The Impact of Short Term Climate Fluctuations on The Rural Population in the Desert Frontier *Nahiye* (Sub-District) of Gaza (ca. 1519-1557). [1]

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Abstract

This study explores the impact of short-term climate fluctuations on rural population by examining the differences in the latter's growth rates within the Gaza *nahiye* (ca. 1519-1557). This small administrative unit (a trapezoid of about 60X35 Km) borders the desert and included both southern semi-arid and northern Mediterranean climate zones. The demographic data – the number of rural taxpayers – were deciphered from Ottoman tax surveys, and the indications for historical climate fluctuations include tree rings, grain prices and qualitative evidence derived from historical documents. The study shows that the population in southern semi-arid villages was more sensitive to climate fluctuations than the population in northern Mediterranean villages. In other words, dry years were followed by a relatively slow demographic growth in southern villages, while bountiful years were followed by accelerated southern demographic growth. The study interprets this pattern as south-north migration aimed at smoothing consumption across wet and dry years. Similar circular migration are familiar as survival strategy in other regions such as the Sahel in Sub-Saharan Africa.

[1] The Author like to thank Nili Lifschitz, Yehouda Enzel, Efrat Morin, Ramzi Touchan, Adi Ben-nun for advices on climate and geographic issues and data. Special thanks to my dissertation advisors Nathan Sussman (Chair), Joel Mokyr and Amy Singer. **Updated: May 9 2008**

Introduction

The current scientific consensus on global warming draws significant attention to the adverse impact of climate changes on human societies. The most famous examples of collapse of civilizations that were attributed to climate change are probably the collapse of the Akkadian Empire in Mesopotamia (ca. 2100 BC) and the classic Maya Empire in Central America (ca. 900 AD).[2] Some scholars claim that climatic changes affected large regions, and not only specific civilizations. Galloway, for instance, suggests that long-term global climate fluctuations between 1300 and 1800 were correlated with growth and decline of the population in middle latitude climate zones including various European countries, China and parts of North America.[3] These studies and most of studies of the impact of climate change on pre-modern human societies are based on correlations between proxies of long-term substantial climate changes and major historical transitions in human societies.

Similarly, many major historical transitions in the history of the Middle East were ascribed or related to climate changes: The dry climate in sixth and seventh centuries was mentioned as one of the reasons for the decay of the Byzantine desert frontier and the vast conquests swiftly made by Arab tribes, which spread Islam in most of The Middle East, Northern Africa, and parts of Southern Europe and Central Asia; A relatively short wet climate was associated with the temporary Crusader successes in the Holy Land during the eleventh and twelfth centuries; Another wet period occurred together with the Zionist settlement during the modern period.[4] It seems that the Middle East is particularly sensitive to climate changes because it includes both Northern parts of the Saharan-Arabian desert belt and Mediterranean areas. Therefore, it is important to understand the impact of climate on Middle Eastern societies, particularly on societies located at frontier between the Mediterranean and the semi-arid climate zones. Notably, significant attention was given to another desert bordering regions, the Sahel, which stretches along the southern frontier of the Sahara.

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[2] deMenocal describes these two and additional examples of hypothesised adverse impact of climate changes: Moche and the Tiwannaku collapse both in Peru-Bolivia. Peter B. deMenocal "Cultural Responses to Climate Change During the Late Holocene" *Science* 27 April 2001: Vol. 292. no. 5517, pp. 667 - 673

[3] Patrick R. Galloway "Long-Term Fluctuations in Climate and Population in the Preindustrial Era"*Population and Development Review*, Vol. 12, No. 1. (Mar., 1986), pp. 1-24.

