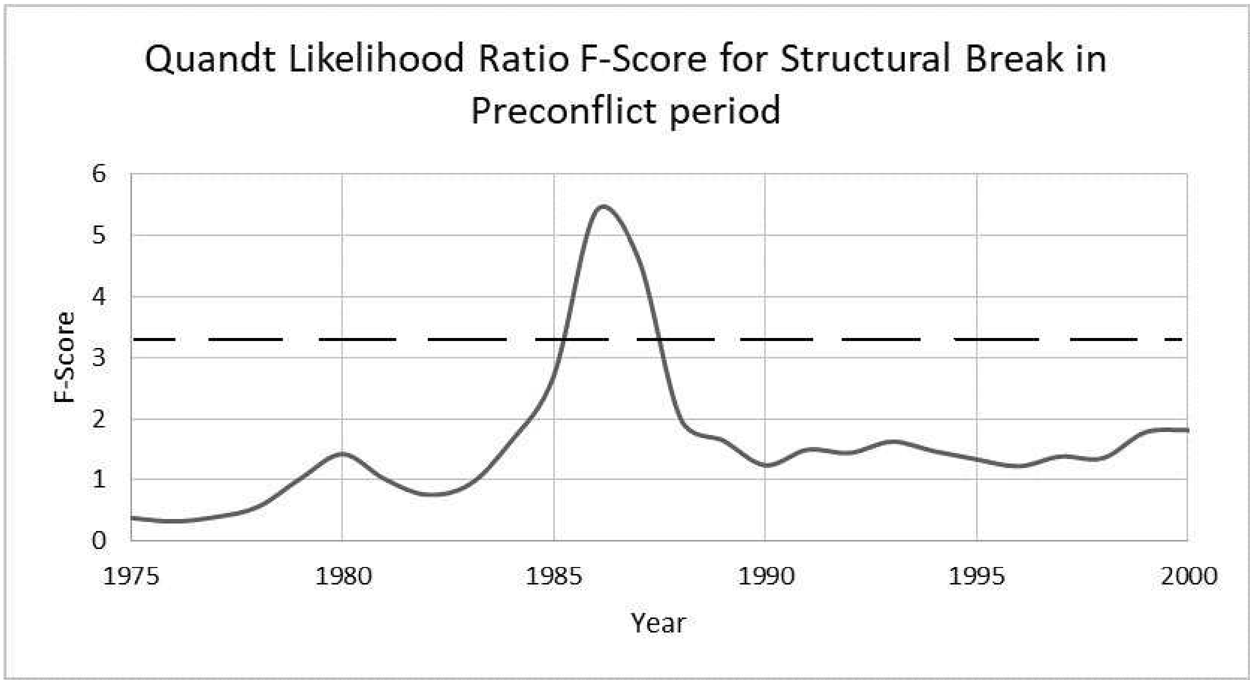

Figure 5.2: The QLR test results for the pre-conflict period to establish other structural breaks. The maximum F-statistic occurs in 1986, coinciding with air strikes against Libya from the US and the beginning of import sanctions. However, the degree of significance in this sub-interval is considerably weaker than for the full period.

While the F-statistic does exceed the 5% significance threshold for the QLR test (F-crit = 3.31) indicating another structural break at 1986[2], the impact is much weaker than change observed in 2011 and is neglected for the remainder of the study.[3]

5.2 Baseline Model and Estimating Input Elasticities

Now that a structural break has been observed, I will need to ensure that I have a model that satisfies the Gauss Markov (GM) assumptions (see section 4.1.2) required for the OLS regression. I begin with the baseline model using the obtained data (equation 4.8) and generate alternate specifications that conform to the GM conditions as needed. The alternate

[2]This structural break coincides with sanctions from Western Europe and the United States in response to the assumed Libyan involvement in the terrorist attacks in Rome, Vienna and Berlin between 1985 and 1986.

[3]The reason to neglect this second result is due to other complications which, when resolved later in the chapter, make the point moot.

specification is expected to retain the same structural break information but will be confirmed through another QLR test. Then I regress the pre-conflict data against the alternate model for the pre-conflict period. Once established, these parameters are used to estimate the agricultural GDP in the absence of conflict.

I estimate the correlation between the logarithm of the input variables (Land, Irrigation, Machinery, Fertilizer and Labor) over the pre-conflict period. The correlation matrix is shown in table 5.1. There is high correlation observed between the land and irrigation inputs, and between the machinery and labor inputs. The presence of multicollinearity in an OLS regression prevents reliable interpretation[4] of the regression coefficients between the highly correlated variables, since the relationship between the input variables to the output is not isolated.

Table 5.1: Correlation Matrix for pre-conflict variables

LN(Land)	LN(Irr)	LN(Mach)	LN(Fert)	LN(Labor)	
1.0000	0.7044	0.4982	0.2281	0.5376	LN(Land)
	1.0000	0.2182	−0.1296	0.1224	LN(Irr)
		1.0000	−0.0331	0.7057	LN(Mach)
			1.0000	0.2337	LN(Fert)
				1.0000	LN(Labor)

I have addressed issue of multicollinearity by modifying the model by bundling the correlated variables into new composite variables as an alternative specification to the baseline model.

One common alternate specification for regression models is the inclusion of interaction variables such as in this truncated form of the base model

[4]However, the predictive capabilities of the regression remain intact even under the influence of multicollinearity

$$\ln(GDP) = \ln(A) + \alpha_1 \ln(Ld) + \alpha_2 \ln(Irr) + \alpha_{12} \ln(Ld)\ln(Irr) + ... \tag{5.1}$$

In this example, an interaction variable consisting of the product of the logarithms of land and irrigation is added. Depending on how the different variable terms are collected, equation 5.1 can take on the form of

$$\ln(GDP) = \ln(A) + \underbrace{(\alpha_1 + f\alpha_{12}\ln(Irr))}_{\alpha_1'}\ln(Ld) + \underbrace{(\alpha_2 + (1-f)\alpha_{12}\ln(Ld))}_{\alpha_2'}\ln(Irr) + ... \tag{5.2}$$

where f is normally assumed to be either 0 or 1 such that the interaction term is combined with only one of the two original variables as part of a simple slope (terms α_1' or α_2'). For example, if f is 1, only the coefficient of land is affected, where the simple slope

$$\alpha_1' \rightarrow \alpha_1 + \alpha_{12} ln(Irr) \tag{5.3}$$

now refers to the impact of the land variable on the output agricultural GDP when the irrigation variable is held constant. However, using this method now suggests that the elasticity parameters are not constant. While that is expected for the full period under study, for the pre-conflict period the elasticities are assumed to be constant. This version of interaction variables is rejected in favor of an alternative specification that does not violate this assumption. Furthermore, interaction effects created this way suffer from being unable to distinguish between the non-additive effects usually seen with the product of inputs, and the non-additive nonlinear effects that show up in the presence of multicollinearity (Cortina, 1993).

As the multicollinearity still presents a problem, I investigate other possible specifications. From equation 4.1, the form of the production function isolates the physical and environmental capitals as separable. Under that assumption, I try a simpler modified form, by reverting back to the environmental variable, Env, and physical variable, $Phys$, that are the sum of the logarithms of each component variable. More explicitly,

$$Env = \ln(Ld) + \ln(Irr) = \ln(Ld \cdot Irr) \tag{5.4}$$

$$Phy = \ln(Mach) + \ln(Fert) = \ln(Mach \cdot Fert) \tag{5.5}$$

Substituting these into the original model equation and renaming the parameter coefficients (α_e for environmental and α_p for physical) leads to

$$\ln(GDP) = \ln(A) + \alpha_e \ln(Env) + \alpha_p \ln(Phys) + \beta \ln(L) \tag{5.6}$$

This modification forces combined inputs to share the same regression coefficient (elasticity parameter). The change to the Cobb-Douglas (CD) formulation (and the related interpretation of the elasticity parameter coefficients) becomes clear. The elasticity parameters now reflect the percentage change in the GDP based on a unit percentage change in the *product* of the corresponding inputs. For example, α_e describes the percentage change in the GDP for a 1% change in Env, the product of the land and irrigation inputs, which might be obtained with a change in either environmental input, land or irrigation. The production function can now be expressed as

$$GDP = A(Env)^{\alpha_e}(Phys)^{\alpha_p}L^{\beta} = A(Ld \cdot Irr)^{\alpha_e}(Mach \cdot Fert)^{\alpha_p}L^{\beta} \tag{5.7}$$

These new variables, Env and $Phys$, now represent interactions existing between the component variables, while also maintaining the assumption that the elasticities are constant during the pre-conflict period. The change to the model requires a second look to ensure that multicollinearity has been addressed. This is shown in fig. 5.2

Table 5.2: Correlation Matrix for pre-conflict variables using modified model

LN(Phys)	LN(Env)	LN(Labor)	
1.0000	0.2616	0.5421	LN(Phys)
	1.0000	0.3857	LN(Env)
		1.0000	LN(Labor)

None of the correlation coefficients for this alternate model suggest worrisome levels of multicollinearity problems. Under this alternate model specification that accounts for the multicollinearity aspect of the original data, I regressed the modified form of equation 5.6 against the logarithm of GDP in Gretl (Cottrell and Lucchetti, 2012), with results shown in table 5.3.

Table 5.3: Pre-conflict (1970-2010) regression summary

	Coefficient	Std. Error	t-ratio	p-value	
constant	−4.456	0.837	−5.325	5.15e–06	***
Phys	0.107	0.031	3.434	0.0015	***
Env	0.146	0.057	2.566	0.0145	**
Labor	1.315	0.091	14.45	8.64e–17	***

Mean dependent var	6.642	S.D. dependent var	0.383
Sum squared resid	0.425	S.E. of regression	0.107
R^2	0.928	Adjusted R^2	0.922
$F(3, 37)$	158.126	P-value(F)	3.80e–21

The measured elasticity estimates during the pre-conflict period displayed in table 5.3 indicate stage II production for both capital inputs, while the labor input exists in stage I. The regression with this alternate specification for the pre-conflict period explains a large portion of the observed variability in the data with an adjusted R^2 of 0.922, while the P-value for F (3.80e-21) indicates the model itself is statistically significant at the 5% level. Furthermore, each regression coefficient is statistically significant, indicating how the modified inputs have a significant relationship to the observed GDP.

The elasticity parameter describes the percent change in GDP found when there is a 1% change in the associated input variable. For example, from table 5.3, the labor elasticity coefficient to two decimal precision is 1.31. This means that a 1% gain in labor will lead to a 1.31% change in GDP. Comparing only percentage increases in the various inputs, a percentage increase in labor has more of an impact on the GDP than an equivalent change in either the environmental or physical capitals by nearly a factor of 12. Each elasticity parameter is strictly positive for the pre-conflict period, indicating that increases in the inputs will lead to a predicted increase in the GDP. The sum of elasticity parameters at 1.568 is larger than unity, indicating increasing returns to scale over the pre-conflict period. Of the inputs, labor is implicated with the greatest contribution to this result. Acquiring new labor to realize these increased gains would have been difficult during pre-conflict since agricultural wages are generally lower compared to the public sector. Hiring sufficient labor from abroad would likewise be stifled as potential workers would have limited means to enter without Libyan government intervention. Furthermore, this may implicate Libya's supply of agricultural inputs for production as insufficient.

While a structural break in the original descriptor variables was found (fig. 5.1), the change in the model specification does not imply the structural break is still present, nor at the start of conflict. Figure 5.3 demonstrates that the structural break still exists for 2011 as expected with a maximal F-statistic of 87.2 (above the 5% critical value of 4.09 (Andrews, 2003)). The appearance of another structural break in the pre-conflict period would affect the interpretation of parameter changes in 2011. As shown in the lower portion of the fig.

5.3, there does not appear to be a significant structural break for the alternative specification during the pre-conflict period at the 5% significance level.

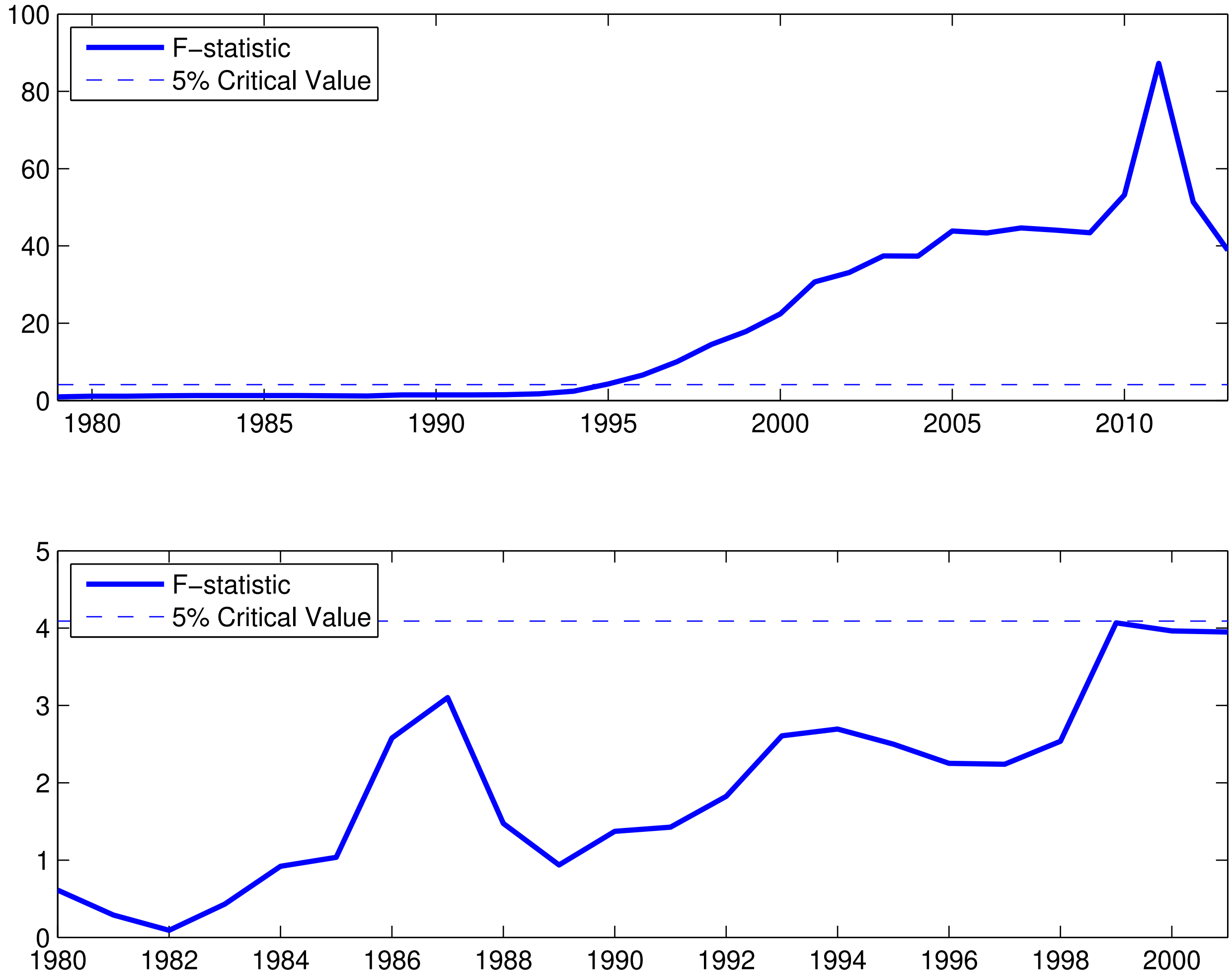

Figure 5.3: The QLR results for the alternative model. The top figure shows the results of running the QLR test with the full data set with non-symmetric trim to include the expected break at 2011. The location of the largest F-statistic at 2011 is above the 5% threshold of significance. The bottom figure shows the QLR test applied to the pre-conflict period data to ensure no other breaks occur within the observation period. This means the full pre-conflict period can be used when estimating the impact of the structural change in 2011, rather than a smaller sub-interval to estimate the pre-conflict parameters.

Figure 5.4 shows the observed GDP for the full period, along with the predicted GDP based on the pre-conflict elasticities found in table 5.3 applied to the inputs over the full period. The drop observed compared to the predicted output suggests that the changes are not from direct changes in the availability of the production inputs, but instead implicates that the changes are structural in the useful conversion of the inputs for agricultural production. This provides additional visual evidence of the structural break occurring in 2011 due to the presence of conflict.

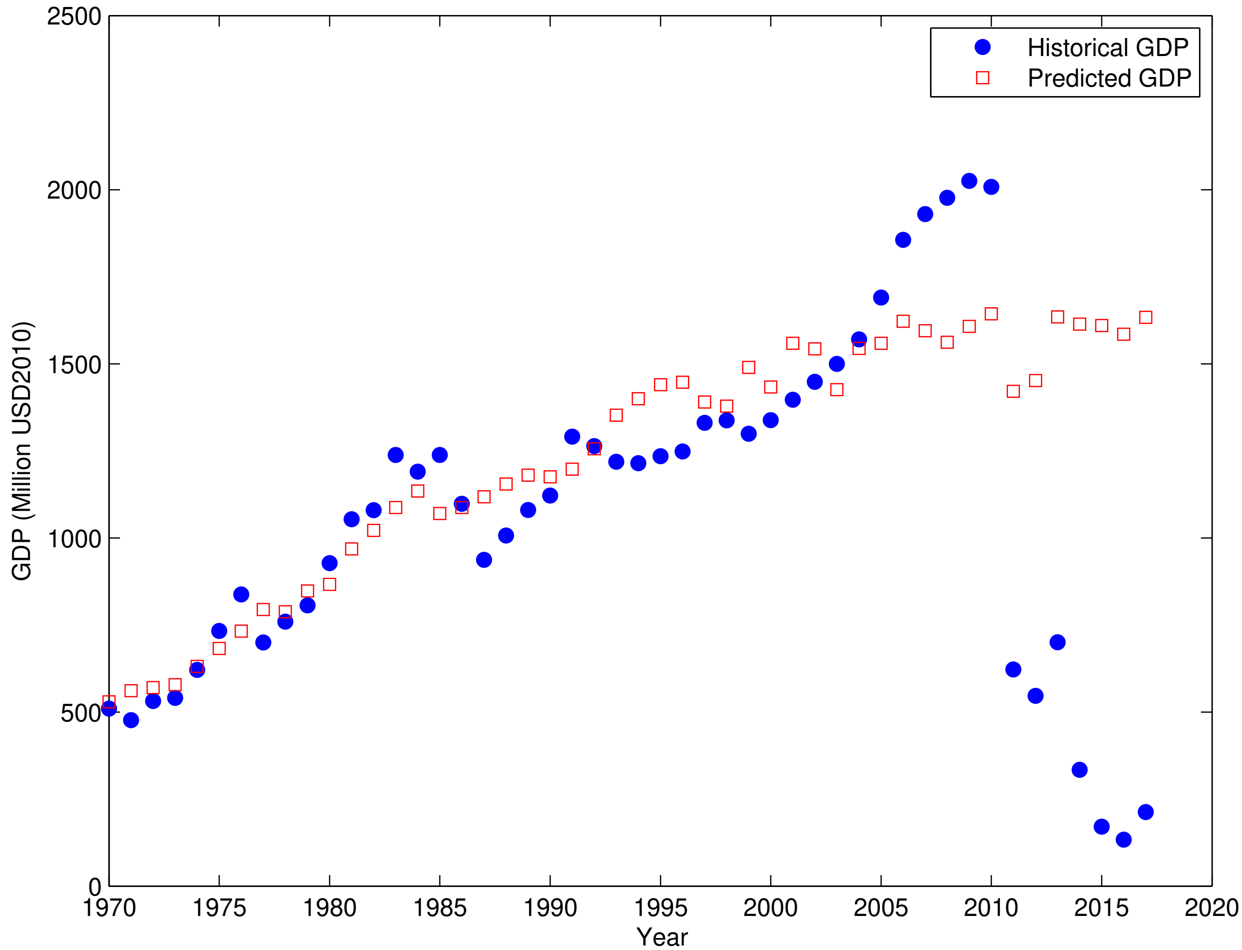

Figure 5.4: Observed GDP and regression predicted GDP over time.

An alternative view is to consider how well the predicted GDP tracks against the observed historical GDP over time using the pre-conflict elasticity parameters as shown in fig. 5.5. In the absence of a structural break, the relationship between the observed and predicted GDP values is expected to have a slope of 1, with an intercept of 0. The conflict period is distinctly separated from the pre-conflict data, indicating the elasticity parameters measured in table 5.3 are poor predictors for the observed agricultural GDP during the conflict period. Unlike fig. 5.4, the regression fit in fig. 5.5 quantifies both how well the predicted GDP matches the observed data during the pre-conflict period and the discrepancy for the conflict period residuals.

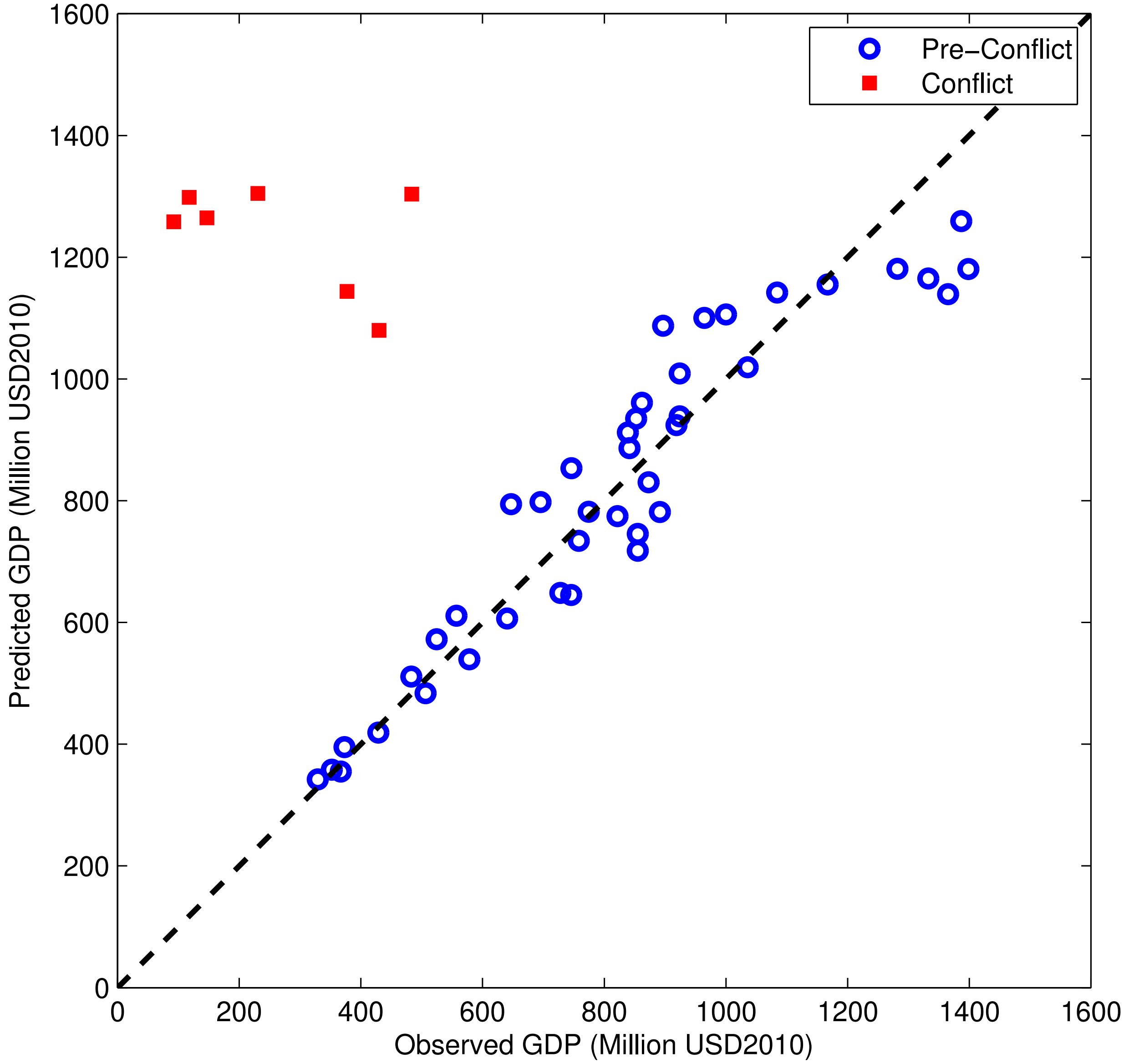

Figure 5.5: Predicted relationship to Observed GDP.