[4] Issar and Zohar provide a radical climate based interpretation of Neast Eastern history. Arie S. Issar, Mattanyah Zohar. *Climate change : Environment and history of the Near East*. Berlin & New York: Springer, 2007; Enzel et al.'s were more careful in this argumentation. They reconstructed the historical levels of the Dead Sea, which as a closed lake is a natural rain gauge. They show that the two prominent falls in the level of this lake coincided with the collapse of the Akkadian Empire and the second overlaps with the expansion of Arab tribes. Yehouda Enzel, Revital Bookman (Ken Tor), David Sharon, Haim Gvirtzman, Uri Dayan, Baruch Ziv and Mordechai Stein. "Late Holocene climates of the Near East deduced from Dead Sea level variations and modern regional winter rainfall" Quaternary Research 60:3 , November 2003, 263-273; I

This study examines the demographic growth in the Gaza *nahiye* (sub-district). This small administrative unit (a trapezoid of about 60X35 Km) included both southern semi-arid (250-350 mm precipitation per annum) and northern Mediterranean (350-550 mm precipitation p.a) areas. It draws on micro-data on taxpayers in about a hundred villages, deciphered from Ottoman tax surveys (ca. 1519, 1532, 1548, and 1557), to examine the relations between demographic changes at the village level and *short-term* climate fluctuations in this desert frontier *nahiye*. It provides evidence that population in the southern semi-arid villages was more sensitive to short-term climate fluctuations than population in northern Mediterranean villages. Hence, it contributes to the literature on the impact of climate on pre-modern human demography by providing a relatively firm quantitative example of micro-demographic changes induced by short-term climate fluctuations. The study suggests that the differences in southern and northern demographic growth rates are the result of migration from semi-arid to Mediterranean villages in dry periods, and in the opposite direction in wet periods. In other words, villagers left the southern drier areas during droughts, while they were attracted to the same sparsely populated areas in wet years. Such movements are familiar as part of survival strategies of households in similarly volatile ecosystems.

The approach used in this study has several methodological advantages over studies of the impact of climatic changes on long-term demographic transitions that took place over large geographic areas. First, most of the relevant historical changes, such as the collapse of the Akkadian and the Classic Maya Empires, were also explained by non-climatic political and economic factors. The following examination of micro-demographic changes at the village level within a small but climatically heterogeneous administrative unit – which was governed by the same administrators, had the same institutions, and was exposed to the same markets – undermines alternative macro economic and political explanations.

Another methodological merit of the current study is related to its distinctive sources. Demographic data that were usually used in historical studies of the impact of climate changes on human demography cover long periods and large areas and thus were generally based on studies of numerous scholars, who examined heterogeneous historical evidence or a variety of archeological sites. Such data is liable to be biased due to different types of the available sources, interests, and training of scholars etc. In contrast, the current study is based on the Ottoman *tahrir defter*s (tax surveys), which provide ample and relatively accurate data on the population of male taxpayers at the village level in a narrow range of years. The data of each survey were collected by the same team of census takers, and hence they are less likely to be geographically biased. Moreover, the higher accuracy and the relatively large number of observations in the *tahrir defter*s facilitate the use of modern statistical methods for the estimations of the impact of climate on human demography. Therefore, this study can draw on more rigorous methods than most of the studies of the impact of climate on pre-industrial societies I have encountered.

This paper also contributes to the methodology of *defterology*, the branch in Ottoman historiography that analyzes the numerous surviving Ottoman *tahrir defter*s (cadastral records). These records cover vast areas in the Balkans and the Middle East. This study is among the first studies[5] that apply econometric methods and GIS generated variables for the analysis of these micro-data. Unlike simple statistics commonly used in *defterology*, econometrics allows to examine the statistical regularities of the heterogeneity of the studied villages. Sometimes it uncovers indications for causal effects, and not mere correlations. Hence, this study highlights the merits of applying this research method to the more than a thousand surviving *defter*s, which cover the vast Ottoman Empire in the early modern period.