With both econometric evidence and visual support, the elasticity parameters from the regression of equation 5.1 are used to project the expected agricultural GDP in the absence of conflict. A projection estimate using the line of best fit with the pre-conflict parameters is shown in fig. 5.4, showing that estimated losses due to the conflict amount to 6.78 billion USD2010 for the first 7 years of the conflict, estimated as the residual in fig. 5.4.

5.3 Model Robustness

My analysis assumes the validity of the Gauss-Markov conditions for the use of the OLS regression. So far, only the condition relating to the collinearity of the input variables has been addressed. The remaining assumptions will need to be validated to justify my use of the OLS regression to measure the elasticities of the model specified by equation 5.1.

5.3.1 Linearity of Parameters

To check the linearity of the parameters within the model regression, a plot of the observed against the predicted values of the log of the agricultural GDP is used in fig. 5.6.

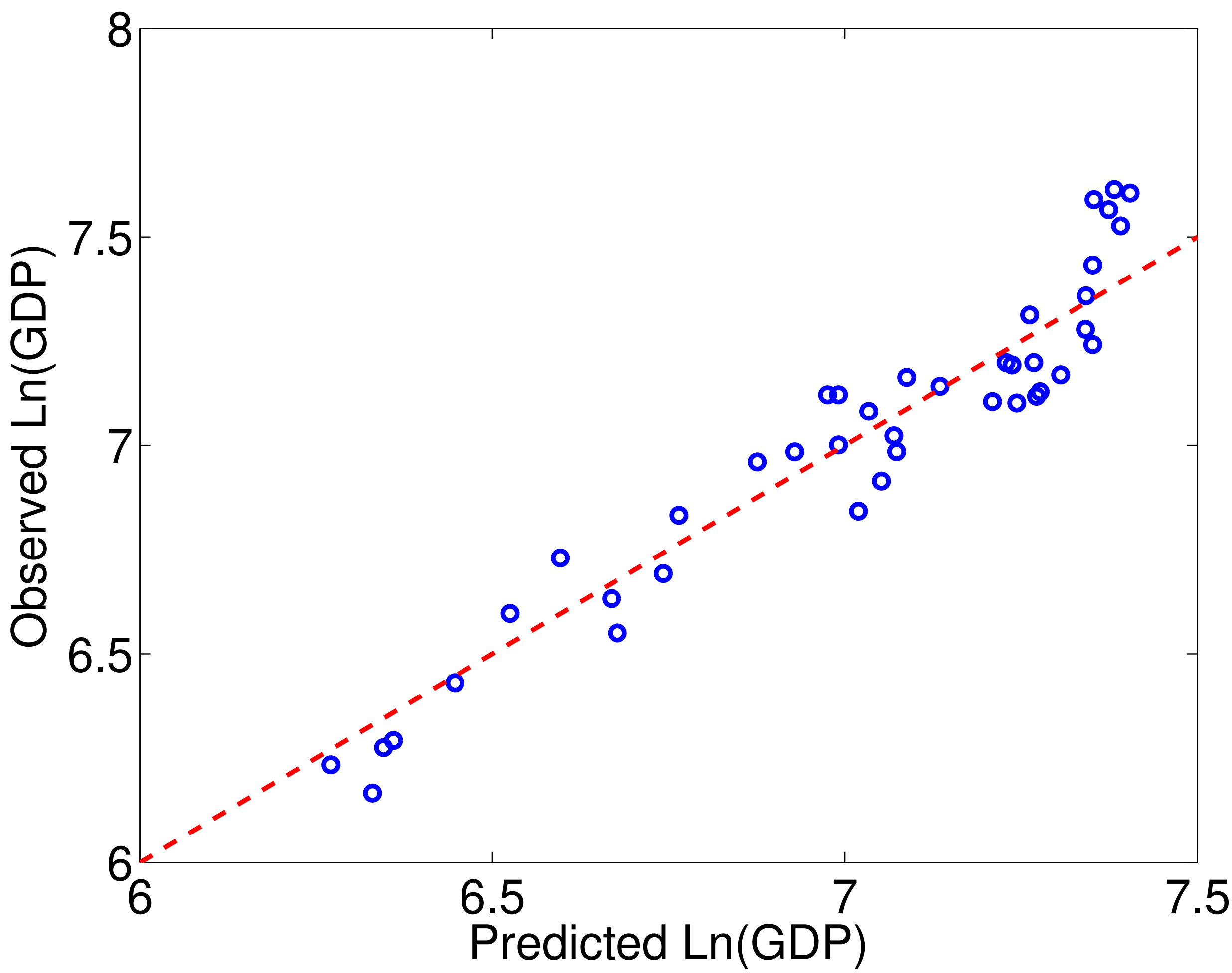

Figure 5.6: Observed and predicted logarithm of the agricultural GDP for the pre-conflict period.

The scatter plot shown in fig. 5.6 visually demonstrates the coordinate pairs close and symmetric about the 45° line (where the observed and predicted values match). This offers evidence that the regression in linear in parameters, since if the linearity assumption does not hold,

5.3.2 Homoscedasticity

If the variance of the error term of the model regression is not constant over the observation period, then the OLS condition requiring homoscedasticity is violated. If this is the case, then too much weight will be given to a subset of the data in determining the regression parameter. Given that the pre-conflict data set is relatively small, it becomes important to check for homoscedasticity. This is done in figure 5.7, where the residuals are plotted over the pre-conflict period and checked to see if they exist in a relatively narrow band around zero with symmetric distribution and no observed patterns.

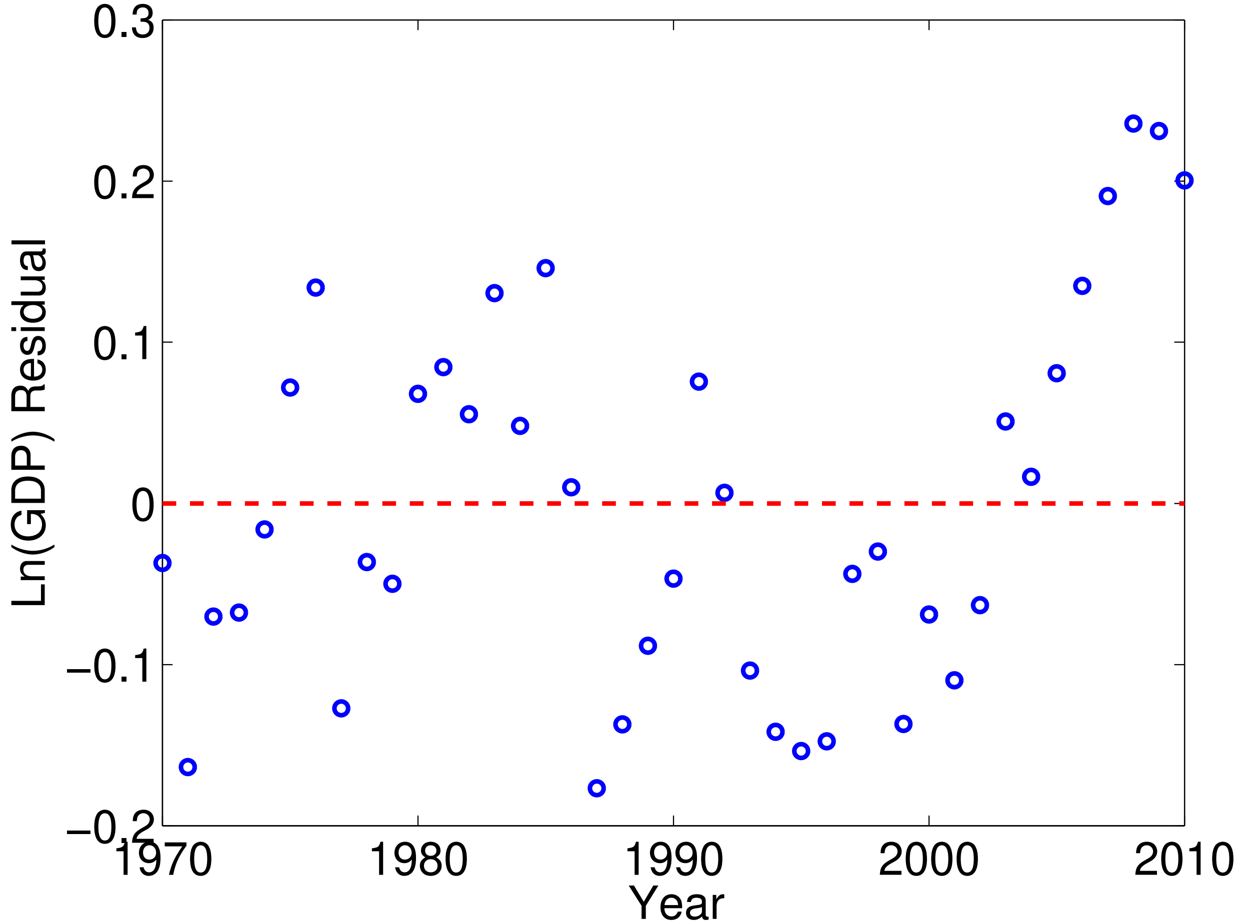

Figure 5.7: Log-Ag. GDP Residual over full period.

The residuals shown in fig. 5.7 appear to not have a defined pattern (further describing the linearity assumption), and the residuals are evenly spaced about the zero residual line. While there is a small uptick at the end of the data series, it is not pronounced enough to suggest the variation is heteroscedastic.

5.3.3 Normality of Errors

Another major consideration for the validity of the OLS regression is the assumption of the normality of errors. Without this condition, the OLS estimates would be unreliable. The normal probability plot shown in fig. 5.8 is used to investigate if the error terms are normally distributed.

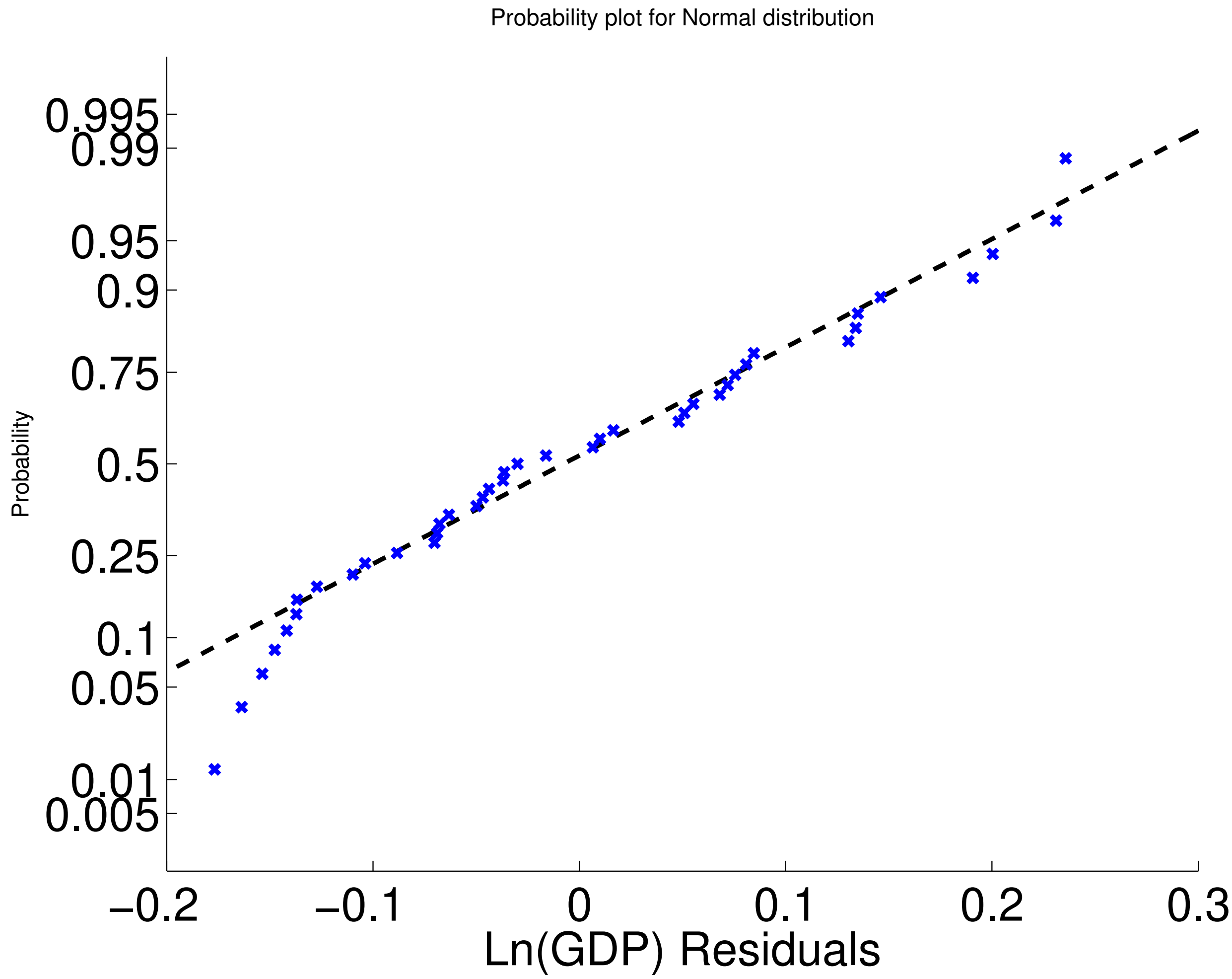

Figure 5.8: Normal probability plot for error term in regression for pre-conflict dataset

There is some deviation from the normal distribution at the tail left end of the data. However, many of the residuals are normally distributed as demonstrated by the plot points tightly surrounding the normal plot line.

5.4 Sensitivity Analysis

Since the input variables related to environment were obtained by making specific assumptions, the regression coefficients found may be susceptible to bias. For example, the land variable includes an assumption of constant fodder crop acreage, rather than a time varying estimate. In order to demonstrate that the choices for input variable representation do not greatly change the obtained results, I regress pre-conflict data against different assumptions to establish the stability of the regression coefficients.

5.4.1 Land

The land input variable is the sum of the crop acreage and fodder crop acreage. While the crop acreage data is readily available, the fodder data was very incomplete, leading to an assumption of stable fodder crop acreage (85,000 ha) based on earlier investigations (Ouchen, 1997). An alternate specification is to assume the fodder crop acreage is normally distributed,[5] $\sim$N($\mu = 85,000, \sigma = 10,000$), the regression for this alternate assumption yields the results shown in table 5.4.

Table 5.4: Pre-conflict Regression Summary for Adjusted Land Variable

	Coefficient	Std. Error	t-ratio	p-value	
const	−4.476	0.829	−5.402	4.05e–06	***
Phys	0.107	0.031	3.433	0.0015	***
Env	0.149	0.056	2.632	0.0123	**
Lab	1.312	0.091	14.46	8.43e–17	***

Mean dependent var	6.642	S.D. dependent var	0.383
Sum squared resid	0.421	S.E. of regression	0.107
R^2	0.928	Adjusted R^2	0.922
$F(3, 37)$	159.47	P-value(F)	3.28e–21

[5]As noted by FAO, this technique has its shortcomings, but may be the only practical way to include variability into forage production information : http://www.fao.org/3/x9137e/x9137e08.htm.

When accounting for variability within the used land variable, the parameter estimates remain mostly unchanged with less than a 2% difference between the parameters seen in table 5.3. The regression of the overall model itself also remains significant.

5.4.2 Irrigation

The specified assumption underlying the irrigation variable is the water requirements for each crop. Each crop water requirement was obtained as a range in FAO (2020). For the original regression, the median value of a water requirement range was used for each crop. For example, the water requirement for wheat is between 450 and 650 mm, but I have used 550 mm to generate the original irrigation data. I have redone the regression under the assumption of low water requirements for each crop, and for high water requirements. These are shown in table 5.5 and table 5.6, respectively.

Table 5.5: Pre-conflict Regression Summary for Low Irrigation Requirement

	Coefficient	Std. Error	t-ratio	p-value	
const	−4.214	0.812	−5.192	7.79e–06	***
Phys	0.109	0.032	3.453	0.0014	***
Env	0.125	0.054	2.333	0.0252	**
Lab	1.329	0.091	14.59	6.40e–17	***

Mean dependent var	6.642	S.D. dependent var	0.383
Sum squared resid	0.436	S.E. of regression	0.109
R^2	0.926	Adjusted R^2	0.920
$F(3, 37)$	153.66	P-value(F)	6.20e–21

Much like increasing the fodder crop variance for the land term, the impact of using the low irrigation requirement weakly shifts the measured coefficients, though each coefficient and the model remains significant at the 5% level. This change is not due to the increase in overall variability of the measured input environmental variable, but more due to the decreased relative contribution for the irrigation to the overall environmental variable. However, the situation described by this scenario is unlikely, as the water requirement for the arid region is more likely to be an overestimate, rather than the underestimate as posed here. The more likely situation, is characterized in table 5.6, where the higher water requirement is more likely induced by higher rates of envirotranspiration.

Table 5.6: Pre-conflict Regression Summary for High Irrigation Water Requirement

	Coefficient	Std. Error	t-ratio	p-value	
const	−4.639	0.852	−5.446	3.53e–06	***
Phys	0.107	0.031	3.455	0.0014	***
Env	0.159	0.058	2.748	0.0092	***
Lab	1.305	0.091	14.41	9.40e–17	***

Mean dependent var	6.642	S.D. dependent var	0.383
Sum squared resid	0.415	S.E. of regression	0.106
R^2	0.929	Adjusted R^2	0.923
$F(3, 37)$	161.90	P-value(F)	2.53e–21

In table 5.6, the relative contribution of the irrigation to the environmental variable has been increased to account for the higher water requirement. In this situation, the environmental variable coefficient showed a 10% change from table 5.3. The significance of the regression and each of the measured parameters each remains below the 5% threshold.

5.4.3 Physical Inputs and Labor

Unlike the environmental capital inputs where distinct choices regarding input selection were made, the remaining input variables (fertilizer, machinery and labor) were obtained based on minimal data availability rather than a discretionary choice of alternative data sets. With the lack of options and general weakness of the data, there are limited methods to test the sensitivity of the elasticity parameters obtained from the regression to changes in those variables without introducing bias. One option is to assume the data sets come from a distribution that can be repeatedly sampled to generate a spread of the estimated parameters from the regression, thereby offering insight into the sensitivity of such parameters on the changes in input specification. This is similar to what was done for the land parameter where the fodder contribution to the land size was assumed to be pulled from a normal distribution. However, the choice to use this distributional form stems from the underlying temporal independence of the fodder crop area over the observed period. This independence is not observed for the remaining three explanatory variables, where there is time dynamic that would not be captured through using a static distribution to obtain related sensitivity information, and the underlying distribution of the variables is likewise unknown.

Various re-sampling schema offer an alternative method to test the sensitivity (De Bin et al., 2016). Whether done with (bootstrapping) or without (sub-sampling) replacement, time series data is often re-sampled in blocks to account for the likely presence of correlation between data (Härdle et al., 2003, Politis and Romano, 1994). These methods furthermore do not make assumptions of the underlying distribution (Fox, 2002).

Applying the block bootstrap method to the data set[6] provides an estimate of how well the regression parameters have been estimated with the observed data.

[6]The data still remains paired in time, e.g., the GDP in 1985 is still attached to the input variables at 1985 only.

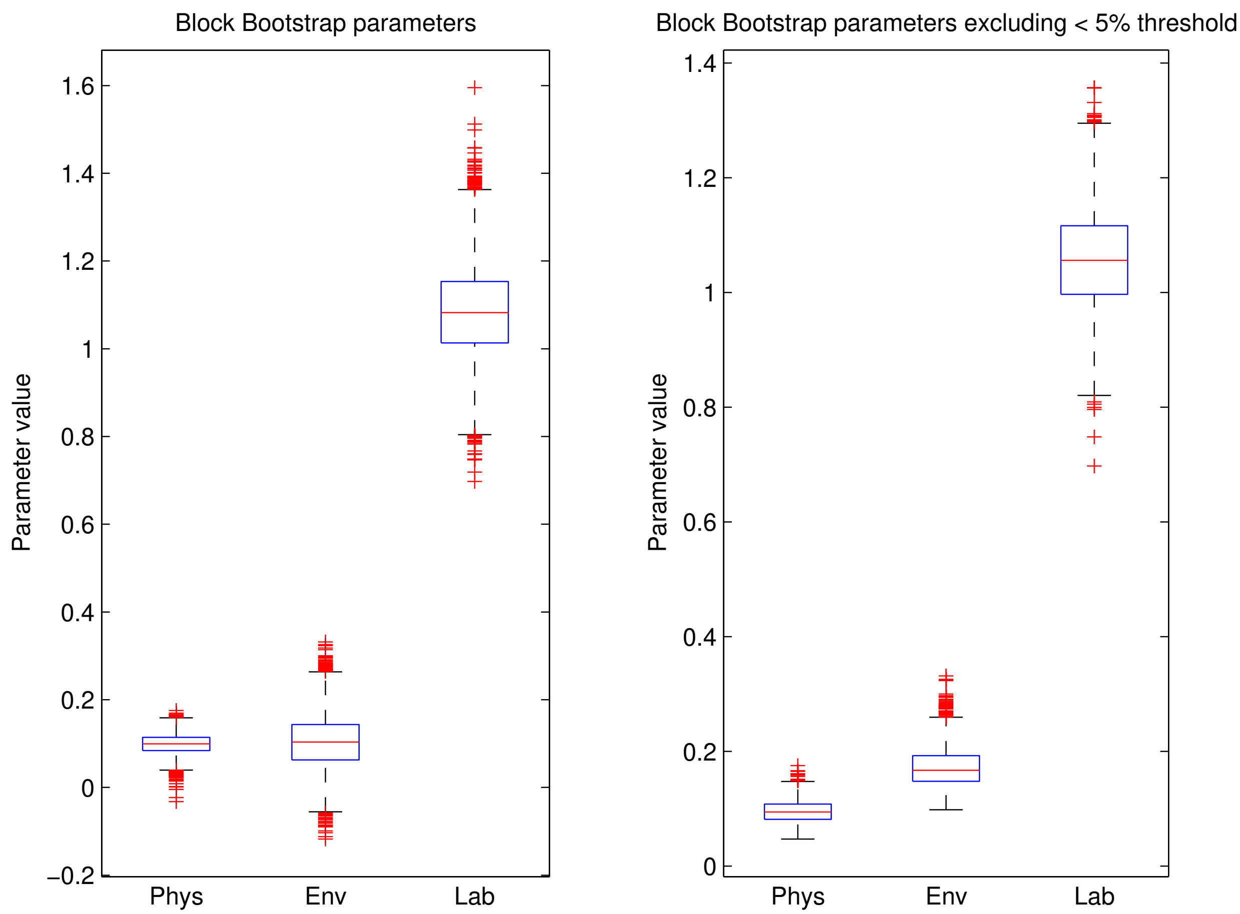

Figure 5.9: Block bootstrap method used to estimate sensitivity of regression parameters. The left figure displays all 10,000 re-samplings regardless of the significance, while the right figure shows only the results where each parameter was significant (approximately half the re-samples).

The results of the block bootstrapping shown in fig. 5.9 show the observed spread of elasticity parameter estimates from the re-sampling procedure for 10,000 repeated samples. On the left side of the figure, all results are shown, with the Labor coefficient always significant (well above a zero estimate for the parameter), while a large portion of the Physical and Environmental parameters also significant, where less than 3% of the observed cases resulted in zero or smaller parameter estimates. The right side of the figure excludes measurements where any of the three parameter estimates were insignificant at the 5% level.[7] While this provides a visual example of the ranges of the parameters expected, the boot-

[7]This is determined by whether or not 0 was included in the corresponding 95% confidence interval.

strapping method is more often used to describe the standard error of the estimates, as reported in table 5.7.

Table 5.7: Summary of bootstrapping results.

Variable	Parameter	
	Mean	Std. Error
Phys	0.1183	0.0342
Env	0.1073	0.0693
Labor	1.198	0.0992

5.4.4 Model Sensitivity Summary

The coefficients of each regression in the pre-conflict period from the original and alternate assumptions is collected in table 5.8. The standard column refers to the original data set. The column with land adjustment has had the fodder crop area pulled from a normal distribution, while the third and fourth columns represent the coefficients pulled from regressions using the low water requirement and high water requirement, respectively.

Table 5.8: Summary of regression coefficients for different data assumptions.

Variable	Model Coefficient			
	Standard	Land Adjustment	Irrigation Low	Irrigation High
Phys	0.107	0.107	0.109	0.106
Env	0.146	0.149	0.125	0.159
Labor	1.315	1.312	1.329	1.305

From table 5.8, the physical and labor elasticity parameters are largely unchanged with regard to the assumed data. The environmental elasticity has a larger variability, but the relative coefficient ranking is the same in each column where the labor elasticity greatly exceeds the environmental elasticity which is slightly larger than the physical elasticity.

Table 5.9 shows the 95% confidence intervals generated using the block bootstrap method with the parameter means and standard errors listed in table 5.7.

Table 5.9: Summary of regression coefficients for different data assumptions.

Variable	Elasticity Parameter Confidence Interval
Phys	0.0513 - 0.1853
Env	-0.0285 - 0.2431
Labor	1.0036 - 1.3924

In each case, the confidence intervals for the three elasticity parameters for the pre-conflict period data using the Phys-Env-Labor predictor variable model specification are positive, indicating significance in the measurement. This provides an estimate of the sensitivity of the model as the bootstrapping method is seen as a perturbation of the original sample (Fox, 2002).

5.5 Estimating the Structural Change due to Conflict

One consequence of the location of the structural break observed is the limited ability to determine elasticity parameters for the conflict period, which has only 7 available samples. By adding a dummy variable coinciding with the structural break, I was able to estimate the changes to the elasticity parameters due to conflict. The changes in the parameters for the labor, environmental and physical variables are listed in table 5.10. The D-coefficients (such as DLabor) that contain the dummy variable, indicate the change in the observed variable over the structural break. Both the physical and labor slope coefficients are significant at the 5% level, consistent with the existence of the structural break. All three coefficients displayed a net loss, with the environmental parameter's change not being significant under conflict. Unlike the QLR test which merely indicates the presence of a structural break, the results presented in table 5.10 describe what the structural changes are. Losses to the labor and physical elasticities might reflect worsening efficiencies due to local conditions, where the system shock arising from conflict leaves an excess of agricultural inputs but no mechanism to assist in the conversion to production. This conclusion seems to be further supported by the overall lack of significance to the change in the environmental variables which show early reduced capacity during the conflict period. The absence of a similar lack of conflict's impact for the physical capital component likely results from the minimal military strategic value of agricultural machinery, fertilizer, and other physical goods. The level of physical capital then represents a surplus to the agricultural production where excess input does not contribute to greater production. This increased inefficiency would manifest as a decrease in the associated elasticity parameter.

Table 5.10: Estimation of Combined Elasticity Parameter Changes due to Conflict using Dummy Variables

	Coefficient	Std. Error	t-ratio	p-value	
const	−4.456	1.571	−2.836	0.0071	***
Phys	0.107	0.059	1.829	0.0749	*
Env	0.146	0.107	1.367	0.1793	
Labor	1.315	0.171	7.696	2.05e–09	***
DInt	126.032	21.787	5.785	9.49e–09	**
DPhys	−0.518	0.142	−3.641	0.0008	***
DEnv	−0.803	0.858	−0.936	0.355	
DLabor	−18.935	3.000	−6.311	1.73e–07	***

Mean dependent var	6.463	S.D. dependent var	0.611
Sum squared resid	1.618	S.E. of regression	0.201
R^2	0.908	Adjusted R^2	0.892
$F(6, 41)$	56.25	P-value(F)	1.04e–18

The results of table 5.10 should be interpreted with caution. The observed parameters during conflict are obtained using a small data set (2011 - 2017). The standard errors of such measurements with low amount of support leave the parameter estimations with larger uncertainties and less likely to be significant at the 5% level. Conversely, the dummy variables are estimated using the full data set in detecting changes of the estimated parameters beyond the break point, and may remain significant at the 5% threshold. More succinctly, while the results can conclude that there is a change to the parameters and the general direction of that change, it is not enough to say with statistical certainty the value of parameters during conflict.

The observed negative elasticities for the input variables indicate a lower output for agricultural production with greater amounts of the corresponding inputs. While this would be consistent with stage III production where a negative marginal product would be observed, this would violate the underlying assumption of rational behavior amongst farmers when using the production function. The presence of conflict can make certain actions appear irrational, especially at the onset of conflict when things like planting decisions are already committed. However, after the initial disruption, firms are expected to adjust technologies accounting for this new environment, making stage III production untenable based on conditions of monotonicity for the production function (Moss, 2022). Conditions for stage III production are often assumed to incorporate free disposal (Debertin, 2012). While this is plausible for disposable goods such as fertilizer, it is not for the labor input. In general additional labor cannot be disposed of freely without governmental support in supplying wages associated with the unused labor. During conflict, the governmental authority is unlikely to have provided the condition for free disposal. Instead, it is more likely the reported labor values represent a larger number of workers with smaller time contributions.

5.6 Summary

Using the QLR for the full model incorporating Land, Irrigation, Fertilizer, Machinery and Labor as distinct inputs of the CD model, the expected structural break at the onset of conflict in 2011 was observed. Separating the period into pre-conflict and conflict periods, multicollinearity was apparent. This was accounted for by combining similarly categorized inputs as a product, where the environmental variable combined Land and Irrigation, and the physical variable combined Fertilizer and Machinery (Labor remained separate). This effectively rendered combined inputs as having identical elasticities. The remaining GM assumptions required for validity of the OLS estimates were also conducted.

To ensure this altered model specification did not impact the conclusion of a structural break, the QLR test was used. This again confirmed the location of a structural break in 2011, with no other statistically significant breaks within the study period. Using this model, the OLS estimated elasticity parameters were 0.107, 0.146 and 1.315 for the Physical, Environmental and Labor variables, respectively. Each estimated parameter and the model as a whole were statistically significant at the 5% level.

Model sensitivity was also investigated. When alternate data was available (usually from conflicting sources or from different assumptions), changes to the determined model parameters (fig 5.8) were under 1%. Since each variable in the model did not have available alternate data, the bootstrapping method was also used to investigate the model sensitivity. Minor shifts in the estimated elasticity parameters were observed (Physical : 0.1183, Environmental : 0.1073, Labor : 1.198), though bootstrapping is more associated with estimating the standard errors.

Binary dummy variables were included in the alternate model to estimate the changes to the elasticity parameters to evaluate the impact of conflict. The parameters associated with the dummy variables reflect the change in elasticities associated with the structural break, showing a decrease in all three input elasticity coefficients, though the change in the Environmental coefficient was not statistically significant.

Chapter 6 Analysis and Discussion

In this chapter, I analyze the results of the regressions obtained in chapter 5, while integrating my work with the literature on conflict. This analysis includes my interpretation of the measured elasticity parameters. I estimate the costs of increasing each of the individual agricultural inputs considered in this study (Land, Irrigation, Machinery, Fertilizer and Labor) and the corresponding impact on the agricultural GDP in the post conflict period assuming the elasticity parameters immediately return to pre-conflict levels. This cost analysis considers an overall worst-case value approach to improve the agricultural GDP since returning to business as usual will not return the GDP trajectory to the pre-conflict levels. This cost analysis consists of estimating and comparing the direct cost of increasing the agricultural inputs (Land, Irrigation, Fertilizer, Machinery or Labor) to effect a 1% increase in the 2017 agricultural GDP (using the 2017 input quantities) based on the estimated pre-conflict regression parameters. Furthermore, I describe the expected impact for the agricultural sector for three future scenarios during the recovery period: Business as usual (BAU) where future growth never converges with pre-conflict levels, convergence in 20 years and convergence in 50 years. Finally, I estimate deadweight losses to the agricultural GDP during the conflict and recovery period based on the conflict duration and the period recovery for the agricultural GDP to converge to the pre-conflict trajectory once conflict has ended.

To provide a deeper understanding of conflict's impact on the agricultural sector, I also examine some of the ecological damages stemming from the civil war. These damages are connected with the environmental capital while not being fully captured within my model. These deadweight losses represent some of the agricultural losses that will need to be addressed with future agricultural policies. Physical capital has no similar catch-all for unaccounted damages. This is due to Libya's dependence on imports, rendering physical capital highly exogenous, where conflict is not expected to damage the value chains outside of Libya.

Therefore, no further consideration is given to sources of physical capital damage not accounted for by my model.

Based on the results of my analysis, along with considerations of effective and ineffective policies in other post-conflict countries, I present policy options to help promote a more efficient post-conflict recovery of the agricultural sector in Libya.

6.1 Sensitivity of Production Inputs

This section is dedicated to understanding the sensitivity of the production input variables (Land, Irrigation, Fertilizer, Machinery, and Labor) on improving the agricultural sector after conflict. Using the OLS regression parameters for the log-linearized model reveals the expected percentage change to the output GDP to a unit percentage increase in the corresponding input for the respective parameter called input elasticity. To effectively compare the different production inputs on a common basis, an estimate of the costs of increasing each separate input leading to the same unit percentage (arbitrary) increase in GDP is needed. This estimate is based on pre-conflict values of the total input.

The elasticity parameters estimated in Chapter 5 are shown in table 6.1, both for the pre-conflict and conflict periods.

Table 6.1: Regression coefficients for pre-conflict period. The reciprocal coefficient column represents the needed percent increase in input to obtain a 1% increase in GDP

	1970-2010		2011-2017
Input	Regression Elasticity Coefficient	Reciprocal Elasticity Coefficient (%)	Regression Elasticity Coefficient
Physical	0.107	9.35	-0.411
Environmental	0.146	6.84	-0.657
Labor	1.315	0.76	-17.62

The reciprocal coefficient is presented in table 6.1 to show how much an input would need to be increased to generate a unit percent increase in the output GDP. When costs are included, the reciprocal elasticity is converted into a monetary basis, where the cost to achieve a 1% increase in GDP can be directly compared across all inputs. This analysis assumes a linear approximation. This approximation does not account for further time dependent elasticities, the non-linear relationship between the inputs and output GDP, nor of the complementary nature of the inputs.

While estimates of the conflict altered elasticity parameters are shown in table 6.1, it is unreasonable to create a cost analysis based on these negative coefficients for the physical and labor inputs (this would imply the conflict induced elasticity parameters remain long after the end of the conflict period). It is more reasonable to assume that the elasticity parameters will return to the pre-conflict values. For the remainder of this analysis, I have elected to assume this condition where the elasticity parameters revert to the pre-conflict values or other fabricated scenarios immediately at the end of the conflict.

Since the measured elasticities refer to a product combination of two types of capitals (For example, the physical capital is the product of machinery and fertilizer variables as in equation 5.5), an effective increase in either input can raise the composite capital. This means that a 1% increase in the physical capital, for example, can be obtained with a unit percent increase in either the machinery or fertilizer variables or in some combination.

Before calculating the costs to individually increase each input to attain a unit percent increase in the GDP, the following assumptions have been used for simplicity

1. There are no cost savings by reducing any inputs

2. The costs associated with an increase in the related input are constant

3. The elasticity parameters revert to pre-conflict levels once the conflict has ended

The first assumption is used to stipulate that there is no benefit to reducing any of the individual agricultural inputs. Without this assumption, the search space for different scenarios would require valuation of the reduced inputs (e.g., the sale of large quantities of tractors) and investigation of more complicated interactions between the five inputs.[1] Given the weaker data set available to use for this investigation, attempting to string together more refined analysis would lead to questionable conclusions at best. If the assumption is used, then each individual input can be examined independently, since none of the agricultural inputs would be allowed to decrease. A comparison between the estimated costs identifies which production input variable is the most cost-effective in increasing the agricultural GDP in the short-term.

The second assumption implies stability of costs for purchasing agricultural inputs. If this is not assumed, considerations of bulk-based discounts and the relationship of the available supply to cost will need to be addressed. However, in many instances, it is unlikely that Libya would be absorbing sufficient amounts to dramatically impact the price or cost of available supply. Notable exceptions would include the land (where there is a set amount of available, productive land in Libya) and machinery (where larger orders are expected to show up as additional lead time for delivery). This assumption reflects how the changeable inputs are exogenously controlled, such as the fertilizer costs being more stable since they are almost exclusively imported by Libya, or how the groundwater draw for the Great Man-Made River (GMMR) is a product of natural factors. This constant cost assumption is clearly not valid in the long-term, but the estimates are meant to describe the best short-term benefits to the agricultural sector to most rapidly increase the impact to the overall GDP.

The third condition is an assumption that the elasticities will snap back to pre-conflict levels once the conflict has ended.[2] None of the conflict literature reviewed examined how the changes in input elasticities immediately after conflict, making it difficult to find research-based justification for this assumption. In the absence of evidence, the option to assume

[1] The physical input total, for example, could have a unit percent increase with a gain of fertilizer and a loss of machinery. Allowing changes to be made to any of the 5 variables then becomes a global optimization problem. The first assumption requires that no original input variable is reduced.

[2] Alternative scenarios could include short-term stability of the elasticity parameters, the gradual restoration to pre-conflict elasticities, or permanent changes to the parameters.

pre-conflict levels becomes prudent, if questionable. However, this remains a gap within the literature that should be investigated further. Additionally, in Libya, capital was not degraded irreversibly making it reasonable to assume BAU will resume without substantial resistance. Other hypothetical scenarios are also considered.

6.1.1 Costs Associated with Increasing Physical Inputs

The physical regression coefficient indicates how a 1% increase in the product of physical inputs (Machinery and Fertilizer) is associated with a predicted 0.107% increase in the agricultural GDP for the period prior to conflict, or a 9.35% increase in physical input is needed to increase the GDP by 1% (table 6.1). While the return on investment may seem small when comparing on a quantity basis, it may be effective when the cost associated with increasing the inputs is included.

The fertilizer input variable is measured in metric tons of fertilizer, without regard to the type of fertilizer or the quality. As of 2017, 35,045 tons of fertilizer was used in Libya, where a 9.35% (Table 6.1) increase would mean an additional 3,277 tons of fertilizer. From the World Bank's (WB) recent Pink Sheet (2020a) detailing fertilizer prices, September 2020's fertilizer price averages USD 273.50/ton,[3] not including transport and distribution costs. The value of a 1% increase in GDP from fertilizer is expected to cost[4] USD 896,000, again without reference to transportation and distribution costs. As fertilizer is a consumable good, this additional cost would exist each year to maintain an increased GDP.

The machinery input is measured in TJ (terajoules). However, this variable is used as a proxy for the total machinery in use, and only reveals the cost of fuel consumption, rather than the complete costs of purchase and maintenance of machinery used in the agricultural sector. Shifting back to the data set describing the available tractors is insufficient as tractors are assumed to comprise a small portion of the total machinery in use. Since tractor purchases

[3] The fertilizer price is the average of DAP, Potassium Chloride, TSP and Urea sources from the Pink Sheet.

[4] Costs are determined by the product of the reciprocal coefficient in table 6.1, the input value in 2017, and the cost per unit input.

may not coincide with purchases in the unobserved portion of machinery, determining the associated cost of machinery leading to a predicted 1% increase in the agricultural GDP is filled with enough assumptions to make the prediction carry a large amount of uncertainty.

As a working estimation,[5] tractors compose between approximately 2 and 7% of the yearly ownership costs in terms of purchase under a straight-line depreciation model. This does not include the operating energy costs or maintenance, which could increase the total annual costs by approximately 130% (W. Edwards, 2015), and will generally overestimate the relative value of tractors since other components of the machinery input are not included.

Based on the last available data for tractor quantity in Libya (FAO, 2020), there were 39,733 tractors in Libya in 2000. A needed 9.35% increase in the Machinery input would coincide with a purchase of 3715 new tractors. Recent reports indicate Libya is already planning on purchases of tractors ("Libya Seeks to Import MTZ Tractors", 2020), where the purchase cost of a new tractor is between USD 11,600 and 20,000 for the commonly used mid-range capacity available in Libya.[6] It is common for tractors in Libya to have a lifespan of 25-30 years, so a straight-line depreciation puts the value of purchase of the new tractors between USD 1.4 and 3.0 million per year. As tractors are estimated to account for between 2 and 7% of the total machinery cost, a rough estimation of the total machinery cost per year is USD 20 and 150 million. Of the two, it is more cost effective to increase the fertilizer used than to acquire more machinery for the physical capital.

6.1.2 Costs Associated with Increasing Environmental Inputs

The environmental elasticity parameter for the pre-conflict period is 0.146, indicating a 1% increase in the product of the land and irrigation input variables is associated with a 0.146% increase in the GDP. However, there is little reason to believe that the land input can be changed in sufficient quantities. It is infeasible to increase the amount of available land that

[5]The machinery considered Tractors, Combines, Milkers, Distribution systems for fertilizer, pesticides and water, and facilities such as poultry houses.

[6]The estimates of prices are based on the horsepower of standard tractors in Libya, rated at 48-80 hp available from Minsk Tractor Works ("Tractor Data", 2020).

is suitable for agriculture within the arid environment of Libya without great costs. Though certain reclamation processes are possible (Barnes, 2012; Padidar et al., 2016), most are unproven or long-term projects that are not suitable for immediate changes to the sector. As such, it makes more sense to evaluate the costs of increasing the irrigation input to current agricultural land.

Libya is already experiencing increased demand for water, from 5.5 billion m^3 per year in 2010 to 7 billion m^3 in 2019 (Laessing and Elumami, 2019). This corresponds to a 2.67% yearly increase in the irrigation input already demanded. In order to achieve a unit percent increase in the GDP, an 6.84% increase in the irrigation input is necessary. This can be accomplished by increasing the capacity of the GMMR, which bears the costs of additional pipe structures, pumping machinery and associated facilities. Another method to increase the irrigation supply would be the construction of and improvements of desalination plants on the coast, perhaps coupled with importing water from neighboring countries.

Based on Libyan estimations of water demand carried out in 2019, the cost of water transported by the GMMR was USD2010 0.28/m^3 as estimated by secretary of the People's Committee overseeing the GMMR's management and implementation (Luxner, 2010).[7] With a needed increase of 6.84% (table 6.1) or 0.376 billion m^3 of irrigated water supplied by the GMMR to obtain a unit increase in GDP, the cost is estimated at USD2010 105.3 million. On a per cubic meter basis, Allafi (2014) reported the costs of groundwater extraction were less than one-eighth of the total cost of either desalination or import methods. However, this does not account for the costs associated with future investment in construction and repair of the damaged pipelines and pumping stations that will need to be addressed, or the reconstruction of the desalination plants that have also been taken offline and fallen into disrepair due to the conflict.

[7]External estimates of the water cost for GMMR water range from USD 0.90 to USD 2.50, with the higher value accounting for inefficiency from not running at full capacity, reported in Heemskerk and Koopmanschap (2012), but without detail on the method of estimation.

The question of whether or not the GMMR should be repaired once the conflict ends is unlikely to be asked. Given the GMMR also supplies a large portion of the available water for the residential sector, the repair of the pipeline is already a forgone conclusion, meaning such costs should not be a factor in determining the best budgeting for the repair of agricultural sector. Even if the cost were to be factored into the decision, there is no current knowledge of the damage caused to the GMMR, mostly due to the lack of security conditions, where surveys and evaluations of the damage have not yet been carried out according to the Chairman for the Statistics and Census Authority (A. Al-Alaq, personal conversation, October 17, 2020). Furthermore, these costs represent the repair of physical capital used only in transport of the environmental resource; there has been no observed destruction or loss of the environmental resource itself.

A conservative estimate of the repairs to the GMMR is USD 1 billion,[8] which represents 3% of the total investment into the GMMR project since its inception. Under a linear model with an expected lifetime of 100 years (standard for cement pipes), the annualized cost is USD 10 million per year. This value does not specifically incorporate a 1% increase in the GDP for irrigation (corresponding the USD 105.3 million estimate of increased water use) but comes as a condition of using the GMMR in a functional capacity to transport the water.

6.1.3 Costs Associated with increasing Labor Input

The largest elasticity parameter stems from the Labor variable, suggesting that it has the largest impact, on a percentage increase basis, where a 0.76% increase in the Labor input corresponds to a unit percent increase in the output GDP. Prior to the conflict, the legal minimum monthly wage in Libya was 450 Libyan Dinars (LYD) (Abuhadra and Ajaali, 2014). Currently, migrant agricultural laborers receive elevated monthly wages accounting for the low number of available workers estimated between 300 and 1200 LYD, though this

[8] This estimate is based on the large number of wells rendered nonoperational due to the conflict (M. Al-Majbry, Deputy Minister for the Ministry of Water, personal communication, October 30, 2020), the damage in the reconstruction of the pipe production facility damaged by the NATO bombing, and other expected repairs and maintenance stemming from the conflict.

includes weekend work (WFP, 2020). The conflict has had important implications for the labor market where migrant workers composed a large proportion of the total labor force in agriculture. Coupled with the fighting and insecurity, the disappearance of many migrant workers and the depressed value of the LYD has pushed up wages, causing new challenges for local farmers already strained in other areas (FAO, 2017). Native Libyans, prior to the conflict, were also further subsidized and would bear additional cost in increasing the labor force (FAO, 2017). Using pre-conflict wages and current employment levels (approximately 260,000 workers), the cost to increase the Labor input to production by 0.76% will require the addition of nearly 2000 new workers, at a cost between USD2010 5.1 and 20.5 million annually for some mix of native and non-native labor. This assumes the wages will revert to the pre-conflict level once the conflict subsides.