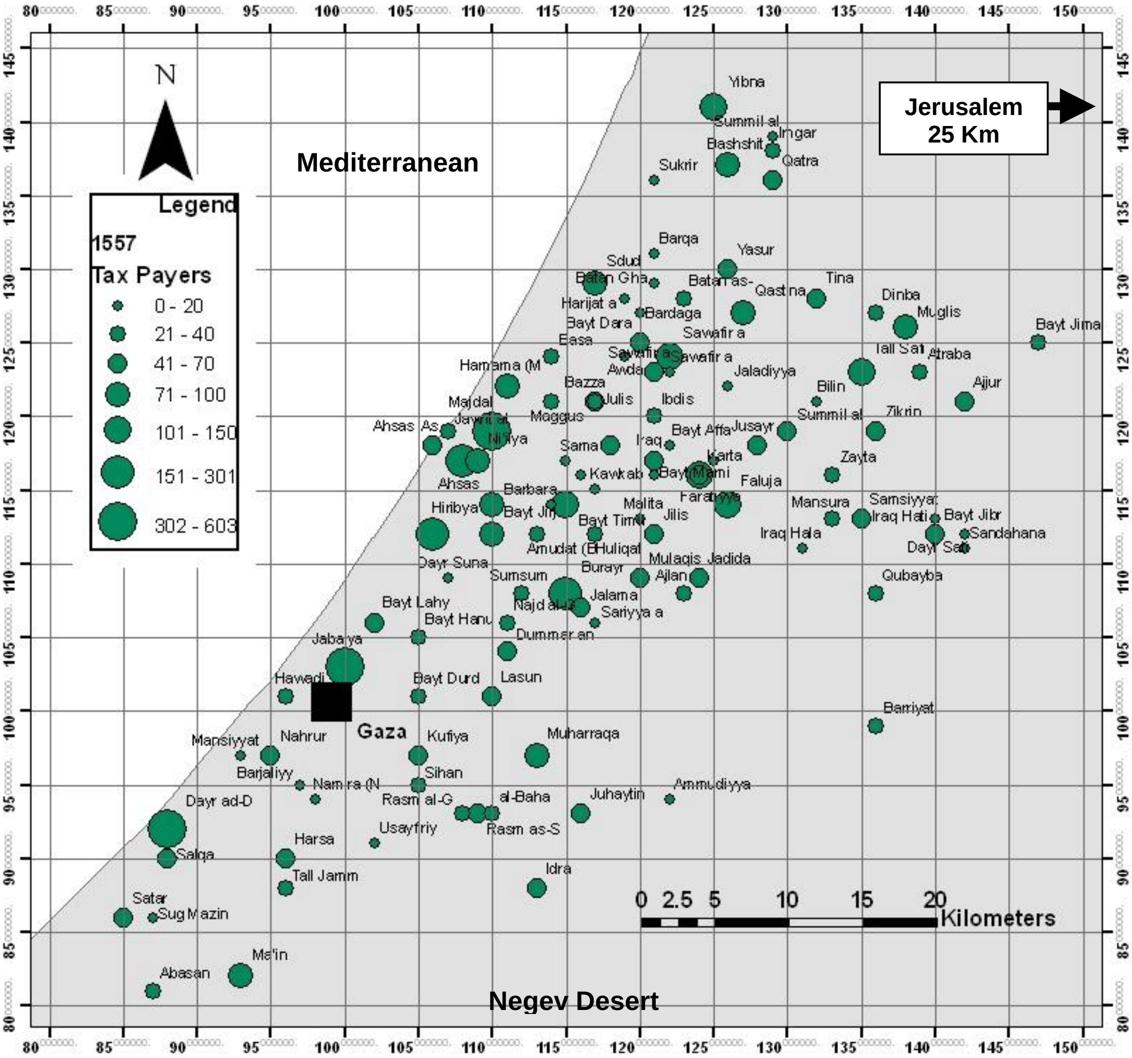
This paper is organized as follows: the next section (II) presents the patterns of demographic growth in the Gaza *nahiye* during the sixteenth century, and their relation to the geographic characteristics of this administrative unit; section III discusses the quantitative proxies and qualitative indications for climate fluctuations in Gaza during the sixteenth century; section IV introduces the primary source of the demographic data – the *tahrir defter*s – and considers its limitations; Section V presents the empirical strategy and the results of estimations of the differential impact of the climate fluctuation on the demography of southern and northern villages; Section VI discusses possible interpretations of the empirical results and section VII concludes.

II – Demographic Growth in the Gaza *Nahiye*

The sixteenth century Ottoman Gaza *nahiye* stretched along about 60 Km in the coastal plains in the southeastern corner of the Mediterranean. Currently, it corresponds to the Gaza Strip and parts of the southern Israeli coastal plains. It bordered the Mediterranean in the west, the mountainous Jerusalem district in the east, the Ramle *nahiye* in the north, the Negev desert in the south, and the Sinai desert in the southwest. Most of the district is flat with a hilly area at northeastern edges of the *nahiye*, in *Bayt Jibrin – Bayt Jimal* area (see map in Figure 1). The population of registered male taxpayers in the *nahiye* increased from 3,086 in ca. 1519, to 4,506 in 1532, to 6,794 in 1548 and to 7,091 in 1557. Under the assumption that an average male taxpayer was married and had three offspring, the recorded taxpaying population increased from about 15,000 to 35,000 within these four decades.

[5] The first study that used econometric method in analysis of *tahrir defter*s is: Coşgel, Metin M. and Thomas J. Miceli. "Risk, Transaction Costs, and Government Finance: The Distribution of Tax Revenue in the Ottoman Empire," *Journal of Economic History*, 2005, 65(3): 806-21.

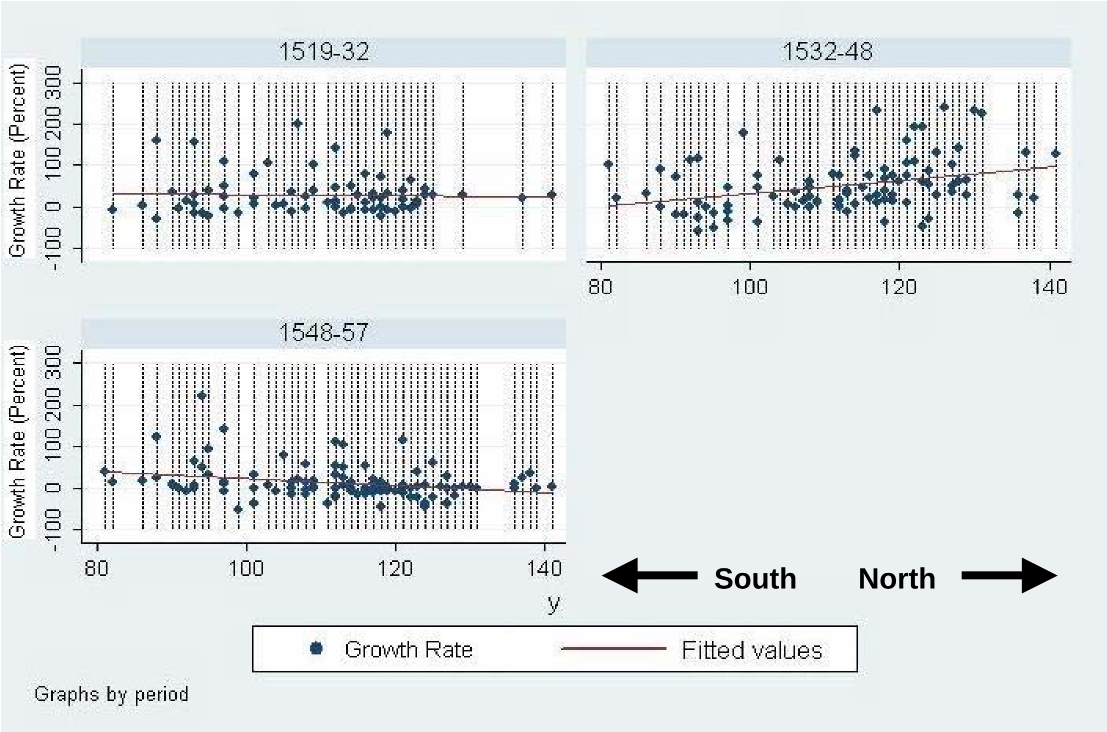
Figure 1: Villages in the Gaza *Nahiye* According to the 1557 *Defter*



Source: see section IV.