6.1.4 Summary of Cost to Increase GDP

Once Libya moves into the post-conflict stage, maximizing the impact of recovery policy will depend on the structural corrections. These corrections reflect the time dependent values of the output elasticities after the system shock.

Once conflict has ended, overall structural changes to the agricultural sector are expected. However, the pre-conflict conditions are the best indicator of what Libya is capable of, especially with the uncertainty on what future structural changes within the sector will occur. Under an assumption of an immediate return to pre-conflict elasticity values, the estimated costs for each of the 5 primary input variables are presented in table 6.2. Results suggest the greatest benefit to the GDP on a per investment dollar basis will come from an increase in the fertilizer, even though the highest elasticity is associated with the Labor variable.

Table 6.2: Annual Input Costs to Increase the GDP by 1% Post Conflict, Assuming Elasticity Parameters revert to Pre-Conflict levels

Input	Cost (Million USD)
Fertilizer	0.896
Labor	5.1 - 20.5
Irrigation	115+
Machinery	20 - 150
Land	NA

While the information listed in table 6.2 relates the associated input costs to gain an effective 1% increase in the output GDP, these numbers only apply for small changes in input quantity where the relationship is approximately linear. Deviations from the linearized estimation become more pronounced from the underlying non-linear relationships with the output product. This is further complicated by not accounting for complementary inputs in the analysis, such as the need for increased water usage that would accompany an increase in fertilizer consumption.

However, these results are consistent with the expectations for Libya. As the land quality for the country is poor, there is little doubt that fertilization is a path to increased productivity. However, it would also be incorrect to assume increasing fertilizer use across the board would be effective. There are numerous references to the current overuse of fertilizer within Libya, (FAO and IAEA, 2007; El-Barasi et al., 2010; Gauthier Fatima et al., 2011). Furthermore, the random application of fertilizer without consideration of the soil type may not offer any production advantage for the local area. The efficient addition of fertilizer is also coupled with the experience and knowledge of the farmers making use of the input, which this study does not investigate.

6.2 Observed Environmental and Ecological Impact

One of the more directly observable changes to the agricultural production are conflict's impacts on the environmental capital, consisting of the Land and Irrigation (water) capital components. Conflict's impact on the land component is expected to include both the use of unexploded ordnance[9] and a general shift of cultivation to lower quality lands that are in more secure locations. The water component is sourced from groundwater in remote locations through the GMMR. Sitting on the largest known fossil water aquifer, the Nubian Sandstone Aquifer, the water is both plentiful and costless in direct terms. The water is not directly threatened by conflict, but the GMMR is affected as the method of conveyance. This infrastructure transports over 70% of the bulk of irrigation from the underground sources in Fezzan, Al Khufra, and Al Sarear to the rest of Libya. The water infrastructure has suffered greatly under conflict since 2011 as an attractive target for deliberate attacks by armed groups, theft, vandalism, and the corresponding poor maintenance from weakened security from the conflict. This damage is to physical capital and clearly impacts the conveyance of irrigation but leaves the water source undamaged. While conflict may impact the use rather than directly damage the environmental capital itself, there are other environmental damages that are induced by the conflict that should be considered when developing a post-conflict agricultural policy for Libya.

There are several direct and indirect adverse ecological impacts that can be traced to the conflict in Libya, but that are not included in my model because their impacts on GDP are difficult to determine and do not funnel through agricultural production. Indirect impacts from conflict usually arise based on the disappearing governmental authority exercised as the conflict continues. Some problems are merely consequences of issues that existed before the conflict. Decades of poor environmental management within Libya are tied into an increase in pollution from the oil and petrochemical industries. The rise of conflict has seen the

[9] Unexploded ordnance includes bombs, rockets, grenades, and ammunition.

explicit targeting of oil storage facilities and pipelines (see fig. 6.1), increasing pollution problems that damage both the local land and to a larger extent, air and water sources.[10]

Figure 6.1: Jan 2016 - Damages to oil facilities as different factions clash, leading to localized land damage and impacts to larger surrounding water and air. Source : NASA/Sentinel-2

The damages to the oil facilities and pipelines also have secondary environmental impacts. For example, officials for the National Oil Corporation of Libya have raised concerns about widespread environmental pollution as warring factions have disrupted the natural gas production leading to utilities to switch to the more accessible but less environmentally friendly diesel fuel (Musa and Debre, 2020). While the losses due to pollution are evident, the continued conflict will likely induce further damages such that the true extent of environmental impacts cannot be clearly defined until long after the conflict has ended.

[10]Oil fires release several soil and water contaminants including sulphur dioxide, nitrogen dioxide, polycyclic aromatic hydrocarbons and lead (Zwijnenburg, 2018).

The conflict also impacts environmental resources such as wildlife. Hunting, for example, has increased dramatically in Libya after 2011 due to increase in availability of weapons and the disappearance of governmental control. The absence of oversight and the development of food insecurity has caused additional pressure on local wildlife[11] populations, leading to many images demonstrating over-hunting within Libya, such as seen in fig. 6.2 (Zwijnenburg, 2016; Alhadaf-News, 2020.).

Figure 6.2: The over-hunting of gazelle has put additional pressure on wildlife stocks during the conflict. Source : Alhadaf-News, 2020

There are three main effects on the local wildlife that are induced by conflict. First, the lack of government oversight leads to issues such as over-hunting, hunting during mating season, and greater likelihood of killing the healthier members of the wildlife stock. A second

[11]e.g., gazelle, hares, lizard and foxes

issue is the migration of wildlife out of the conflict area which reduces available capital stock. The third effect stems from the government and non-governmental organizations (NGO) inability to support the wildlife population. This support includes rehabilitation and re-population programs that are unmanageable due to the conflict. Each of these impacts leads to a local disruption of the ecosystem capital within Libya which will take years after the conflict to recover.

The damages to the wildlife are not limited to land-based wildlife stocks. There has been a noted rise in the use of blast fishing, where old munitions are combined to form explosions. While officially against the law in Libya, conflict has drawn away the focus in preventing the use of explosives for fishing. Damages to fishing stock comes from direct depletion, but also leads to the loss of fish row, larvae and sea plants (Taher, 2018). The economic value of such practices is questionable, as the blasts damage the skin of the fish and further damage the local underwater environment. This problem comes partly from the historically foreign labor force within the fishing sector, which fled the country due to the conflict. Few Libyans have been willing replace these workers, often using easier methods such as blast fishing to make up for minimal experience in fishing to increase their income.

The weak application of governmental control over regions outside of population centers has impacted more than just wildlife and fishery stocks. The breakdown of authority has led to the neglect of other environmental actions such as pest control. Before the conflict, the government tightly controlled Libya's locust population by regularly monitoring environmental conditions and enacting pest control actions to prevent locust swarms ("Gaddafi's Fall Leads to Desert Locusts' Rise", 2012). These swarms destroy both croplands and vegetation needed to support grazing livestock and wildlife. Based on the heavier rains shortly after the conflict began led to a desert locust outbreak in Libya. The turmoil from government failed to prevent the early response to these locusts, and also hampered the actions of external organizations such as FAO attempting to minimize the severity due to a weakened security situation ("Countries in Emergency : Libya", 2012).

Another ecological impact stemming from the absence of applied governmental authority is deforestation. Without the local control, some public land has been seized in the confusion brought on by conflict. Such actions have partly been associated with the loss of forest area in the Aljebel Alakhdar.[12] Alawamy et al. (2020), used GIS and remote sensing techniques to observe the land-use land-cover of the region between 1985 and 2017. The authors concluded that there has been a loss of over 9,000 hectares (ha) in that time, with more than half of the total loss happening between 2010 and 2017. Of the average loss of over 500 ha/yr of deforestation during the conflict period, nearly 40% is associated with urbanization, which is also highest during the conflict period (Alawamy et al., 2020). The remaining deforestation rate is accounted for by the gains in agricultural land. There may be some competing explanations for why this has occurred, none of which are mutually exclusive. The conflict may have driven some out of high population areas for security concerns, there is the possibility of armed factions setting up residence in the region where with less government interaction, or the urbanization is associated with land grabbing while the government is in disarray. Regardless of the actual situation, the environmental damage has been increased due to conflict's reduction of the local government authority.

6.3 Lessons of Conflict Impacts from Other Countries

There are several remaining questions regarding the recovery of the Libyan agricultural sector in the transition and post conflict periods. Fundamentally, these center around the following:

- How long is the transition period after conflict ends to start seeing a recovery?
- Will there be a significant jump in the Agricultural GDP after conflict, possibly describing a reversion to pre-conflict elasticities?
- What growth rate, if any, is expected in the agricultural GDP after the transition period?

[12] The Green Mountain.

- Is it possible to close the gap between the pre-conflict and post-conflict trajectories, and what are reasonable expectations for the duration?
- What post-conflict actions (agricultural policies and programs) will likely be successful in promoting the growth of the Libyan agricultural GDP?

Since these questions are all based on future developments in Libya that are unknown, I rely on observations of other countries that experienced conflict in the modern era. I limit the observations to include countries that have experienced civil war conflict with a duration of at least 10 years, where the conflict was resolved after 1990, and any transition/post-conflict period has not seen a resurgence of large - conflict for at least 15 years after the end of the original conflict. The 15 countries satisfying these conditions are shown in table 6.3, along with the dates and official duration of their conflicts, the average relative contribution of the agricultural sector to the total GDP, the predominate climate of the region and if there was a fundamental change in the government from the pre-conflict to the post-conflict period.

Table 6.3: Characteristics of countries experiencing conflict. (FAO, 2020)

Country	Conflict Period	Ag. Share GDP[a] (%)		Climate	Government Changed
Algeria	1991-2002	9.8		Arid	No
Angola	1976-2002	7.2		Tropical	No
Burundi	1993-2005	46.4		Tropical	Yes
El Salvador	1979-1992	18.0	(5.0)	Tropical	Yes
Ethiopia	1974-1991	45.7		Varied	Yes
Guatemala	1960-1996	20.0	(12.0)	Tropical	Yes
Lebanon	1975-1990	4.6		Subtropical	No
Malaysia	1962-1990	16.0	(10.0)	Tropical	No
Mozambique	1975-1992	25.8		Tropical	No
Nepal	1996-2006	43.5		Varied	Yes
Nicaragua	1970-1990	17.0		Tropical	Yes
Peru	1980-2000	9.5	(7.0)	Varied	Yes
Sierra Leone	1991-2002	44.3		Tropical	Yes
Sudan	1983-2005	33.9		Arid	Yes
Yugoslavia	1991-2001	8.4		Varied	Yes

[a]Numbers in parentheses indicate the average % Ag. GDP share over the last 10 years for countries that have less stable GDP shares in recent history.

Table 6.3 includes a variety of local conditions present for conflict countries that have some overlap with Libya's current experience. Algeria, for example, has conditions that are the most similar to Libya in terms of climate and oil sector dominance. This table is not meant to be authoritative, as there are some underlying details not fully expressed within the table.[13] The duration of conflict can relate to years of lost agricultural production. Each

[13]For example, Sudan split into two countries due to the conflict while Yugoslavia separated into 6 autonomous regions just prior to the conflict which provides an interesting ability to compare the impacts of different policies across different regions starting from the same divergent point in time and closely related agricultural practices. The agricultural share of GDP is taken as the average over the period from 1970-2018 where the data is available, though this is sparse for some countries. In particular, El Salvador, Guatemala, Malaysia and Peru have experienced more recent declines in agricultural share, meaning the listed average agricultural share is higher than the last 10 years average. The column indicating governmental change is subjective and determined if there are fundamental differences between the post and pre conflict administrations, such as the development of a new constitution.

country's share of the agricultural GDP, calculated as the average of available data from the WB between 1970 to 2018, references the significance of the sector to the economy. This in turn may reflect the effort put into rebuilding the sector once conflict has ended. In some cases, particularly El Salvador, Guatemala, Malaysia and Peru, the agricultural share of the GDP has decreased over a wide range from the beginning of the study period. In each case, a smaller average of the last 10 years is also included and shown in parentheses. Including the climate in each country can put post-conflict agricultural policies related to climate in perspective. I have also included whether the government of the country underwent fundamental change over the course of the conflict. This might be important in understanding whether new governments have increased delays and early inefficiency problems in the agricultural sector until the administration settles in.

Most of the countries listed in table 6.3 have decreasing agricultural shares of the total GDP, with the exception of Sierra Leone, which has seen an increasing agricultural share in recent years. Many different climate types in the countries are represented, though more often in arid and tropical regions. In most cases, the countries experience fundamental changes within the government. This is expected since civil wars are the most likely event leading to changes in government identity and function.

The factors in table 6.3 only allow the most cursory comparisons to Libya that have similar local conditions. However, other factors have influences on the recovery. Some of these factors include the nature of the conflict (e.g., political, religious, or ethnic), involvement of intrastate actors and governments in the conflict or recovery, governmental support and investment in the agricultural sector, relative economic significance and health of the agricultural sector before the conflict, the dynamics related to the export crops in the post-conflict period, and the post-conflict agricultural policies.

In tables 6.4 and 6.5, I list the agricultural growth profiles of the conflict countries. The purpose is three-fold. First, examining the early agricultural sector growth before and in the shift to conflict can detail if there are similar underlying conditions for Libya. This may reveal which of the conflict countries are better comparisons to Libya for the immediate impact of conflict. Second, examining the experiences of other countries provides an envelope of feasible agricultural sector responses in the post-conflict period. Third, the post-conflict trajectories of the listed countries have practical implications for Libya. Countries that experienced weak and delayed growth may set examples of practices and policies that should be avoided for Libya, while countries that show strong growth and convergence to the pre-conflict trajectory may provide insight into policies that should be emulated.

Table 6.4: Agricultural GDP growth and change for conflict countries

Country	Duration (years)	Pre-Conflict Annual % Growth	Early Conflict %[a] Change	(Exp[b])	Early Post-Conflict % Change[c]
Algeria	11	3.4	17.8	(14.3)	28.7
Angola	26	3.4	-8.8	(14.3)	24.6
Burundi	12	2.2	-10.1	(9.1)	1.9
El Salvador	13	2.3	7.8	(9.5)	-0.5
Ethiopia	17	1.8	1.3	(7.4)	8.3
Guatemala	36	N/A	N/A		9.2
Lebanon	15	7.0	-54.5	(31.1)	65.3
Libya	N/A	3.5	-73.7	(14.8)	N/A
Malaysia	28	N/A	N/A		4.9
Mozambique	17	4.2	14.2	(17.9)	11.1
Nepal	10	2.2	12.4	(9.1)	8.4
Nicaragua	20	N/A	N/A		1.6
Peru	20	-0.4	3.0	(-1.6)	25.4
Sierra Leone	11	2.8	-13.5	(11.7)	47.4
Sudan	22	2.3	-4.85	(9.5)	16.9
Yugoslavia	10	1.0	-41.2	(4.1)	2.6

[a]This value is the % change between the GDP averages of three years before conflict to three years after the conflict begins.

[b]Numbers in parentheses indicate the expected Ag. GDP growth calculated from a 4-year period at the pre-conflict growth rate. For example, in Algeria with a pre-conflict growth of 3.4%, the equivalent 4 year growth rate is $1.034^4 - 1 = 0.143$

[c]This value is the % change in the GDP averages of three years before the end of conflict to three years after conflict ends.

Table 6.4 presents the pre-conflict annual growth for each of the conflict countries, including Libya, based on agricultural GDP data collected from FAO. This growth rate was estimated using agricultural GDP data from the earliest recorded value up until two years prior to the conflict with the compound growth model, when available. The decision to not include the year prior to conflict is to minimize any impact of local conditions that were likely contributors to the appearance of conflict. A higher pre-conflict agricultural growth rate both implies strong sectoral development, but also makes it more likely that the post-conflict period will never converge to the pre-conflict trajectory since doing so would require even larger sector growth rates.

Another useful piece of information is the early impact of conflict on the agricultural GDP in table 6.4 as illustrated in fig. 6.3. This was estimated as the percent difference between the averages of the agricultural GDP before the conflict, and the first three years average starting the year after conflict began. Counterintuitively, many countries experiencing conflict had agricultural sectors demonstrating net positive reactions in the agricultural GDP. This neglects the predicted growth that would be observed using the pre-conflict growth rate, shown in parentheses in the same column. El Salvador, for example, would expect a change in agricultural GDP over four years of 9.5%[14] had the conflict not happened and growth continued on the pre-conflict trajectory. Since the measured change in GDP is 7.8%, El Salvador is still negatively impacted by having less net growth compared when compared to the pre-conflict growth path.

The early post-conflict change presented in table 6.4 is calculated in a similar manner to the early conflict change values. This value is the change in the agricultural GDP between the average agricultural GDP of the three years before the end of the conflict and the three years following the end of the conflict.

[14]This amount is determined by taking the pre-conflict growth rate of 3.4% and determining the equivalent growth over a 4 year period.

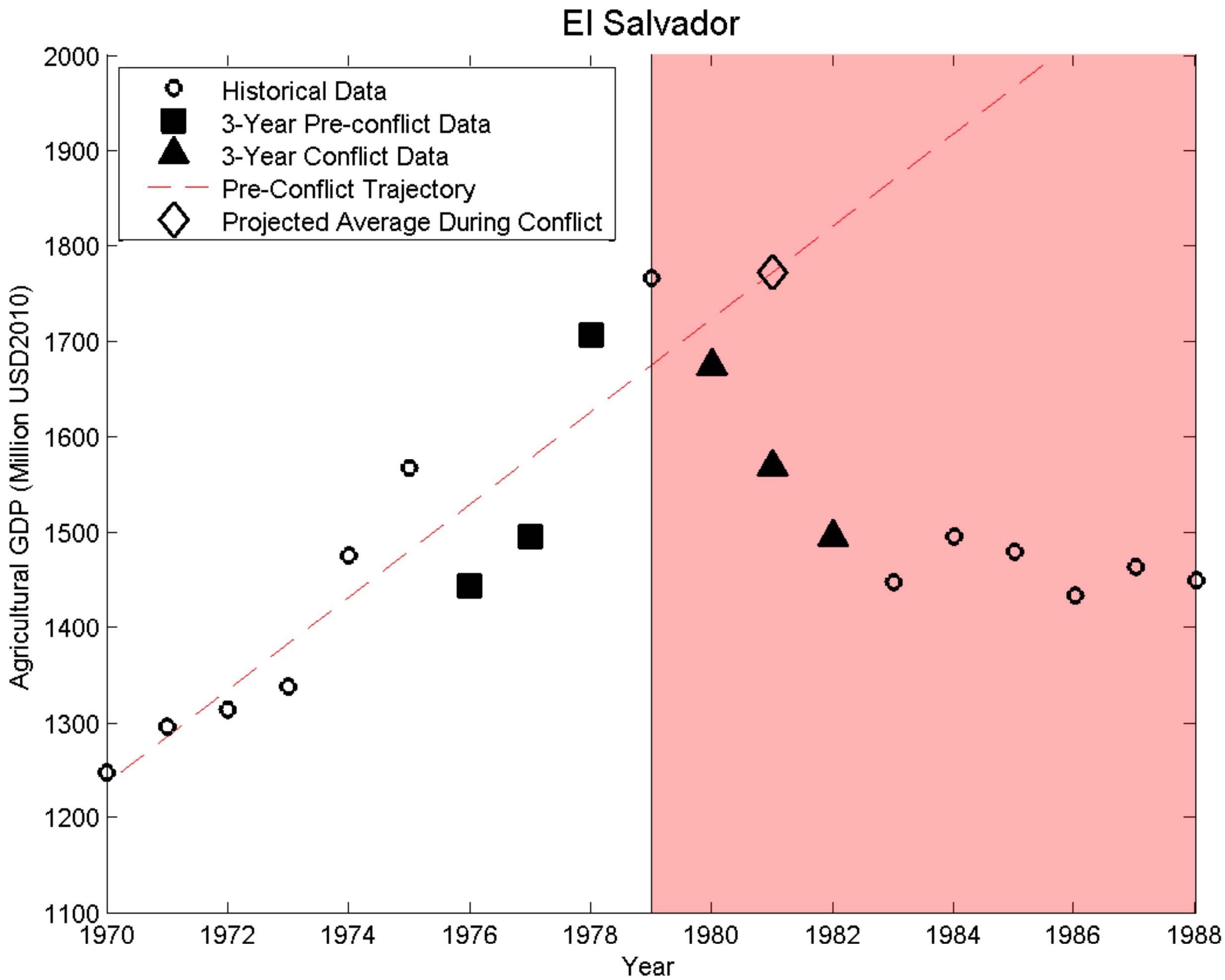

Figure 6.3: Agricultural Data for El Salvador both before and during conflict, shaded in red. When calculating the early conflict GDP % change, the average of the three years before conflict (squares) and the average of the first three years of conflict (triangles) are compared. The expected GDP following the pre-conflict trajectory into the conflict period at the point where the early conflict effect is measured is also shown (diamond).

Both Libya and Lebanon have experienced heavy production losses in the early conflict period; the agricultural GDP change was more pronounced than any other country. The agricultural GDP change for the country as it exits the conflict period helps identify if the conflict still has a lingering impact on the sector. Similar to the early conflict agricultural GDP change, this is calculated as the percent difference between the average of the three years prior to the end of conflict to the average of the three years after the end of the conflict. The GDP change in the early post-conflict period was large for some countries, particularly for Lebanon and Sierra Leone. However, a majority of countries had less than the expected change again based on the pre-conflict growth rate. With the exception of Burundi and Yugoslavia, countries like Libya that experienced an early loss in GDP when the conflict began, saw a large rebound when the conflict ended.

For some countries, the rebound following conflict was weak. This is linked with the existence of a transition period after the conflict, where transient changes still exist. As indicated in fig. 6.4, a transition period is not guaranteed. Many countries successfully begin on a long-term growth path shortly after the cessation of conflict.