The main pattern that this study aims to explain is the differences in demographic growth rates between northern and southern villages within the Gaza *nahiye*. Figure 2 presents comparative the growth rates of male taxpayers in villages along the north-south axis, between latitude 80 and 143. It demonstrates that between the first and the second surveys (ca. 1519-1532) southern villages grew slightly faster than northern villages, while between the second and third surveys (1532-48) the north enjoyed substantially higher growth rates. Finally, between the third and fourth surveys (1548-57) the southern demographic growth rates overtook the northern growth rates.

Figure 2: Demographic Growth of Villages in the Gaza *Nahiye* (ca. 1519-1557)



Source: See section IV.

- The above sample excludes three outliers that had more than 300% or shrank by more than 66.6%.
- The latitude values are according to the Old Palestine Grid. Every unit of latitude represents one kilometer

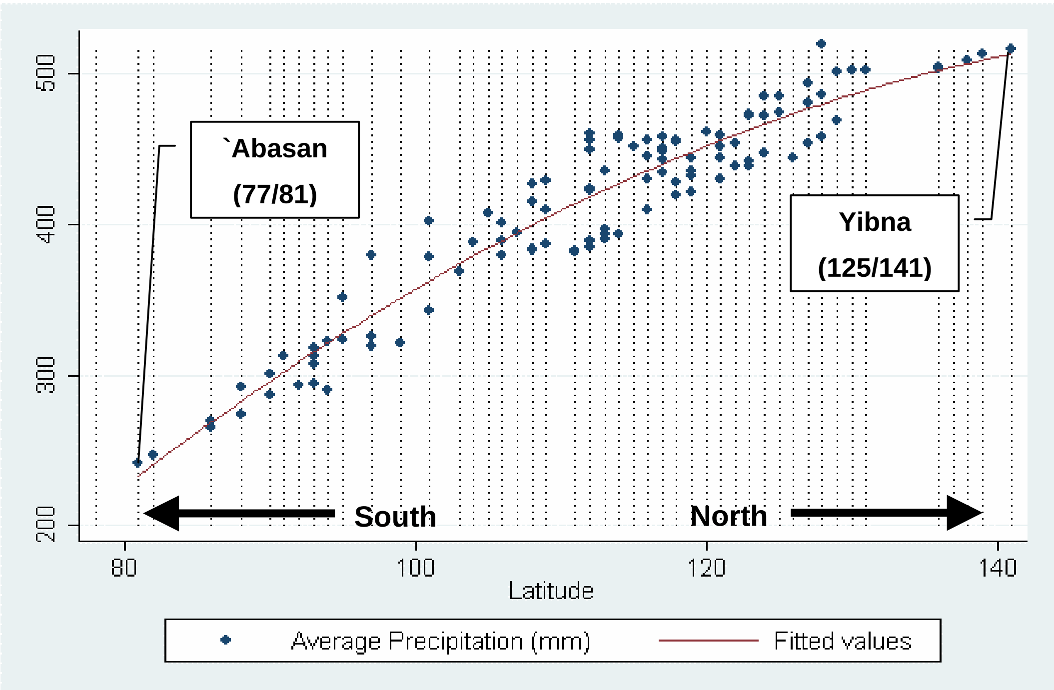
Table 1: Average Demographic Growth of Villages by Longitude

	i	ii	iii	iv	v	vi
	← South				North →	
Latitude	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-142**
1519-32	31.8% [4]	26.1% [15]	36.2% [14]	26.6% [25]	14.1% [14]	25.7% [2]
1532-48	49.7% [5]	19.1% [16]	29.3% [15]	44.9% [29]	83.4% [23]	108.1% [7]
1547-57	43.5% [5]	72.9% [17]	10.1% [17]	22.7% [35]	1.1% [24]	9.9% [8]
Note: Each cell includes villages that were identified in two successive surveys. The number of villages in each cell appears in brackets.						