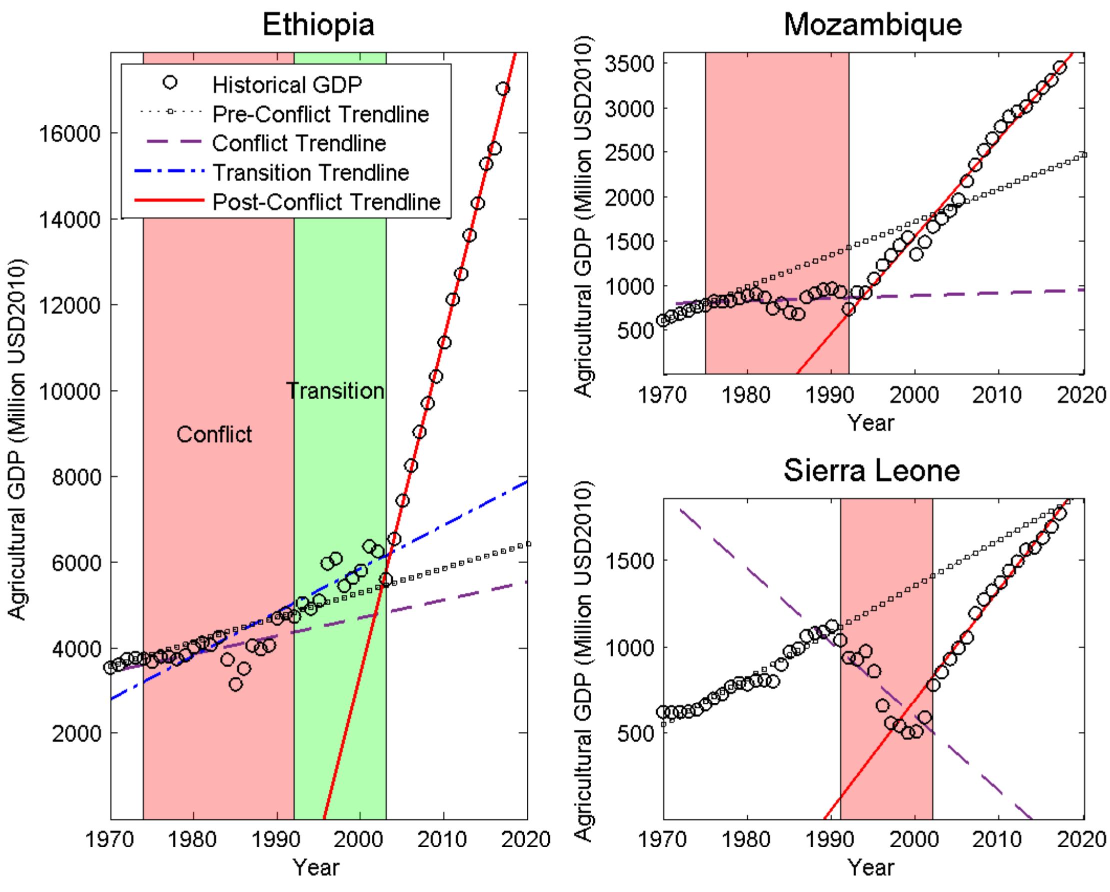

Figure 6.4: Agricultural GDP for Ethiopia, Mozambique and Sierra Leone. The conflict period (left shaded) is not a guarantee of declining production as it has been in Libya. A transition period (right shaded) after the conflict but before an established long term growth is likewise possible as shown for Ethiopia, but was non-existent for Mozambique and Sierra Leone. For each sub-period (Pre-Conflict, Conflict, Transition, Post-Conflict), a trendline has been included to demonstrate the changes in agricultural growth during the different sub-periods.

Looking closer at these specific conflict countries in fig. 6.4 indicates some possible future trajectories for countries coming out of conflict. In each image, the trendlines corresponding to the pre-conflict growth path, the conflict growth path, transition path (if it exists), and the future growth path are shown. As of now, Libya's profile most closely resembles Sierra Leone's historical trajectory, with a strong marked drop in the agricultural growth at the onset of the conflict. These figures should provide some optimism for Libya's future, as they point to likely increased growth rates exceeding the pre-conflict rate in each case.

Commonly, the transition period is marked by continued weakness in the sector that eventually changes into sustained long-term growth. Both of these features (the existence of a transition period and the long-term growth rate) determine how long the expected convergence of the post-conflict agricultural GDP to the pre-conflict trajectory. This information is presented in table 6.5.

Table 6.5: Agricultural sector recovery in post-conflict period

Country	Transition period (years)	Post-conflict Long-term Annual % growth	Convergence period (years)
Algeria	0	5.1	0
Angola	0	7.8	14
Burundi	6	0.8	∞
El Salvador	4	2.2	∞
Ethiopia	11	7.7	13
Guatemala	0	3.0	N/A
Lebanon	3	1.6	∞
Malaysia	10	2.6	N/A
Mozambique	0	5.4	11
Nepal	0	2.9	0
Nicaragua	0	3.8	N/A
Peru	0	3.4	0
Sierra Leone	0	5.0	35
Sudan	0	3.2	0
Yugoslavia	5	-0.1	∞

Table 6.5 describes possible future paths for Libya based on the experience of other conflict countries that have an observable post-conflict period. The first consideration is whether Libya should expect to have a transition period (marked by either instability or by non-growth) following the official end of the conflict leading to the recovery period. Most of the observed countries did not experience a transition period and instead demonstrated stable, long-term growth immediately when the conflict ended. The longest transition period is 11 years in Ethiopia, but this was followed by the strongest long-term post conflict agricultural GDP growth. The length of a transition period could indicate the level of success of post-conflict agricultural policies or the confidence in the area not returning to conflict.

The long-term post-conflict growth listed in table 6.5 is based on the stable growth of the agricultural sector. This measurement is dependent on the period of growth for each individual country, but is measured using no less than a period of 8 years. The estimates for different conflict countries provides an expected envelope of Libya's future growth. Both Angola and Ethiopia experienced the largest long-term growth rates, with Yugoslavia[15] and Burundi on the low end. The long-term post-conflict growth rates listed provide a bounded feasible region of growth that can be expected in post-conflict Libya. While it is possible to escape this feasibility region, it would not be expected.

The post-conflict growth rate partially affects the convergence period, the length of time after the conflict ends where the agricultural GDP crosses the pre-conflict trajectory. The convergence period appears to fall under a few categories. Some countries have met or exceeded the pre-conflict trajectory when the conflict ended, such as Algeria and Nepal. Others, like Burundi and El Salvador, do not appear to be on a convergent path, unless future changes lead to increased long-term growth. In between these two extremes are countries that demonstrate early convergence, on the order of 10-15 years before convergence, late convergence, more than 30 years after the end of the conflict.[16] Countries that had no convergence were characterized by having gains throughout the conflict period itself, but often are not associated with the largest long-term agricultural GDP growth rates, which are instead associated with countries having early convergence.

I find it more likely than not that Libya will experience a transition period where the agricultural GDP is not on a stable growth path. This is a consequence of the likely governmental priorities to focus on the rebuilding of the oil sector. The oversized importance of the oil sector and the underdevelopment non-oil sectors nearly force this prioritization to generate sufficient revenue for all governmental function. Furthermore, outside of agricultural ministry, there is little interest in bolstering agricultural production in the short term; the calculus for those making decisions regarding the agricultural sector will likely conclude efforts are better spent in repairing the oil sector and to import food, rather than invest in a

[15]Here, Yugoslavia refers to the aggregate growth of Bosnia, Croatia, Macedonia, Montenegro, Serbia and Slovenia.

[16]Sierra Leone, the only country with this expected late convergence, required linear extrapolation to estimate the actual convergence point. All other convergence periods are the observed convergence period.

historically weak sector. Furthermore, the value chains that were present during the Gaddafi era necessitated direct governmental intervention in procuring many of the inputs to production for distribution. Should the future government not continue the practice, the lack of private sector development will further inhibit rehabilitation of the sector. The involvement of foreign aid and outside agencies, although needed, will be undercut by governmental indifference.

Back in chapter 1, an estimated plot showing the possible future paths of Libya was presented. A revised version accounting for the likely transition period assumed to end in 2025 is shown in fig. 6.5. The conflict induced elasticity changes measured in chapter 5 were several times larger in magnitude than the original elasticity parameters. The minimal amount of observations available characterizing the conflict period contributes to this by widening the error estimate. Since there is little certainty in how a transition period would present itself, I have assumed rather arbitrarily that the agricultural GDP in the transition period is stable. Sector production is unlikely to further deteriorate when order is restored; there is little more that could contribute to further production losses to the sector.

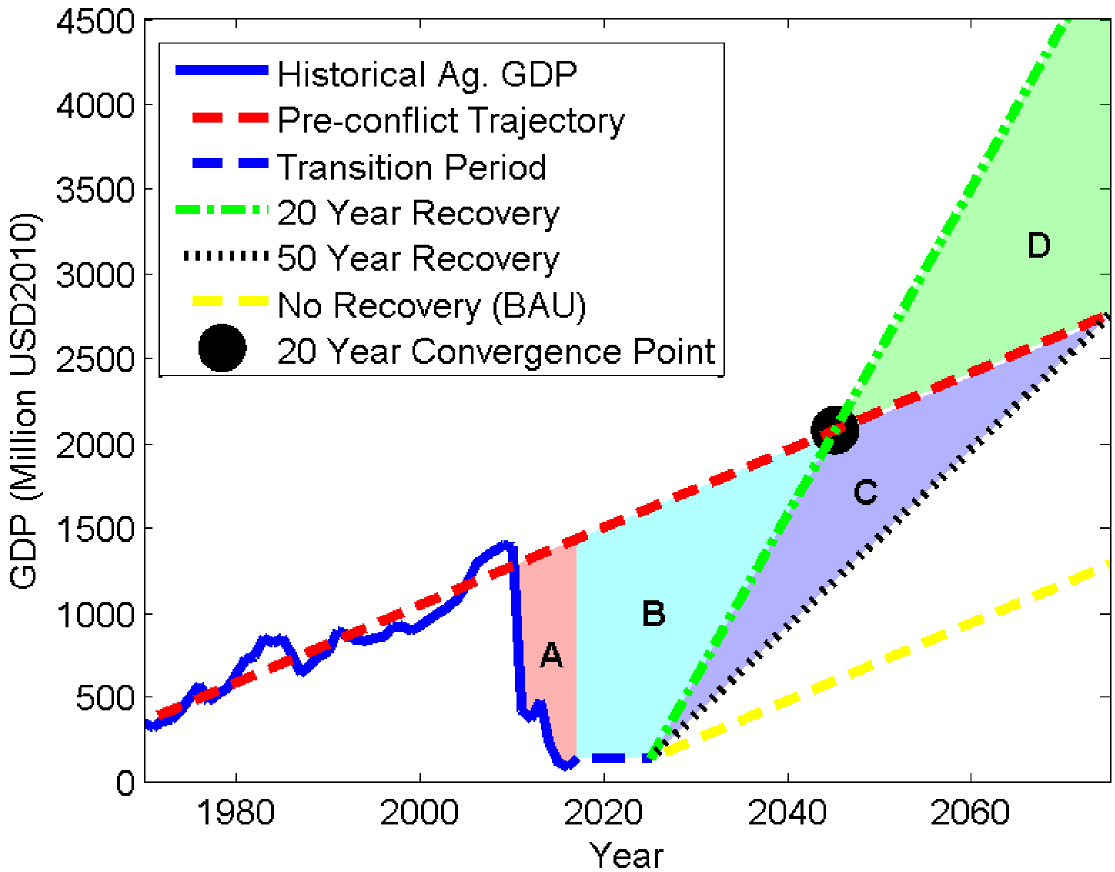

Figure 6.5: Possible future agricultural production profiles in post-conflict. Shaded areas represent the already observed loss (region A) that is independent of future scenario. A scenario dependent projected loss (region B) is shown for a transition period until 2025 and a 20 year period to reach the convergence point in 2045 where the recovery path intersects with the pre-conflict trajectory. Gains (region C) made after the convergence point reduce the net losses experienced before the convergence.

Each future scenario shown in fig. 6.5 is designated based on the period of convergence. Comparisons between the trendline slopes and the associated growth rates are given in table 6.6.

Table 6.6: Libyan pre-conflict and future scenario path slopes and growth rates

Trajectory	Slope (MM USD2010/Year)	Standard Growth Rate[a] (%)	Normalized Growth Rate[b] (%)
Pre-Conflict	22.9	3.5	3.3
No Convergence (BAU)	22.9	5.1	3.3
50 Year Convergence	52.3	7.1	5.0
20 Year Convergence	96.5	8.6	6.4

[a]Standard growth rates are computed from the average annual GDP growth rate for a period of 40 years, starting from 1970 or 2025 for the pre-conflict and future trajectories, respectively.

[b]Normalized growth rates are computed maintaining the measured slope over a duration of 40 years for each path starting from the same initial GDP value. The base GDP is set to the Libya's agricultural GDP in 1970.

Standard growth rates are calculated using the traditional compounding formula:

$$A = P(1+i)^n \tag{6.1}$$

where P and A are the GDP values at the 0^{th} and n^{th} years, respectively and i is the associated growth rate. For the pre-conflict period, the historical GDP was used to estimate the standard growth rate over a period of 40 years (from 1970 - 2010). Descriptively, the growth rate paths are represented by slopes, as shown in fig. 6.5.

Given that the future scenarios do not have an explicit end point like the pre-conflict, I have calculated the standard growth rate for these future scenarios based on a period of 40 years along the trendline to be consistent. However, the standard growth rate is dependent on slope, initial GDP and duration through the following

$$i = \left(\frac{mn}{P} + 1\right)^{1/n} - 1 \tag{6.2}$$

where m is the slope of the line as indicated in table 6.6. To compare the future scenarios directly to the pre-conflict trajectory, both the duration n and the initial GDP value are fixed at 40 years and 352 million USD2010 (the agricultural GDP in 1970) in calculating the normalized growth rate.

Accordingly, the required slope of BAU, 20-year recovery and 50-year recovery can be converted to a normalized growth rate that corresponds to the lower GDP starting amount and a 40 year future time frame. A BAU post-conflict path with the same slope as the pre-conflict path would not have the same growth rate for a forty year future; the equivalent growth rates would be 3.5% and 5.1%, respectively.

The process used to "push" a recovery path back to the pre-conflict trajectory (e.g., the 20- or 50-year scenarios) is to invest inputs. That is investments in capital or labor will be required to recover to pre-conflict levels. Even with recovery, there will be losses during transition, which are discussed below.

It is clear that Libya will not be among the countries that has immediate convergence due to the clear loss in agricultural GDP during the conflict and will instead likely follow one of the other three paths, either early convergence, late convergence or no convergence. Ideally, Libya will adopt agricultural practices to maximize the post-conflict growth leading to early convergence and minimizing the total losses induced by the conflict. Governmental focus on non-oil sectors will only begin in earnest once national authority is cemented and the oil sector is back to pre-conflict production levels.

Under the assumption that the recovery of the sector begins a long term growth path beginning in 2025 as shown in fig. 6.5, a 20 year convergence to the pre-conflict trajectory (red dashed line) will mark the end of loss accumulation (areas A and B). Should the long-term growth trajectory continue past the convergence point, there will be a net gain (area D) that will eventually negate the losses prior to the convergence point. The growth rate under this scenario is 8.6%, more than double the pre-conflict growth rate of 3.5%, but that is largely due to percent growth being dependent on a smaller starting GDP, thus requiring a larger percentage growth rate to compensate.

The losses and gains of the shaded areas represent the differences between the pre-conflict trajectory and the future GDP growth path. The losses represented by area A are already known. Additional losses depend on the length of the transition period and the long-term growth path (assuming a single growth rate after the transition period), where a 20 year convergence will have a loss region of A+B, and a 50 year convergence will have A+B+C. The gains made in area D are dependent only on the relative pre- and post-conflict long-term growth rates. For the different convergence scenarios with a transition period lasting until 2025 as shown situation in fig. 6.5, the opportunity costs (In terms of 2010 present value with a 3% discount rate) are tabulated below.

Table 6.7: Net losses as opportunity costs for shaded areas for 20 and 50 year convergence including a transition period until 2025.

Shaded Area	Loss (Billion USD 2010)	Year Range
A	-6.65	2011 - 2017
B	-18.4	2018 - 2045
C	-11.3	2025 -2075

The losses of the shaded regions are in the tens of billions of USD2010 under even the best-case scenario. If the long-term growth rate continues past the point of convergence (under the 20 year convergence) it is possible to negate the opportunity cost. Although Libya would be back on track with the pre-conflict trajectory 34 years after the start of the conflict, it would only recover 150 years from the initial conflict in this optimistic scenario when accounting for the present discounted value and under maintained growth. Similar calculations are obtained for the other scenarios and are summarized in table 6.8. The more conservative 50 year agricultural growth path further illustrates the deep impact expected on the agricultural sector, with total losses nearing USD2010 36.3 billion, without the possibility of recouping the opportunity costs. Should the sector growth continue on following the BAU path, the losses will become embedded, accruing 1.47 billion USD2010 per year while never catching up to the pre-conflict path. At a 3% discount rate, the net present value of such a perpetuity is USD2010 49.0 billion.

Table 6.8: Summarized Scenario Losses and Opportunity costs

Future Scenario	Loss (Billion USD2010)		Present Discounted Value:2010 (Billion USD2010)	Break Even Year
	Region	Total		
20 Year	A+B	32.0	25.0	2155
50 Year	A+B+C	54.1	36.3	∞
BAU	N/A	1.47 per year	49.0	∞

Whether Libya follows one future agricultural growth path or another is partly dependent on the administrative steps taken at both the national and local level to curb the greatest losses already expected. Part of the purpose of examining countries that have experienced conflict in the past is to observe both beneficial and detrimental agricultural programs and policies leading to successful reformation and development of the agricultural sector in the post-conflict period. The ideal country to emulate would exhibit large post-conflict long-term growth, a short-lived transition period, with an observable impact on the agricultural GDP during conflict. During the conflict, no effort to improve the agricultural sector is expected, while damage to the sector is possible. This suggests that in the absence of agricultural intervention, the post-conflict growth rate will be equal or below the pre-conflict growth rate. It is therefore assumed that successful policies translate into larger differentials between the pre- and post-conflict growth rates.

Table 6.9 shows the ranking of 10 of the conflict countries,[17] along with the agricultural policies enacted in the early post-conflict period as reported in the literature. The ranking is based on the difference in the GDP growth rate from the pre-conflict period to the long-term growth period. Special care should be taken when interpreting this information; it is likely that the reviewed literature focuses on particularly successful or particularly problematic policy decisions while other policy actions may not have garnered enough interest to be investigated. However, since the purpose is to establish effective policies, the loss of information on policies that were not largely important is a useful method for discrimination on policy effectiveness.

[17]Some conflict countries are excluded due to the absence of pre-conflict data to determine the change in long-term agricultural GDP growth rate (e.g., Guatemala), while Yugoslavia is specifically excluded since the division into six autonomous nations likely plays a role in the weakened production observed, rather than inherent agricultural policies.

Table 6.9: Change in long-term Growth Rates and Enacted Post-Conflict Policies

		Post Conflict Policies																		
	Δ GDP growth rate	Market Liberalization	Guaranteed Markets	Subsidies	Export Bans / Taxes	Credit and Loan Reform	Land Reform / Redist.	Env. Conservation	Infrastructure Construction	Infrastructure Modernization	Equipment Modernization	Food / Cash / Seed aid	Labor Reintegration	Forming of Cooperatives	Agricultural Research Support	Training	Institutional Reform	Sustainability Development	Precision Agriculture	Wildlife Support
Ethiopia	5.9	✓			✓	✓	✓	✓		✓				✓		✓			✓	
Angola	4.4	✓				✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓
Sierra Leone	2.2			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Algeria	1.7	✓							✓	✓			✓					✓		
Mozambique	1.2	✓		✓			✓	✓	✓	✓	✓	✓	✓					✓		✓
Sudan	0.9																			
Nepal	0.7	✓					✓		✓	✓							✓			
El Salvador	-0.1	✓					✓	✓	✓				✓	✓	✓		✓			
Burundi	-1.4			✓	✓			✓	✓	✓		✓			✓	✓	✓			✓
Lebanon	-5.4	✓	✓	✓		✓	✓	✓	✓			✓	✓		✓	✓		✓		

There are limitations in interpreting the qualitative information in table 6.9. The extent of the policies that have been marked reflect broad overall goals without specification of the scope, duration, appropriateness and breadth of application of the given policy. Inferences based on why certain policies were enacted can only be gained from further examination, which is beyond the scope of this work. As such, it can only be used to make casual, surface-level inferences on collective policy decisions. Caution should be used to avoid association bias when considering the policies in regions where there is strong recovery in the agricultural sector. Such policies may not be applicable to Libya.

In nearly every case, the literature reviewed would interpret the post-conflict agricultural policies as worse than expected in relation to ideal future scenarios. For the purposes of Libya, it is more important to examine the feasibility of improved production in a comparison with real world results rather than best-case but unrealized goals. Ethiopia and Angola both should be emulated for what was achieved, rather than for missing the targets on what was desired. Most commonly issues surrounding environmental capital (land reform and environmental conservation programs) and physical infrastructure were implemented as part of the post-conflict recovery.

One of the most striking observations of table 6.9 is the most and least successful countries in regards to improvement in long-term agricultural GDP is the similarity in using a wide range of policies. Countries that saw little change between the pre- and post-conflict growth rates enacted fewer policies in general. The cause of this might be attributed to the lack of scholarly interest where there was less change in agricultural growth before and after the conflict. Alternatively, it may also describe how enacting few policies is a recipe for returning to the status quo. This makes it difficult to associate particular policies with success, leaving Libya without a clear-cut path forward just based on past experiences from other countries that have experienced conflict. This is captured most clearly in a report published by FAO regarding the policies in Sierra Leone (again, interpreted as falling well short of idealized goals) where policies "never lacked good content" but instead were plagued by mismanagement and insufficient financial and logistical input to establish tangible productive agricultural activities (Kargbo, 2009).

The problems faced in each post-conflict country when looking deeper into the literature can be broken down into three main categories: endogenous, exogenous and future impact issues. Briefly examining these issues in the context of post-conflict recovery processes provides insight into issues Libya should consider when implementing its own agricultural policies.

Endogenous issues are internal factors that remain problematic in implementing policies. These issues include cultural factors impacting the efficiency and local acceptance of government authority. Strong changes in government following conflict periods may have pronounced problems in this regard. Recovery efforts are also hampered by residual weakened institutions. El Salvador, for example, encountered protracted problems under when working with "weak, inefficient or rigid bureaucracies" leading to outside interventions by the WB being restructured or cancelled outright (J. R. Eriksson et al., 2000). In Libya, other expected endogenous issues for policy include Libya's inability to produce many agricultural inputs leaving it dependent on imports, cultural resistance in the forms of Islamic religious bans on usury making loan instruments using interest untenable.[18] Loans offered by the Agricultural Bank of Libya (ABL) have historically charged service fees in place of interest based on the duration of the loan. Former policy at the ABL was to charge 1 % on overdue loans to drive timely payment. However, recent laws prohibiting collecting interest have effectively rendered the practice unenforceable and will need to be addressed for ABL to underwrite incipient loans. Historical expectations such as the long-term reliance on public sector employment and large wage differentials making agricultural labor less desirable will also need to be considered.

Exogenous issues affecting post-conflict reconstruction are beyond local governmental control. In Nepal, for example, this is highly problematic. Surrounded on both sides by

[18] There is high demand within Libya for shari'ah compliant financing lead to the Libyan General National Congress adopting a law in 2013 prohibiting interest on all transactions against the recommendation of the Central Bank of Libya as there was little knowledge of Islamic financial modes across Libyan firms (World Bank, 2020b).

China and India, two large protectionist regimes, Nepal has difficulty in competing the open market regardless of governmental policy (Poudel, 2011). Libya's primary exogenous issues stem around both the reliance on imports and more importantly, the price of oil to effectively fund government policies. This is further complicated by Libya's over-reliance on the oil sector and underdevelopment of other sectors making the country extremely vulnerable to changes in the energy market.

One primary concern for post-conflict countries is ensuring policies (particularly relief aid) limit the development of dependency that would otherwise stagnate growth once the aid is removed.[19] This is exacerbated with efforts by outside interventions by foreign governments, international governmental organizations (like FAO and the WB), and NGOs which may or may not be working in tandem with the local authority. While normally intending good, such external organizations can create problems by not shifting early enough from relief actions to development actions. In Sierra Leone, an oversaturation of NGOs had profound consequences, where the philanthropic models based on freely giving away goods and benefits served to increase financial vulnerability and economic dependence of the population (Herrera, 2017). Without the necessary motivation to develop, private business meant to replace the aid has too great a barrier to entry when competing with free goods and never has a chance to thrive.[20] The flow of food aid specifically can depress local agricultural food prices, incentivizing a reduction in agricultural production that can persist long after the aid has ended (Bovard, 1986). Note that since Libya has been a net food importer since long before the conflict, the concern should really be about increasing the amount of dependency (in relation to food), rather than in generating dependency at all. The dependency already existed in Libya, but an increase in dependency would mark a stagnation in the growth of the agricultural sector and the growing inability of Libyan's ability to meet their own basic needs.

[19]Literature regarding the effectiveness of foreign aid in development remains controversial. A brief discussion of the main theoretical camps is covered in S. Edwards, 2015.

[20]Peschka and Emery (2011) is recommended for a deeper look into the role of the private sector in the post-conflict period, along with constraints affecting the growth and development.

A second future impact concern is the relationship between the post-conflict country and other foreign governments in the post-conflict period. In exchange for development aid and conflict period efforts, the national authority may have negotiated away economic freedom in exchange. Countries like Libya with valuable and extractable commodities are more likely to experience this issue. In Libya, retaining economic independence has been a continual goal since the early Gaddafi-led government but only in the sense of oil production. Agriculturally, ceding control over resources is expected to be a non-issue due to the relative low-quality land available.

The takeaway for the experience of other conflict countries can be summarized as follows:

- Most countries experience a sizeable jump in agricultural GDP change in the early years after conflict, especially those where conflict induced a drop early on in the transition into conflict. This may be related to outside interventions.

- A period of transition after the conflict to establish long-term growth is not always guaranteed. Transitions that do occur are on the order of 5 to 10 years long.

- Long-term, post-conflict agricultural GDP growth ranges between -0.1 to 7.8%. This provides an estimate of expected growth to the Libyan agricultural sector after the conflict.

- Convergence to the pre-conflict agricultural trajectory is common, but not guaranteed. While in a few cases convergence is immediate, those instances required larger than normal growth of the agricultural sector during the conflict, which is not seen in Libya. Libya is more likely to experience short-term convergence ($\sim$ 10-15 years), long-term convergence ($\sim$ 35 years) or will never reach the pre-conflict trajectory.

- Using changes in long-term growth between the pre- and post-conflict periods as a measure of success in the conflict country, there are no distinguishing patterns between generalized policies employed for the most and least successful conflict countries. Instead, the common consensus in the literature is that all policies have good content, but successful implementations require sufficient governmental support, management, evaluation and follow up.

6.4 Policy Recommendations

A major concern at the end of any conflict is plotting the path forward in reconstruction. This is echoed in a statement from FAO about the challenges of beginning the post-conflict period, a country "cannot wait for a strategy to start addressing some priorities [...focusing on...] starting up new projects between government and the private sector, with a strong link to research and education" (Heemskerk and Koopmanschap, 2012). Regardless of which governmental authority assumes control in Libya after the conflict, focused policy objectives are needed to repair and strengthen the damaged agricultural sector. However, such policy decisions will likely occur over several years after the end of the conflict. The reality is the new government in Libya will likely see the agricultural sector as a low priority compared to repairing the oil sector which provides economic stability. Without available financing provided by the functioning oil sector, or the intervention from outside agencies, the agricultural sector will stagnate and remain deteriorated. However, many investigations also conclude that bolstering the agricultural sector is important beyond economic benefits, being able to absorb ex-combatants, improve food security and enhance livelihoods (Birner et al., 2010). The importance of involvement of the government in rebuilding and expanding the agricultural sector cannot be understated. Governments provide infrastructure, services and address market failures with long-term visions focused on the aggregate sector (Giordano, 2011). Many agricultural focused policies are of benefit to the sector and should be used in the early stages of recovery.

In this section, I establish specific policy goals, with broad policies that might be enacted to achieve these goals and their likely effectiveness in the case of Libya. The recommendations put forth are only a discussion in regards to the health of the agricultural sector, and should not be understood as beneficial to Libya as a whole. Policy makers will still have to negotiate between the importance of the agricultural sector's needs and within the larger context of a functional Libyan government, ensure aligned interactions between the governmental authority with outside foreign aid providers, and consider the realistic implications for Libya as a whole.

Before policies can be implemented, it is important to determine the issues surrounding the recovery period. An in depth look at the many problems existing during conflict are established in Rohwerder (2017), efficiently broken down into environmental, economic, governance and social issues, with those related to the situation in Libya summarized in table 6.10.

Table 6.10: Categorized Issues affecting Libya

Environmental	Economic
• Physical damage to land and water sources • Land contamination with unexploded ordnance • Infrastructure damage • Poor coping mechanisms and land degradation	• High repair and loss costs • Market and value chain disruption • Increased direct costs and reduced income • Absence of capital for reinvestment • Labor shift into other sectors
Governance	Social
• Disruption of programs supporting farmers • Increased dependence on foreign aid	• Labor displacement • Reintegration of ex-combatants

These issues will clearly not be resolved when the fighting stops and will remain during the rebuilding of the agricultural sector. Combined with the results of the regression analysis, several post-conflict policies can be recommended to strengthen the agricultural sector. Policy decisions based on the observed results can be grouped into the following general goals:

1. Short-term
    (a) Understanding sector inefficiencies
    (b) Rebuilding critical infrastructure (e.g. GMMR and roads) and institutions
    (c) Promotion of agricultural labor
    (d) Emergency interventions (Cash/Food/Seed aid, usually in conjunction with external assistance) and hazard removal (unexploded ordnance)
    (e) Improved sector regulations (including creation of monitoring and evaluation agencies for the agricultural sector)
2. Long-term
    (a) Reverse and prevent further environmental degradation
    (b) Improve education and training
    (c) Incentivize efficient use of agricultural inputs
    (d) Restructuring and redistribution of land
    (e) Development and improvement agricultural facilities (Production, storage and distribution)
    (f) Modernization and support of value chains
    (g) Partnering with international agencies
    (h) Increased agricultural investment

The main priority is to restore the agricultural sector by reducing the effective losses sustained by the sector due to conflict. This involves bringing the post-conflict GDP back to the pre-conflict level, which would require a a sustained higher growth rate. That is, the slope of the recovery must exceed the pre-conflict level in agricultural GDP growth (see fig. 5.4). This requires in part a change in the way the agricultural sector's overall mission is viewed. Prior emphasis in Libyan agriculture has been the promotion of food self-sufficiency. As communicated by the Deputy Minister of Agriculture, a more realistic goal should instead be the improvement of efficiency in exports and imports within the agricultural system (Heemskerk and Koopmanschap, 2012).

Many of the policy recommendations are based both on my experience as Director of Credit Department[21] and as Chairman of Fishery Committee,[22] both positions within the ABL. This information is largely supplemented based on interviews conducted by Heemskerk and Koopmanschap (2012) with Libyan agricultural officials, businesses and international organizations at the beginning of the conflict period.

6.4.1 Short-Term Goals, Challenges and Recommendations

In the short-term, the primary objectives for policy makers in the agricultural sector should be to provide relief, support private development and lay the groundwork for long-term sector growth.

Deficiencies within the agricultural sector predate the conflict, leading to weak production efficiency compounded by the absence of high-quality agricultural inputs. The conflict continues to both reveal and create new problems within the agricultural sector. While the conflict is unfortunate, the reconstruction post-conflict affords the opportunity to strengthen the agricultural sector by addressing the problems existing both before and due to the conflict. This should not be interpreted as a call for widespread and fundamental change in rapid succession; maintaining social order and security as short-term interests will be more important than the desired overall long-term goals of reform for the immediate future. There

[21]This position acted as oversight for all disbursements of agricultural loans. As part my duties, I would audit and review the economic and technical feasibility studies, introduce new credit instruments to service the agricultural sector and contribute to sector development, and take part in field visits to monitor and evaluate development progress.

[22]In this role, I would draft and report on the fishing sector to advise the Minister of Agriculture, including issues of capacity, technology, and overall health of the fishing, hunting and marine components of the agricultural sector.

should still be a carefully constructed path to enable a transition to these long-term agricultural goals.

Understanding Sector Inefficiencies

While the agricultural sector is small in comparison to the dominant oil sector, it remains significant as a form of rural employment. While this investigation is a step toward understanding the mechanisms affecting the agricultural sector, it also highlights the need for a deeper look into the inefficiencies based on the lack of meaningful data needed to put policy plans into action. For example, while this study has determined that labor elasticity is larger than unity for the sector, this is an aggregated look that does not examine regional differences, nor clarify if the value stems from the employment of foreign labor over native employment, neither of which is understandable using currently available data. Understanding the agricultural sector inefficiencies at a disaggregated level helps to pinpoint local weaknesses to address and fine-tune the policies for adaptive use within Libya. These may include different policies and programs for different sub-regions in Libya. Data collection is then important for two reasons. First, the data underscores the inefficiencies of the agricultural sector. Second, the only way to gauge the response of the adopted policies is to evaluate the change based on data both before and after the intervention.

The Libyan institutions in place already measure some necessary agricultural data. However, the data is not often granular enough to be of meaningful use to drive agricultural reform. Measurements are either too aggregated to extract information needed to address specific problems (as with the usage of fertilizer per ha), sparsely measured (such as the irrigation used for farmland being captured every 5 years), or imprecise (as found in the Labor measurements where the definition of worker is fluid in any given year). The measurements of the disaggregated inputs to production are needed to evaluate the inefficiencies that exist within the agricultural sector. This includes, for example, the active land use from all farming land plots, age and state of repair for large-scale machinery such as tractors, deeper profiles of farming labor including age, experience and level of employment within agriculture, among many other topics.

The absence of meaningful data for the purpose of improving the agricultural sector should not be construed to indicate a failing on the part of the institutions. Instead, it is an acknowledgement of the low relative importance of the agricultural sector (compared to the dominant oil sector) to the economy that diminished the necessity of acquiring useful data during the pre-conflict period.

It might be reasonable to assume that international agencies such as FAO would have the necessary data that drives policy decision. However, these agencies rely on information provided by the national government and often supplemented through unofficial sources or other agencies. Some governmental supplied agricultural data has exceeded external estimates by a large margin (Heemskerk and Koopmanschap, 2012), leading to questions of the accuracy of government provided data. While the discrepancy's underlying causes are beyond the scope of this paper, the impact is not. The data used to determine policy going forward needs to reflect the real situation in Libya and should be internally scrutinized before publication.

The policy used to address the weak data problem in Libya should accomplish three main objectives:

- Measure sufficiently disaggregated data
- Analyze and scrutinize both current and prior data collection
- Evaluate effectiveness of current policies to determine future agricultural reform

The primary problem for data collection in the past was the lack of authority given to the institutions charged with the data collection. Without governmental authority, responses were largely voluntary and self-reported, leading to the sparse data collection for long periods of time and questionable data reliability when available. Much of the collected agricultural data relies on self-reporting in the form of surveys, which have strong potential for inaccuracy.[23]

In order to analyze and scrutinize prior data sets and to develop good practices, the Statistics and Census Authority (SCA) needs a mandate from the National Security Authority (NSA) giving authority for the collection and dissemination of data for the agricultural sector. While the Ministry of Agriculture should direct the department regarding the methods and standards of data collection, oversight of the reported data should remain with the Chairman of the SCA to ensure data reliability and validity before publication.

One implementation of a desirable organizational structure incorporating the goals of data collection and oversight is shown in fig. 6.6.

[23]Consider, for example, the request for the herd size. The value reported may be influenced by the perceived intention of the question. If the question is based on tax liability, the estimate of herd size will be shifted downward. If the question is based on subsidy for feed, the estimate may be shifted upward (Abay et al., 2019).

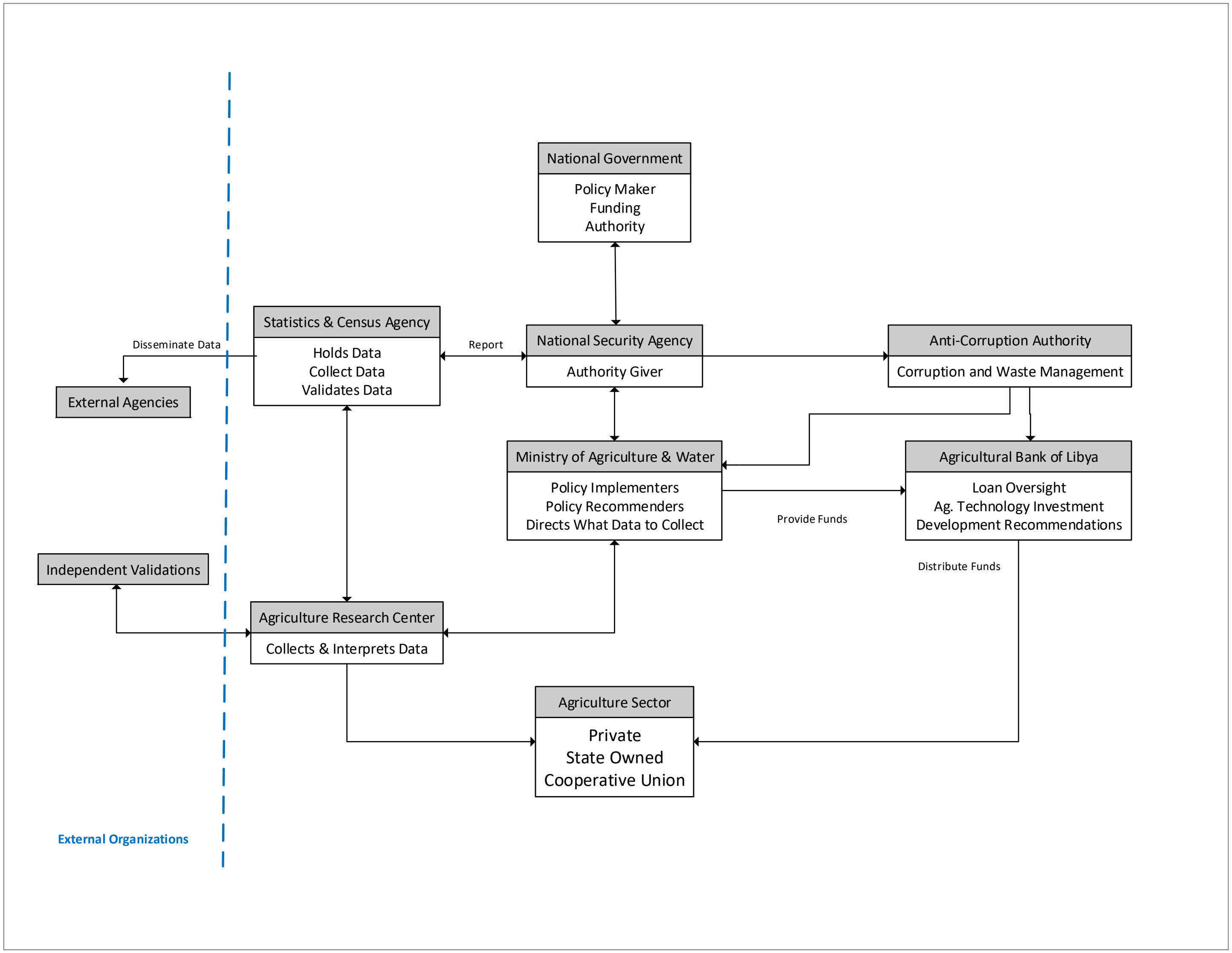

Figure 6.6: Improved Agricultural Organization Relationship Dynamics

In fig. 6.6, a broad general expression of the organizational relationships to improve sector production and stimulate growth is given. This structure consists of two primary objectives, data collection (left side) and funding/investment (right side). The NSA is given authority by the Libyan Government to pursue actions in the agricultural sector in the interests of food security (among many other roles in other sectors). The NSA further supports the SCA by providing the authority to collect data. This avoids the historically weak data collection problem where lack of authority to compel responses. The SCA is likewise overseeing more than just the agricultural sector, and should be tasked only with being the repository of data, both to report to policy makers and to disseminate data to external agencies (e.g. FAO). Ideally a small group within the SCA will have the ability to validate any data collected to ensure accuracy. Data collection itself should come from a dedicated department. I recommend the Agriculture Research Center (ARC) for this task in collecting data from the agricultural sector,[24] including efforts to interpret the collected data possibly in connection with outside researchers. As part of the data collection process, special focus needs to be given to establish what measurements are necessary for interpretation and policy guidance, standardization of those measurements for consistency, and training of individuals and organizations conducting the measurements to ensure accuracy. Due to prior data accuracy concerns, it is beneficial to include outside independent validation of data collected by ARC on an ongoing basis to develop a culture of strong data collection. The ARC serves a dual purpose under the associated Ministries of Agriculture and Water Resource (MOAW) where the ARC should recommend what data is important to collect to the MOAW while also being directed by the MOAW on what data is important to guide policy decisions made within the MOAW. The evaluation of the data leading to other agricultural reform policies should also be headed by a stakeholder with knowledge of agricultural practices, including familiarity with the different needs of the southern and northern regions of Libya. This includes reviewing data collected in prior years and accounting for discrepancies using

[24]Consisting of privately held farms and businesses, state owned operations, Cooperatives/Unions and other agricultural organizations within Libya.

better available techniques that are beyond the ability of this author. The ministries are further responsible for implementation and focused development of agricultural policies, which are confirmed by the national government.

The other half of the organizational relationships focus on funding for the agricultural sector. The MOAW has funds distributed from the Libyan government to pursue the agricultural policy goals set by the ministries. Primarily, these funds are allocated to the ABL to be further distributed as loans for small, medium and large agricultural projects. Having the ABL be responsible for disbursement of loans requires additional training and education for the ABL employees to responsibly create feasibility reports for proposed loans, maintain oversight of in progress investments, and act as stewards providing funding to generate growth in the agricultural sector.

In the past, agricultural funds were not always used responsibly at various levels, leading to inefficiency. Such waste, driven by either poor choices or misuse, would cripple the intended growth for the sector. The low perceived importance of the agricultural sector makes fund misuse less easily noticed without proper safeguards. Given the limited availability of funds expected in the early post-conflict period and sector importance, wasteful use of funds is more likely to shift what little expenditure on the sector to other priorities. One successful component within the experience of other post-conflict countries is the establishment of an Anti-Corruption Authority (ACA), tasked with maintaining accountability of money flows. Unlike the ABL which focuses on oversight at the individual and company level, the ACA would focus on oversight at the institutional level. This ensures funds are released in a way consistent with established goals that are not diverted through unnecessary overhead.

While a restructuring of data collection and analysis is needed to drive policy implementation, there are some quickly identifiable deficiencies within the sector to address early on after the conflict. Some of the easily identifiable obstacles to the current farming operations include (FAO, 2017)

1. Poor security affecting the value chain (production, transportation, sales, storage and processing)

2. Scarcity of water and fuel

3. Frequent power outages and irregular electric supply

4. Lack of inputs or high prices of inputs (fertilizers, pesticides and seeds)

5. Depressed income to invest in machinery and equipment

6. Market accessibility and transportation constraints

It is clear that some existing policies are not beneficial and can hinder agricultural development. The Head of Human Resources Directorate within the Ministry of Agriculture noted, for example, pesticides and seeds are already obtained exclusively through the government. For pesticides, this results in farmers not obtaining product they need, while seeds may not be climatologically suitable or generally not preferred (Heemskerk and Koopmanschap, 2012). Expanding choice and encouraging private sector development to address these inefficiencies is of importance to the future health of the sector.

Rebuilding Critical Infrastructure and Institutions

The results of this study and a deeper investigation reveal a shortage in the infrastructure of the agricultural sector and inability of current institutions to function efficiently. This is not unrelated to how poor public services were a focus of the uprising in 2011 (Laessing and Elumami, 2019). Some of the infrastructural deficiencies existed long before the conflict, while others such as pipeline and local manufacturing for agricultural products have been partially or completely destroyed during the unfinished 10-year conflict.

Before the conflict, some agricultural infrastructure was in need of examination. Of particular importance is the absence of sufficient storage for agricultural product, where

Heemskerk and Koopmanschap (2012) describes how back in 2012 the high levels[25] (up to 25%) of post-harvest loss existed already. Addressing the storage and loss issue can increase food availability, reduce pressure on environmental resources and improve agricultural livelihoods.

The ABL is tasked with the disbursement of loans for the sector. In order to increase the available investment early on during the post conflict period, the ABL will need to adopt different practices, especially as post-conflict societies are prone to corruption that functions as a serious obstacle to recovery, stunting "the development of capable institutions of government critical for long-term societal reconstruction..." (Ware and Noone, 2003). Tolerance for inefficiency within the agricultural sector through corruption losses, due to the relative sector unimportance, is minimal. For their part, the ABL will need to focus on ensuring viability of loan repayment, simplifying and streamlining of the loan process, educating staff responsible for assessing the expected impact of the loan and evaluating the ability to repay before issuance of the loan.

A weaker component of the agricultural sector is the absence of sufficient training and educational facilities for agricultural research. While a long-term goal is to increase the number of native Libyans that are trained in agricultural practices, a short-term goal should be to create the institutions and lay the physical groundwork to make that transition possible in the long-term.

While infrastructure issues prior to the conflict were apparent, further deterioration or destruction of many pieces of infrastructure during the conflict has been observed, particularly in regards to irrigation. Some of the problems stem from direct conflict, such as the NATO bombing of the pipe facilities used to construct pipes for the GMMR project.[26] Other causes of degradation of infrastructure are indirect consequences of the conflict include the dismantling of nearly 25% of the available wells on the pipeline system as people reclaim

[25]FAO's Food Loss Index (FLI) measures the post-harvest loss from post-harvest to distribution. In 2016, the FLI for Western Asia and Northern Africa was 10.8% (FAO, 2016b).

[26]The bombing of the facilities was predicated on NATO's claim that the facility additionally served as a military storage facility and rocket launch point.

the copper in well heads for sale (Laessing and Elumami, 2019). Desalination plants have also been affected, with nearly 80% of them broken down leading to a water crisis for both the agricultural sector and the population at large (Laessing and Elumami, 2019). Some of the destruction is politically motivated, with individuals destroying pipes to have a stronger position in talks with officials from the capital. Coupled with a lack of funding and maintenance, the flow of water just to Western Libya has decreased by a third, though agricultural demand for water has increased by 25% since 2011 (Laessing and Elumami, 2019). The electric infrastructure of Libya has been in decline since the 1990s, stemming from the difficulty in hiring engineering companies as a result of the international sanctions. The electrical infrastructure remains important for the agricultural sector as a source of cooling for storage buildings, pumps required for water irrigation, and lighting. For the short window between the lifting of the sanctions in 2004 to just before the current conflict, there was little move for needed updates to the electric grid of the country which had minimal maintenance for decades (Abulkher, 2020). There has already been some forward motion on the current 3 Giga-Watts [27] deficit where Libyans have already faced daily acute power outages sometimes lasting for 16 hours or more (Zaptia, 2020; Abulkher, 2020). The demand peak has a constant annual growth rate of 4% since the beginning of the conflict, though this rate is half the pre-2011 levels (World Bank, 2017).