The above pattern is also apparent in table 1, which presents the average growth rates of villages grouped by their latitude. The table includes the growth rates in taxpayers in villages that were identified in any successive surveys. It shows that the number of taxpayers increased throughout the period under study. Specifically, between the first survey (ca.1519) and the second survey (1532) the demographic growth rates of southern villages are slightly higher than northern growth rates. However, between the 1532 and 1548 southern villages (groups i and ii) grew by 49.7% and 19.1% while northern villages (groups v and vi) grew by 83.45 and 108.1% (respectively). Conversely, between 1548 and 1557 southern villages (groups i and ii) grew by 43.5% and 72.9%, while northern villages (groups v and vi) grew only by 1.1% and 9.9%. The pattern examined here is clear: virtually balanced growth (ca. 1519-32), substantially higher northern growth (1532-48), and significantly higher southern growth (1548-57).

This study conjectures that the above pattern is related to the climatic heterogeneity *within* the Gaza *nahiye*: The northern part of the sub-district is characterized by a Mediterranean climate and the southern part by semi-arid climate. The north-south difference is readily evident in the modern average precipitation for sixteenth century village locations presented in Figure 3: northern villages, such as *Yibna,* enjoy from about 500 mm of rainfall per annum, southern villages such as *`Abasan* have to endure with merely 250 mm rainfall per annum. The almost perfect correlation between the latitude and average precipitation (0.91 for the 109 located villages in the 1557 survey) is easily noticeable to contemporary wayfarers during the spring: a brief trip of a few kilometers northwards reveals taller and greener vegetation. The changing vegetation is also evident in the satellite image presented in figure 4.

Figure 3: Modern Average Precipitation of Located Villages



Source: See description of the sources (Section IV).

- The longitudes are quoted according to the Old Palestine Grid. Every unit of latitude equals one Km.
- The villages at the northern and southern edge of the sub-district and their coordinates are designated.

Figure 4: Satellite Image of Gaza, Jerusalem and Dana Reserve

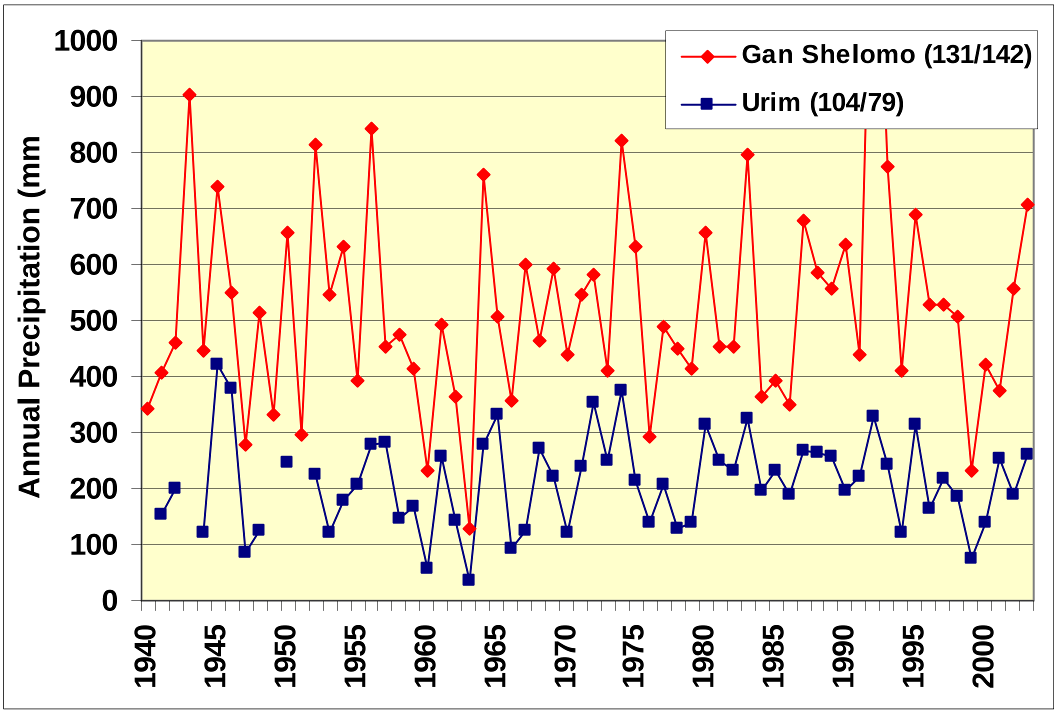
Source: Maps.Google.com

Notes: The Gaza *nahiye* stretched between *Yibna*, *Bayt Jibrin* and *`Abasan*; The Price data used in this paper are from Jerusalem and the tree rings data from Dana Reserve; The Sinai and the Negev deserts south to the Gaza and Jerusalem districts are clearly visible.