Efforts to manage the blackouts have not been effective due to unauthorized power connections, theft of copper wires, corruption and destruction of power stations due to political conflicts and armed groups' illegal activities. In a report commissioned by the World Food Programme (Barelli, 2020), the electric crisis has led to decreased productivity and revenue in the agricultural sector by impeding irrigation and storage efforts of harvested crops. The impacts have been compounded by attacks on remaining produce by pests reported by many farmers (FAO, 2017). Some Libyan farmers spend money on purchasing and maintaining generators in order to keep their farms working (McDowall, 2020), but the costs are pro-

[27] This represents approximately 50% of current production levels averaging 5.8 Giga-Watts.

hibitively high for many, where new equipment and machinery can be purchased in low quantities that the majority cannot afford (Barelli, 2020).

To combat this in the post-conflict setting, policies will need to account for many of the components of the sector's infrastructure including groundwater sources from wells, rehabilitating damage to distribution stations and water pipelines, and rehabilitating roads that facilitate access to markets.

Promotion of Agricultural Labor

The rate of native employment in agriculture has been in decline since the discovery of oil as workers leave the agricultural sector for more lucrative employment, dropping from 25% of the total workforce in the early 1980s to close to 5% in the early 2000s. Conflict has furthered the trend, with approximately 7.5% of the workforce abandoning agricultural activities between 2014 and 2018 (FAO, 2018). This has had two major impacts on the agricultural sector economy: a loss of working experience resulting in less technical efficiency, and an increase in associated production costs due to the prevalence of unskilled native and foreign labor and corresponding loss of harvest. Addressing this problem of workforce loss has been attempted before. In the 1970s, agricultural development plans lead to stronger government investment within the agricultural sector in order to improve economic diversification. This was not enough to stem the exodus of native laborers from the sector leading to an agricultural economy based on a large unskilled foreign labor contingent. Libyan government officials organized a strategy to replace foreign labor with Libyans in 1994 in the hopes to improve agricultural and manufacturing sector productivity, with limited success, including the large dissemination of agricultural loans.

The situation continues today. There is a reluctance of young people to work in the agricultural sector due to physical difficulty of agricultural operations, the length of the farming season, and low pay relative to other sectors. The current workforce includes a small fraction of native owners but is largely comprised of foreign labor and internally displaced persons

(IDP) stemming from the conflict (Barelli, 2020). The barrier to entering the agricultural workforce is low since there is a low educational requirement coupled with a high demand of unskilled labor in the sector. However, once conflict ends, there is an expectation that the roles filled particularly by the IDP will remain vacant, leading to further workforce demand.

The recommendation to address the labor shortfall when many are reluctant to join the agricultural sector is to apply encouragement in the form of increased availability of loans with favorable conditions, especially for individuals with prior expertise and for newly developed agricultural endeavors. This is more than just encouraging labor to return to fields and includes development of new operational activities such as packaging and services, encouraging development of the private sector. For direct farming applications, mitigating risk for crop production through guaranteed markets at realistic prices (neither low enough to induce losses nor too high functionally distorting the market value).

It is misleading to say the agricultural sector requires unskilled labor. It would be more accurate to say that unskilled labor is sufficient to do the work, but not with increased efficiency. Foreign laborers often do not have enough skills in the field, with the exception of migrant workers from Arab countries such as Egypt, Sudan, and Tunisia, who generally come prepared having already worked in the agricultural sector. Many foreign laborers acquire experience in Libya and return back to their native land after a few seasons, perpetuating a low skill cycle within the Libyan agricultural sector.

The conflict has presented an unfortunate opportunity by further straining the public sector bloat with reduced oil revenues. This has opened up the number of individuals who are available to join the agricultural sector as a form of employment, especially as it becomes more evident that the public sector will start becoming more competitive. Capitalizing on this opportunity to fill gaps within the sector (both in field work and within more agricultural service positions) should be a primary goal of the MOAW. This can be accomplished with enhanced salary subsidies (likely still lower than what was available during pre-conflict) and active training.

One issue identified by the Head of Human Resources Directorate within the Ministry of Agriculture was the staffing and organizational structure needing review, particularly within the service and administrative areas. The previous government focused on providing a function or position, rather than ensuring positions were filled with people with the appropriate strengths and qualifications leading to, for example, "agricultural engineers having a job as waiter within the ministry" (Heemskerk and Koopmanschap, 2012). Such practices are highly inefficient and actively hinder the development of the agricultural sector. Labor recruitment post-conflict must be based on new policies ensuring strong work standards and verified experience, with expressly written job descriptions.

Emergency Interventions and Hazard Removal

Emergency interventions are immediately necessary actions for the government to address short-term critical problems. This can take the form of the government assuming local control of some agricultural processes, education and policy changes, but more often takes the form of direct cash infusion into the sector. These interventions are needed to provide early stabilization and promote sector regrowth but have also been attributed to stagnating growth when overextended (S. Edwards, 2015).

Food aid has been used before to provide immediate relief for both conflict and early post-conflict periods. The normally cited benefit is that additional food helps prevent farmers from remaining in subsistence forms of agriculture. However, this policy has remained questionable in terms of benefits, where there is difficulty in ensuring food aid goes to those in need and simultaneously is not used as a supplementary income for those who are not in need. By unloading free or cheap food on the open market, Libyan production is undercut by the distorted low prices from the excess supply, leading to low incentive for agricultural development and counter acting the desired purpose. Food aid is therefore not recommended as a useful intervention, except in limited and specific instances of impending or existing famine.

Agricultural production is affected by economic and environmental shocks when disasters (including conflict) occur. There is an absence of capital flow and capital availability for farmers due to the system shock induced by conflict. For this affected group, the conflict disrupts by removing government resources in the form of loans to other concerns, shifting practices to more subsistence farming, and decreasing income from market factors where revenues drop while input costs increase.

Left alone, this lack of available capital will lead the sector to remain stagnant long after the conflict. Kaarud Mansour Mohamed (2020) indicates that insurance for agricultural production has become an urgent necessity in many countries. In the reconstruction process, agricultural insurance is one of the reforms that must be included in policies for dealing with problems and designing safety networks whose function is to protect farmers and agricultural production directly from shocks.

The conflict has put farmers in a poor competitive position, where the main challenges identified by WFP (2020) focuses on the low-quality and high costs of inputs, tools and machinery, a lack of support services and storage facilities. Some highly suggested emergency interventions suggested by the WFP include subsidies for good quality agricultural and livestock inputs (seeds, fertilizers and feed, for example), and provision of materials and seedlings to reestablish nurseries for fruit production (FAO, 2017).

The lack of safety imposed by unexploded ordnance (UXO) may also inhibit returns to the agricultural sector, particularly in farm areas. While the majority of landmines and other UXO are concentrated around population centers such as Tripoli and Benghazi, those areas also tend to encroach on agricultural lands that are also the most productive within Libya (UN-News, 2020). Early governmental effort paired with foreign organization expertise in clearing remaining UXO to improve the safety of labor and maximizing available land for production.

Improved Regulations

The dominance of the oil sector within the Libyan economy minimizes the concern and oversight of other sectors, inviting inefficiency and corruption that the Libyan Council for Public Planning deemed were a major barrier to the country for socio-economic and development objectives (Shariha et al., 2014). Improved regulations are necessary to reduce inefficiency and combat corruption while leading to good governance and growth for the Libyan economy.

Prior policies and programs often focused on cash disbursements with little oversight, including granting agricultural loans prioritizing quantity over quality of investment. Loan determinations were less concerned with the viability of the projects as returns on the investment, often driven by political will rather than agricultural need.

The problem of management of agricultural projects in Libya, according to Ahmad and Wee (2013), is because funding has not been systematic and constant. Part of the problem was the lack of agricultural education for ABL officers providing the loans to evaluate the quality of the projects that were being funded, nor in follow-up characterizing a weak administrative control in implementing effective loan policies. Some of the changes to increase the impact of investment include the streamlining of the loan process and a reduction in application costs, especially immediately after the conflict.

In many ways, the farmers of Libya cannot compete well with foreign imports of many agricultural goods and will find greater difficulty during the rebuilding period after the conflict as markets become more open due to lessening security issues. While this does provide the farmers with greater access to sell their harvest, it is stymied by the availability of imported varietals which has long been an issue for some crops that are conducive to Libya's environment. One obvious method to protect the Libyan producer's success within the local market is to apply tariffs to imported agricultural goods that are commonly produced in Libya. However, such manipulation should be carefully considered so as to not reduce local innovation and efficiency by removing competition.

Leaving in place the agricultural regulations existing before the conflict will contribute to poor overall recovery of the agricultural sector. One example is Law No. 37 of 1977 which limited each Libyan family's ownership of agricultural land as determined by the Minister of Agriculture. The policy for land distribution was designed so that every family would be self-sufficient regarding food production, but this wound up fracturing farming plots to small holdings, with further issues based on inheritance leading to smaller plots. While there is much debate about whether small plots can have higher productivity than large plots (see Collier and Dercon, 2014), it is clear that smaller plots are more likely to suffer from inefficiency in other ways. For example, use of machinery and tools that can service more area effectively may not be used to the full potential on smaller plots. While one option is to rely on local private firms to generate equipment loan services, it is less burdensome to regulate plot sizes to be related to a minimal size for commercial agricultural production.

Sometimes the regulation is not the actual problem, but the political will and authority to enforce the regulations are missing. For example, there has been an excessive increase in drilling wells for the purpose of cultivation by farmers without licenses or any strict monitoring by the state. This has led to usage of poor-quality water without oversight.

In other cases, political will and not underlying need will drive the regulations. Such an example exists already with the 2013 law attempting to shift all transactions to follow shari'ah compliant financing. Conventional transactions were not grandfathered in, and effectively all interest still on the books of the bank were unenforceable, marking a capital transfer directly from the bank to the borrowers (World Bank, 2020b). Based on the troubles faced by the ABL, recommendations by the WB are to rethink the role of ABL and similar institutions, including changing to credit guarantee schemes (World Bank, 2020b). This option is perhaps misguided for Libya. First, with the shift to Islamic shari'ah compliant financing which is both strongly desired in Libya and at the same time poorly understood within Libya, adoption makes it difficult for private lending to take on the role of the ABL in the short-term. Second, with loans effectively underwritten by the ABL as desired by the

WB suggestion, private lenders are more likely to take inappropriate risks as there is reduced incentive to ensure feasibility of repayment and viability of the projects the loan covers. The ABL remains the best option as the financial support for the agricultural sector, so long as corresponding regulations for the institution's objectives are modified.

6.4.2 Long-Term Goals, Challenges and Recommendations

In the long-term, the main objective is to stimulate enough growth in the post-conflict agricultural sector to converge to the pre-conflict GDP trajectory. While closing the gap to return to the pre-conflict economic path is important, the goal does not address some of the systemic problems in Libya's agricultural sector predating the conflict. Without considering those deficiencies of the old system, it is unlikely the agricultural system of Libya will become significant. The following goals reflect the issues of the agricultural system in Libya that will continue to be issues once the conflict ends. As many goals have significant overlap (e.g., the involvement of international agencies may reflect additional training for Libyans), choices of where to include goals and challenges are based on my interpretation of greatest relevance.

Reverse, Prevent, and Minimize Environmental Degradation

The land in Libya is of poor quality leading to low efficiency of production. This problem is exacerbated due to many environmental factors such as desertification and seawater intrusion leading to salinization of the soil, which has compromised nearly 60% of the freshwater wells currently active (J. Lee, 2020). Furthermore, there is a loss in groundwater resources that may need to be addressed. A threat to the soils of Libya also comes in the form of water erosion, affecting 1.3 million ha, and wind erosion of soil, affecting 2.4 million ha (Abdalla, 2015)

Water overuse in irrigation is implicated in lowered agricultural production rates and high salinity levels in the soil leading to degradation of the environment and loss of productivity for the agricultural sector (Abdudayem and Scott, 2014). Soil salinity has been associated with the decrease in wheat yields in the Jifara plain from 5 tonnes/ha in the early 1980s to 0.5 tonnes/ha in 1987 (Abdalla, 2015). In Libya, soil salinity problems affect 2.46 million ha, mostly in coastal marshlands and in the southern regions where there is low rainfall and high evaporation (Ross-Larson et al., 2002)

When there is little high-quality land available, environmental problems like desertification becomes a major issue worth examining. Libya has been involved in efforts to combat desertification since the early 1960s as part of a broad policy effort, including reforestation, maintenance of soil fertility and the protection and improvement of pastoral areas (Saad et al., 2013).

Given the important nature of land in the agricultural process, it is important to investigate and prevent further land degradation with solutions varied as improved land management (Saad et al., 2013) to the introduction of nano-clays for improved water retention (Ditta, 2019). My recommendation for preventing early land degradation issues (while alternative anti-desertification technologies are pursued) is to increase vegetation cover through planting of indigenous tree and shrub species. This vital method in desertification management helps through improving soil stability, reducing soil erosion, improved retention of moisture and nutrients and increased carbon sequestration (Olagunju, 2015).

Education and Training for Agricultural Labor

Education in the agricultural sector is clearly an important piece of the puzzle in repairing the agricultural sector in Libya. The work of Reimers and Klasen (2013) established how education had a significant, positive effect on the agricultural productivity, robust against many control variables and methods. While Reimers and Klasen also concluded that the highest impacts for increased education would be found among the countries on the frontier of technological change, there were still gains in productivity for countries where the technology is more exogenously determined, such as Libya.

The literacy rate in Libya has made marked improvements since the beginning of the study period. Between 1980-2005, the literacy rate increased from from 49 to 82% due to efforts of literacy training centers that teach vocational and technical programs to local populations (UNESCO, 2020). As expected, many of these gains have been among the young where the literacy rate exceeds 99%. However, the profile of native Libyans working in the agricultural sector is increasing as fewer new workers join the agricultural profession in favor of the more lucrative work in the oil and service sectors. The literacy rate of those over 40 is considerably lower, at approximately 50%, back in 2004 (UNESCO, 2020). This data is similar with the sample of farmers (n=300) surveyed in West Tripoli in 2017 by Lagili et al. (2020), finding a composite educational level of nearly 70% completing high school, though not broken down by age in the profile.

Most Libyan farmers are older than the average worker in Libya. Furthermore, a larger portion of farmers lack knowledge of updated agricultural practices and skills. Even when the government formed agricultural institutions and colleges to guide efforts in the sector, little advancement was made. This can be attributed to two main causes. First there is a general distrust of governmental institutions by farmers. This leads to a rejection of information from academic sources. Second, the literacy rate of farmers in Libya is low, partially due having few literate young farmers join the sector skewing both the age and literacy rate.

The Libyan workforce still lacks skilled and trained workers to reach a level close to peak efficiency (Shihub et al., 2009). Without government intervention, there is little chance for change. There is a reluctance of young people to work and practice in the agricultural profession because the job requires hard physical work, difficult tasks, and low compensation. It is essential to redefine the concept of farming and to encourage young generations to attend agricultural institutes and colleges, and to enter the agricultural profession. Part of the training of local farmers requires a focus on modern methods in agricultural operations.

Libya also needs training not just of the direct agricultural workers such as farmers and field workers, but also in all administrative areas in order to have sound judgement with accepted standard practices (Ahmad and Wee, 2013). Concerns brought up by associated leadership of the ARC including the Director General identified weaknesses in the labor training component for those entering the academic and research side of the agricultural sector. These weaknesses focus on the human resource capacity of research including low rates of Libyan students being able to study abroad to both increase motivation for agricultural education and ensure high-quality of education, an increase in the practical rather than theoretical agricultural knowledge, and the ability to speak English (Heemskerk and Koopmanschap, 2012). This should be further coupled with training for entrepreneurs to develop agribusiness within the sector, which should ideally be tied in with the ABL to fund new startups. There remains a strong need to increase local experience rather than to exclusively rely on outside expertise (Heemskerk and Koopmanschap, 2012)

To achieve the goal of improving the education and training of those engaging in agricultural sector work, I recommend the following actions. The MOAW should expand subsidies for agricultural studies for both Libyan and foreign Universities in exchange for specific sector employment. The expansion of this policy is needed to grow the pool of native Libyan candidates to fill roles within research, administrative and policy roles to complement and encourage growth of the sector. Sub-fields within agricultural research that are a priority for Libya include horticulture, grain crops, water harvesting and irrigation, livestock science, soil science and integrated pest management (Heemskerk and Koopmanschap, 2012). To further encourage staying within the sector, the ABL should actively seek out both current and former graduates with agricultural degrees, offering better terms on loans (compared to those individuals with less expertise) to increase private sector development. Additional training on both technology and best farming practices should also become part of the MOAW's objectives, focusing on making supplemental education easy to access for current farmers. This training will need to account for the lower expected literacy by implementing more visual programs. Educational institutions should be directed to incorporate practical field experience programs to complement the theoretical knowledge, working in tandem with either locally or with outside international organizations. Within the agricultural sector institutions, certification and training will need to be a component of the employment. This should include the necessary skills to evaluate agricultural programs/policies, new technology and feasibility studies to ensure proper oversight and management at the institutional level.

Incentivize Efficient use of Consumable Agricultural Inputs

One of the benefits of additional education and training for agricultural labor is the higher efficient use of agricultural inputs in the overall production cycle. Primary inputs considered for increased efficiency are irrigation, fertilizer, pesticides, animal feed and seeds, all of which are consumable. While education is a step towards increasing the efficiency, incentivizing efficient use provides necessary motivation.

Libya's policies have often incorporated subsidies on both the supply and demand sides. Combined with other distortionary policies, the incentives driving a market economy were suppressed while simultaneously making the population and private firms dependent on the state (Araar et al., 2017). Longstanding subsidy policies will need to be re-examined for Libya to have meaningful growth both overall and in the agricultural sector.

Water pulled from the Nubian Sandstone Aquifer through the GMMR is highly subsidized, costing farmers an estimated 0.03-0.08 USD/m^3 where extraction and transportation costs are expected to be no lower than 0.90 USD/m^3 (World Bank, 2009; Heemskerk and Koopmanschap, 2012). The low-cost encourages waste and overuse of water, which is both costly as a government subsidy and may be detrimental to agricultural endeavors. There also now an expectation of low cost water, making it difficult to reform in the short-term.

Historically, other agricultural inputs (fertilizers, pesticides, animal feed and seeds) have all been subsidized by the Libyan government, though many input subsidies were being reduced or phased out entirely by the early 1990s (Heemskerk and Koopmanschap, 2012). Since the previous government would resell imported agricultural inputs directly, the input access disruption from the conflict was widespread. Unlike water, adjustments to cost on these inputs are not feasible in the short or long-term due to unavailable local capital and cheaper foreign produce, which implies training is the best method to reduce inefficiencies in the application of these agricultural inputs. However, a recommended policy is a short-term application of subsidies for these inputs, with a specified, gradual decrease in subsidy phased out in the years following the end of the conflict.

Restructuring and Redistribution of Land

Statistics indicate that the area of farms with less than 5 ha decreased from about (45.8%) in 1987 to about (34.3%) in 2000. However, the number of holdings between (5-20) ha expanded from about (41.9%) in 1987 to about 56% in 2000. The state-owned large holdings (more than one hundred ha) did not exceed (1.26%) between 1987 and 2000 (FAO, 2020). The existence of an inverse farm size-productivity relationship is well established if not still thoroughly debated and often found lacking in African contexts[28] (Collier and Dercon, 2014). Evidence of increased yield productivity for larger farms has also been seen with larger increases in labor productivity (Gollin, 2019). Taking for granted the inverse relationship is problematic for policy makers and must be carefully investigated.

Policy changes regarding land use and distribution should include

1. Standards for studies must include types of agricultural lands in terms of soil quality, climate, quantities of water, rainfall rates, and crops that must be planted in accordance with those criteria

2. Redistribution, and possibly concentration, that is fair and equitable

3. Involvement with civil society organization in implementation of policies

4. Involvement from international groups such as FAO and the Organization for Economic Cooperation and Development (OECD). Consultations with these groups will assist in

[28] Of particular importance in this field is how in most African countries, smallholder farms account for a large portion of the total number of farms. Such studies investigating the inverse relationship are, as Collier and Dercon (2014) points out, really considering productivity differences within a range of smallholder farms.

the reconstruction and distribution of lands based on scientific grounds to greatly contribute to the success of redistribution policies and programs

Land governance regulations are also implicated as barriers to agricultural sector growth, including title deeds, land registration and the use of land as loan collateral (Heemskerk and Koopmanschap, 2012). Policies limiting or removing excessive bureaucratic hurdles would enhance possible agricultural growth through increased access to funds, though at increased risk that would incentivize efficient development.

Support of Agricultural Value Chains

The agricultural value chain is the full range of value adding activities required to bring a product or service through the different phases of production, including procurement of raw materials and other inputs (Singh et al., 2012). The agricultural value chain in Libya has lacked efficiency, even before the onset of conflict (Heemskerk and Koopmanschap, 2012) and has further degraded during the conflict. One direct example can be found through the Chief Veterinary Officer, who described the meat value chain within Libya as poorly developed and weakly organized (Heemskerk and Koopmanschap, 2012). Focus should also be given to considering the balance between production of local consumption and export. For example, the production of urea remains a more attractive option for export, than for local consumption yielding wheat at higher costs (Heemskerk and Koopmanschap, 2012).

Libya's poor agriculture value chains weaknesses include

1. Production / productivity
2. Storage capacity
3. Processing facilities
4. Transportation

Of these weaknesses, only transportation was efficient in the pre-conflict period in Libya, pointing to system wide deficiencies that would benefit from targeted policies post conflict as part of the reconstruction effort.

To better support these challenges, farmers will need

1. Better access to inputs such as seeds, feed, fertilizers and pesticides

2. Agricultural financing (Through the government and disbursed by the ABL)

3. Digital Agriculture (technological solutions), including the use of remote sensing and automating of time intensive processes

The process to improve value chains should not be addressed solely by the government with motivations that may not reflect the best agricultural practices. The inclusion of the private sector to seek out and evaluate opportunities to grow is more organically market driven. One seed quality company in Libya interviewed by Heemskerk and Koopmanschap (2012) identified several opportunities for growth, including packing of vegetables for local markets to reduce food loss, and the processing of potatoes into chips and pre-cooked varieties to match the expected increase in consumption of these goods.

Livestock value chains with special focus on the dairy industry can also be improved, specifically incorporating increased veterinary services and capacity development requiring investment and highly educated labor (Heemskerk and Koopmanschap, 2012). Other expansions in the agricultural sector are advised that rely less on the goal of food production at the field level. Very clearly, both land and water in Libya come at a premium, so efforts made to increase production and productivity in terms of crop growth are already limited. Instead, additional focus on agribusiness development as a new modality for sectoral growth, particularly in food processing and packaging (Heemskerk and Koopmanschap, 2012). Developing fundamentally new agricultural businesses also provides additional benefit as a method of absorbing former militia and offering alternative positions for the expected paring down of Libya's public sector bloat (Heemskerk and Koopmanschap, 2012).

Partnering with International Agencies

One of the concerns in Libya has been the appearance of accepting foreign intervention in Libya. This is not surprising, given the strong desire for self-sufficiency within Libya and the highly desirable oil interests for outside governments, let alone the importance of the area geostrategically, ideologically and historically (Hill, 2020). Even during the existence of the interim government before the further drop into conflict in 2014, some Libyans questioned the role of foreign powers for security reform and transition guidance. Wariness and rejection of foreign involvement has continued as the conflict persists, leading to accusations of disloyalty and treason of factions partnering with foreign forces (Blanchard, 2016). Partnering with foreign governmental organizations and non-governmental organizations is expected to suffer similarly due to mistrust of outside influence within the region, especially with the nascent government. Externally, Libya is viewed as having an urgent need to rebuild after conflict, but "lacks sufficient expertise, experience and professional 'hands-on' support to accomplish this huge task" (Zaptia et al., 2018). Programs designed to assist with the rebuilding effort will need to be heavily scrutinized to ensure the benefit exists for the local population and not exclusively for foreign actors taking advantage of the weakened state of Libya.

International organizations provide expertise and resources that are of considerable use to the growth of the agricultural sector in Libya. In an advisory capacity, institutions like the WB and FAO should be tapped to bring in both training and examine policies to promote sector growth. Analysts at the WB back in 2012 had already identified some of these interaction goals when the conflict originally appeared short-lived. One such anticipated program is on irrigation practices, bringing in expertise from surrounding areas as Egypt, Tunisia, Morocco and Jordan (Heemskerk and Koopmanschap, 2012). While Libyans are hesitant to trust outside organizations to work in the best interest of Libya, this is reflected with international organizations concerns over good choices made by within the nascent Libyan government. The motivation to make politically or socially advantageous selections, rather than agriculturally productive economic ones may explain the WB's stated positions.

For example, although the WB supports staff training in other countries, it also stipulates the final candidate selection process should not be done by Libyan authorities (Heemskerk and Koopmanschap, 2012).

The International Center for Agricultural Research in the Dry Areas (ICARDA) is one organization with narrower focus that should be incorporated more heavily in training, research and support for Libya's agricultural sector. Before the conflict, this organization helped develop the Research and Development Programme focusing on management of irrigation, small ruminant livestock, and staple crops (ICARDA, 2013). Part of the stated goals of the programme were to increase ARC capacity through technological modernization and innovation, training, and establishing research and development exchange and linkages with neighboring regions (Heemskerk and Koopmanschap, 2012). Given the highly specific nature of the organization and the abundance of arid land in Libyan agriculture, I recommend continued partnership with ICARDA to develop the agricultural sector based on arid land needs. ICARDA has also developed expertise in working with countries to develop the agricultural sector in post-conflict settings, most notably in Afghanistan, Iraq and Palestine (ICARDA, 2017).

Increased Investment

Agriculture is no longer central to the economies of many Middle Eastern countries, including Libya due to the discovery of oil. As a steady source of income contributing 90% of the GDP, the expansion of the agricultural sector within Libya is largely contingent on the energy market and oil income, along with responsible policies directing funds.

A short-term goal was the inclusion of cash infusions within the sector to provide necessary startup capital for the severely depleted resources of local farmers from the conflict. In the long-term there will need to be a larger investment into the agricultural sector for growth and food security. Tawiri (2010), examining Libya between 1962 and 2008, determined that there has been a positive relationship between investment and economic growth for Libya and a low efficiency of such investment due to suspension of many agricultural projects that wasted available resources. This common theme within Libya, the inconsistent commitment and often abrupt early ending of agricultural projects, is likely responsible for many sector issues.

Some needed investments into the agricultural sector are already prescribed. The Deputy Minister of Agriculture noted fish production as a prime example of an underdeveloped portion of agriculture, and the strong need to increase seed sector development which have been met with limited success in the past due to inconsistent funding (Heemskerk and Koopmanschap, 2012). While development of fisheries has long been stated as a goal before the conflict, it was not developed due to low governmental priority and lack of deeper investigation into the capacity for this component of the agricultural sector. Without dedicated intervention and continued effort, there is no reason to expect fishery production to naturally increase. In the absence of local capital depleted by the conflict, early development assistance will be likely required to have a meaningful impact in both fishery production and development of seed banks even in the long-term.

Foreign direct investment in particular is hobbled by longstanding policies within Libya meant to ensure Libyan control within its borders. Foreign investment legislation[29] since 2013 requires Libyan co-financing, where foreign investors are only allowed to take minority shareholdings, with at least 51% held by Libyan nationals, except under special approval by the Minister of Economy. While the decree is designed to improve Libyan access and control, this decree has wide implications beyond the agricultural sector leading to reduced overall foreign investment due to increased restrictions. It remains unclear if blunting or removal of this decree will have important consequences for agricultural sector growth, whether or not the decree is a net positive in the overall economy.

Based on my experience, large agricultural projects have the greatest potential for mismanagement of funds once disbursed by the ABL or other institution. A common problem

[29] See Libyan Ministry of Economy Decree No. 22 of 2013.

with the process was incorrect evaluations of costs of project proposals in feasibility studies conducted by the bank. Undervaluing the costs would lead to the bank taking on unacceptable risk, while overestimates would lead to rejection of otherwise sound investments fulfilling the objectives of the ABL. While increased training and more dedicated investigations of proposals will minimize this concern, an additional recommendation would be to include an evaluation of the proposer's qualifications. This both increases the likelihood of successful bank funded ventures while also curtailing the number of high-risk loans that can tie up otherwise needed (and limited) resources.

One present issue in the sector is the aging machinery. This exists due to several factors. The average farm size in Libya is between 5 and 10 ha, with nearly 90% of farms under 20 ha (FAO, 2017), making it difficult to justify replacing and upgrading related agricultural machinery for many individual farmers. Even with the support of the Libyan government through the ABL, small scale farming will not lead to repayment of the loans for tractors where the costs of tractors in Libya were already elevated pre-conflict. In an effort to improve the number of employed, the Libyan government set up an import business to acquire tractor parts for assemblage, rather than importing all tractors fully constructed. Developing the manufacturing capability for tractors and other machinery would be one way to improve the costs associated, however, many of the needed manufacturing skills involve a higher technological ability than currently present, with a long period of completion to initial production. It will be better to directly import the needed equipment from a timeliness perspective, such as already intended ("Libya Seeks to Import MTZ Tractors", 2020). A future long-term consideration for the agricultural sector may be the manufacture of smaller replacement parts for machinery and other low tech equipment, but it would be inadvisable in the short-term.

6.5 Improving Future Analysis

The analysis and conclusions obtained thus far have relied on data that has been difficult to acquire and that represents a deficiency based on the needs of today. As new investigations come to light, updated data acquisition and more careful measurements are needed to refine the conclusions. There is a trade-off between data that has ease of collection and is useful implications for study.

It is evident that measurement of data is a large problem, as there is little accounting for the inputs that make the complete profile of the agricultural sector. It is also true that standardization of measurements is also needed to obtain useful data moving forward. A crucial component to fixing the measurement issue is to have clear definitions on what is measured. For example, the definition of farm labor is ambiguous in the context of an agricultural input in Libya, where a laborer may do farming exclusively during the week or may have other primary employment. The large employment of foreign labor further complicates the issue and should be segregated to unravel other dependencies that are likely overlooked through aggregation.

The inconsistency seen in available measurements reflects either changes in methodology, estimations rather than data collection, misrepresentations based on subject reports, or outright fabrication. Regardless of the source, certain steps can be taken to provide meaningful and reliable data for future investigations. Some of these meaningful changes are institutional and have already been discussed, such as the education and training of agricultural labor (especially those focused on data collection) and the advancement of a dedicated agricultural department within the SCA that has been given authority through the NSA to collect the required data. But these changes are ineffective without real consideration of what data needs to be collected that is useful for study. There is a strong need to develop accurate measurements, even when those measurements are annual aggregated national data. Attention to accurate measurement and the corresponding standardized scientific models enables plans and solutions to observed situations that reflect reality.

One difficulty encountered in obtaining data is the decentralized sources of the data. This introduces unnecessary complications arising from differing definitions, collection methods and interpretations. While international repositories such as FAO, ILO and WB are all invaluable, they rely explicitly on the self-reporting, or estimations when either no data is reported or is of poor quality. In some instances, the data are highly sparse (such as AQUASTAT) or are pieced together (such as with Libyan agricultural labor). This presents numerous problems in regards to consistency and interpretation.

While several institutions in Libya collect data for agricultural production, there remains unexplained inconsistencies that run counter to expectations. Efforts to provide meaningful interpretation are hampered under these conditions. To address these concerns, I propose a statistics department within the SCA to be created that is responsible for compiling all state collected agricultural data and functioning as a repository for the benefit of Libya. Their function should include oversight of the methods conducted by all data collecting agencies within Libya with particular focus on validation of collected data. This department should remain a functional repository for academic research.

More reliable insight into the problems facing the agricultural sector will come from the acquisition of relevant, consistent and well-defined data. Capturing relevant data is clearly the most important aspect of data collection, where the relevance drives evidence based adjustments for agricultural sector policies. Those in charge of the data collection and reporting should work closely with international organizations that have long acted as data repositories and investigatory bodies (such as FAO and WB) to determine the best measures to base future policy, if those measures are sufficiently disaggregated. Data consistency refers to the similarity of measurements conducted by different observers, with a method of collection that is standardized across different measurement periods. Objectively independent and repeatable, measured data should be the same to within a reasonable standard of error for different observers to be considered consistent. In order to be well defined, the definitions must not be ambiguous (which may also affect consistency).

6.6 Summary

Using the pre-conflict elasticity parameters estimated from the linear regression for the agricultural inputs used in this study (Land, Irrigation, Fertilizer, Machinery and Labor), it appears that increasing fertilizer use is the most cost-effective way to improve overall production within the sector. This assumes that conflict does not permanently alter the elasticity parameters of the production relationship once the conflict has ended. A caveat is that blind application of additional fertilizer across all cases is not a correct interpretation of the results of a model using national aggregated data. Instead, making more fertilizer available to address poor usage and declining soil quality in a targeted response is required.

The production model used does not explicitly account for environmental damage, nor other changes to efficiency of input use. The ecological impacts of the conflict do play a role in agricultural production and should be considered when implementing policies intending to restore the sector. In Libya, direct environmental damage exists from conflict-driven destruction as different groups target the oil facilities to cut-off opposition resources. As these facilities are primarily situated on the coast, the resulting pollution deposits contaminants the surrounding soil, water and air. The land near the coast is also where the most agriculturally productive land in Libya is, making the effects more pronounced. The loss of local oil production has further induced a shift to less ecologically friendly diesel fuel within Libya. Wildlife resources are also being depleted as a result of food insecurity, increased availability of weapons and loss of governmental control. Weakened governmental authority in the conflict has impacted normal conservation and environmental efforts, leaving crops more susceptible to pests and increased deforestation from multiple sources.

Examining the experiences of other post-conflict countries, including the efforts to rebuild the agricultural sector, is helpful in plotting Libya's best path forward once the conflict has ended. Each country under consideration needed to have a modern conflict with long duration and likewise a long uninterrupted period without the renewal of conflict. The conditions of these countries prior to conflict were varied, with some having low relative agricultural sector importance to the GDP like Libya, and others with more dominant agricultural sectors. Other primary differences such as the local climate and the switch to a new government were also noted. Pre-conflict growth rates for the agricultural sector of these countries were often lower than Libya's (3.5%), while only in a handful of cases did appearance of conflict correlate to an immediate change in the agricultural GDP, where Libya's relative drop was the most severe (-73.7%). Those countries with an early drop in the GDP also tended to have a jump in GDP once the conflict ended, giving hope for a similar response in Libya. This was particularly pronounced for Lebanon which had a severe drop like Libya early on (-54.5%) but experiencing a later jump of (65.3%). In a few cases, the post-conflict period was offset by a transition period which may indicate early problems in enacting good policies. Using the experiences of these countries, the long-term post-conflict agricultural growth for Libya is expected to fall somewhere in a range between 0.8% and 7.8% annually, marking the observed growths of Burundi and Angola, respectively. So long as the actual post-conflict growth rate in Libya exceed the pre-conflict rate (3.5%), there will be an eventual convergence to the pre-conflict GDP trajectory.

The change between pre-conflict growth rate and post-conflict growth rate is used as a proxy to measure success of a post-conflict government's interventions and policies. The end of conflict provides an opportunity to make fundamental changes in governmental priorities that can benefit the agricultural sector, though such changes need to be balanced with other needs and may face resistance for social, religious or political reasons. Interestingly, the types of policies do not appear to be a large factor in successful rehabilitation of the agricultural sector. Instead, more successful responses seem associated with continued effort in maintaining, evaluating and modifying policies to fit the needs of the sector. However, policy and policy changes should avoid being abrupt and based on meaningful evidence supporting agricultural sector benefit, rather than political and social whims. Some short and long-term policy recommendations based on transforming the agricultural sector and improving the sector's growth are given, but each hinge upon making changes to improve data collection to better guide policy.

Based on the available data and comparisons to the experiences of post-conflict countries, Libya is likely to experience a short-term recovery where the post-conflict growth will converge to the pre-conflict trajectory between 10 and 15 years after the end of the conflict. This is highly contingent on the absence of a transition period that delays convergence, and effective, consistent management of good agricultural policies without the reappearance of conflict in the short-term. Under this assumption, the losses sustained until the convergence to the pre-conflict trajectory within the agricultural sector would amount to 46 billion USD2010.

Chapter 7 Conclusion

The beginning of this investigation sought to characterize the impact of Libya's 2011 armed conflict on the Libyan agricultural sector. The rise and dominance of the oil sector contribution to the overall GDP of Libya contributed to weakened institutions and inconsistent state support of agriculture over the last 50 years. Libya's agricultural sector also faces other constraints such as climate, a shortage of surface water resources, seawater intrusion of the more fertile coastal strip, as well as limited technology and native expertise. Even with large outlays such as the multi-billion investment in the Great Man-Made River that provides much of the needed irrigation for this arid country, follow through has been largely absent. When coupled with weak agricultural data collection practices, the large inefficiencies of the sector existing before the conflict are unsurprising.

The three main objectives of this investigation were to measure and describe the agricultural production within Libya both before and during the recent armed conflict, to identify the influence of environmental, physical and human capital on the resilience of agriculture to the conflict, and to estimate the long-term impacts of the armed conflict and evaluate the potential for recovery for the sector in Libya.

To characterize conflict's impact on the agricultural sector within Libya, the first step was to obtain quality data describing the factors of agricultural production within the country. I focused on the period between 1970 and 2017, marking a long period of stability coinciding with the Gaddafi-led government and transitioning into the period of armed conflict starting in 2011 and continuing through the observation period.

A model of production based on Cobb-Douglas formulation was created, chosen both due to the model's parsimony and to avoid unnecessary complications that already exist with the weaker available data. This model incorporated land and irrigation as representations of the environmental factors of production. The number of tractors in use and the amount of used fertilizer in agriculture was pulled as expressions of the physical factors of production within the model. Agricultural labor was also included to describe the use of human capital in the production process. Based on considerations of present model multi-collinearity, a related inputs were combined (as a product) into representative group variables denoted as environmental, physical and labor variables.

The Quandt-Likelihood Ratio test (based on the Chow test) was employed to econometrically establish a structural change in the model occurring at the onset of the conflict. The data from before the structural change (up until 2011) was regressed, with estimated elasticity parameters of 0.107, 0.146 and 1.315 for the physical, environmental and labor variables, respectively. Each of these estimates and the corresponding regression were statistically significant at the 5% level. A dummy variable analysis was used to estimate the relative changes in these parameters due to the presence of conflict. Decreases in each parameter estimate were observed as -0.518, -0.803, and -18.935 for the Physical, Environmental and Labor variables, respectively. Of these, only the Physical and Labor estimates were significant at the 5% level. These values should be not be overemphasized; the limit of available data on the conflict side of the structural break retains large standard errors for each estimate compared to the pre-conflict estimates.

The elasticity parameters estimated with the regression establish which inputs to production are most effective in increasing the desired agricultural output on a quantity basis, but may overstate the economic importance of each input. Transforming relative quantities of each of the investigated inputs (land, irrigation, machinery, fertilizer, and labor) into a cost basis highlighted the economic return of each component. Fertilizer was established as the best ROI in the short-term to increase the agricultural production once the conflict has ended, relying on the assumption that the elasticity parameters revert back to the pre-conflict values.

Investigating the post-conflict experiences of other countries was used to implicate possible strategies and pitfalls to avoid in trying to improve post-conflict recovery. Cursory observations of these conflict countries indicate that sustained dead-weight losses are recoverable, based on a long-term post-conflict growth rate exceeding the pre-conflict trajectory leading to convergence to the original path. The period of convergence is dependent on many factors, including the existence of a transition period post-conflict where long-term growth has not been established. While each of the conflict countries examined attempted to repair the agricultural sector in various ways, the success or failure of these generalized policies did not show obvious patterns in methods to improve post-conflict recovery and growth. The common theme that appears to relate the successful conflict countries is the consistency in governmental involvement through support, management, evaluation of policies and follow through.

Beyond the scope of this dissertation, there were already a set of problems within Libyan agriculture to address which I have not measured. This represents a limitation of this investigation where measurements are conducted within the agricultural structure that already existed within Libya. The measurements do not include anything outside of the given system. For example, one consideration might include making better use of the abundant supply of water, shifting from lower-value, but highly drought-tolerant crops to more high-value permanent crops. A large-scale conversion of land towards more specialized would be associated with increased impacts from fertilizer, irrigation and labor with a reduced impact of machinery. Policy makers should consider all changes that affect agricultural efficiency, not just the ones that are recommended in this dissertation.

Several shortcomings facing the agricultural sector within Libya are present. The conflict presents a unique opportunity to pivot, making long needed changes to promote healthy sustainable growth within the sector that has floundered for decades. Not every needed change can or should be implemented immediately. Instead, policy makers will need to more thoroughly investigate the benefits and drawbacks of addressing each individual instance of sectoral weakness in the context of the larger agricultural system.

The most fundamental change needed to the agricultural sector is developing and supporting better agricultural data collection needed to make informed policy decisions. The repair of the agricultural sector should also include rebuilding and restructuring of agricultural institutions and infrastructure (particularly storage), maintaining involvement and partnerships with international organizations such as FAO and WFP, and active training of native agricultural researchers and administrators.

Once the conflict has ended and enough time has passed such that governmental authority has stabilized, the success of the renewed agricultural sector will be characterized by its long-term growth. Barring the existence of a transitional period (as seen in some other post-conflict countries), a quantitative measure of success in rehabilitating the agricultural sector is how long (if ever) the agricultural GDP takes to match the projected pre-conflict trajectory as if conflict did not occur. While I remain hopeful that no transition period will occur after the conflict based on observations of experiences in other conflict countries, there is a stronger likelihood the nascent government will discount the importance of revitalizing the agricultural sector to promote growth and improve rural livelihoods. Without direct governmental support in designing and maintaining needed agricultural reform policies, the sector will not recover and stagnate under a business-as-usual approach.

Under this belief, a transition period where there is little effective growth is expected through 2025, further increasing the welfare losses generated from conflict's impact. However, given weakness of the sector before the conflict, there is a strong possibility for future growth to exceed the pre-conflict growth rate. I further believe a long term growth leading to convergence to the projected pre-conflict trajectory will occur within 20 years at the end of the transition period. This scenario is dependent on the successful implementation of agricultural policies and other favorable events assisting the sector's revitalization, rather than operations returning to business-as-usual. This would require an average post-conflict long-term growth rate of 6.4%, which fall within the range of experiences of other conflict countries.

Even at the convergence point, the opportunity costs to the sector have accrued since the beginning of the conflict. Under the assumption of a 20 year convergence after the end of conflict and transition period (estimated in year 2025), the opportunity costs are estimated at USD2010 25.0 billion. Unless the post-conflict growth rate exceeding the pre-conflict rate is maintained past the convergence point, then these costs to the sector would be permanent. If the growth is maintained beyond the point of convergence, the gains made over the pre-conflict trajectory would balance the opportunity costs nearly 150 years later in 2155 (under an assumed discount rate of 3%).

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Appendix A Raw Data

Table A.1: Data

Year	Ag. GDP (MM USD2010)	Land (ha)	Irrigation (MM m^3)	Fertilizer (MM tonnes)	Mach/Energy (TJ)	Labor (1000s)
1970	352.1	495565	3.48	12460	3209	127.0
1971	329.0	347449	2.82	17500	3232	127.0
1972	367.0	424325	3.05	15500	3298	127.7
1973	373.1	599279	4.15	14200	3372	129.5
1974	428.7	638522	3.61	21900	3499	131.4
1975	506.2	746798	4.73	38900	3626	133.1
1976	578.3	890217	4.74	40400	3659	141.2
1977	483.0	557994	3.43	51200	3708	144.9
1978	524.5	858647	4.97	36900	3872	147.9
1979	556.9	780226	5.18	60140	3975	150.0
1980	640.6	732582	4.66	53148	4004	153.4
1981	727.7	622480	4.02	74330	4069	162.4
1982	745.6	552085	3.16	77760	4119	167.5
1983	855.1	725735	3.69	84382	4156	177.0
1984	821.9	652110	3.93	72130	4160	185.5
1985	855.1	701770	3.49	61500	4164	178.2
1986	758.1	748175	3.35	71840	4168	178.5
1987	646.9	783142	4.15	95190	4173	180.0
1988	695.3	770817	3.63	79772	4251	186.0
1989	745.9	829006	4.33	73800	4270	191.6
1990	774.6	760047	3.29	67600	4000	188.9

1991	891.6	727973	3.04	75800	4000	189.6
1992	872.7	667033	3.43	86800	4000	195.7
1993	841.6	625656	3.24	107000	5000	201.2
1994	838.7	612740	3.15	72600	5000	213.4
1995	852.4	588434	3.12	101700	5000	212.7
1996	861.9	618579	3.39	62400	6001	219.5
1997	918.8	640937	3.44	61700	4000	219.2
1998	923.8	695333	3.68	42000	4000	225.1
1999	896.9	762625	4.58	60000	5000	232.0
2000	924.1	767270	3.93	31500	4000	239.1
2001	964.4	732560	3.83	72700	3924	240.8
2002	1000.2	735719	4.24	48430	3845	247.4
2003	1035.6	769941	4.33	16119	5051	246.8
2004	1084.1	832475	4.45	34492	5076	249.9
2005	1167.0	856435	4.29	28854	10620	241.1
2006	1281.8	829608	3.90	32311	9230	249.3
2007	1332.7	830673	4.02	29684	9724	246.5
2008	1365.0	831386	4.10	24126	8032	249.8
2009	1398.4	833250	4.12	35320	7434	250.1
2010	1386.8	887841	4.77	47028	7913	249.5
2011	429.6	947029	5.11	3865	6318	273.0
2012	377.2	996652	5.67	16077	5378	253.0
2013	483.5	1017397	5.30	45025	5216	258.9
2014	230.7	1024479	5.82	31396	4338	267.8
2015	117.8	1009723	5.86	24521	4378	272.3
2016	92.3	966326	5.70	17997	4428	274.5
2017	147.0	948620	4.83	35046	4489	266.1