This pattern – wet climate in the north and semi-arid in the south – is related to the location of the Gaza *nahiye.* Virtually all the rain that showers the Gaza area arrives in rain systems above the Mediterranean. The center of most of these rain systems is near Cyprus (400 Km north to Gaza). Rain clouds from these systems do not move southwards because of the barometric heights above the Sinai and Negev deserts south to Gaza. This pattern prevails both in wet and in dry years. Modern precipitation data shows that in wet years most of the area of the Gaza *nahiye* enjoys from more than 300 mm of rainfall, which is desirable for successful cultivation of grain, while during dry years significant parts of the southern region of the *nahiye* had less than 300 mm of rain.

Figure 5 presents the annual precipitation at a northern location and at a southern location in the historical Gaza *nahiye*: Gan Slomo, (5 Km east to *Yibna*), and Urim (15 Km east to *'Abasan*). The averages of the annual precipitation in these locations between 1940 and 2003 are 524 mm and 212 mm (respectively). The annual precipitation series in these locations are well correlated (0.63), and the precipitation in northern location stochastically dominates the southern precipitation. In other words, wet and dry years occur together in both locations but the northern location is always wetter than the southern location.

Figure 5: Annual Precipitation in a Northern Location and a Southern Location (1940-2003)



Source: The Israeli Metrological Service.

The above figure reflects the fundamental climatic difference between northern villages and southern villages. It implies that southern villages were more vulnerable to climatic shocks than northern villages. Specifically, the southern villages were liable to get less than

200 mm of rain in a year and thus unable to sustain agriculture-based economy, and may even be constrained in human water consumption. This north-south pattern is the basic regularity used in the empirical analysis of the reaction of the rural demography to climate fluctuations in sixteen-century Gaza.[6]

III - Climate Fluctuations in Sixteenth Century Gaza *Nahiye*

The reconstruction of the sixteenth century climate in the Gaza *nahiye* is based on both quantitative proxies – tree rings and prices of agricultural goods – and qualitative evidence. None of these indications by itself provides solid information regarding historical climate. Only verification by comparison of the above *independent* indicators can yield a reliable indication for climate fluctuations in sixteenth century Gaza.

Tree-Rings from Southern Jordan

The tree ring data used in this study were extracted and published by Touchan et al. They used seventeen series of tree rings of *Juniperus Phoenicia* trees from Dana Reserve (30°38'N, 35°43'E) and Tor Al-Iraq (30°28'N, 35°30'E) in south Jordan (the location of the site is marked in figure 4) for the compilation of a single de-trended chronology (growth index, average=1000). The trees were located in semi-arid Mediterranean highlands that are elevated 1,100-1,400 m above sea level. They are located about 140 Km south-east of Gaza and benefit from the same westerlies that bring rain systems to Gaza. However, these trees could receive also limited amount of spring and autumn rainfalls that arrive from the Red Sea Trough; hence they received some rain from systems that did not pass over Gaza and were not correlated with Gazan rainfall. The mean modern annual precipitation in the nearby climate stations is 270 mm, which makes the trees sensitive to changes in annual precipitation. Of the seventeen tree ring series only four series cover most or all of the sixteenth century: BAR21 (1517-1995), WDD01A (1520-1888), WWD004 (1485-1962), and WDD09B (1469-1995). This study uses both the single tree-ring series and the integrated chronology compiled by Touchan et al.[7]

Touchan et al. report that the tree-ring index they calculated fits well the October-May precipitation recorded in stations near the sites of the trees between 1946-1995 (R^2=0.64). They used the growth index they calculated for reconstructing past climate in Jordan from the

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[6] It should be noted that under the climatic regime prevailing in the region rainfall is always a conducive for grain cultivation. In this water scarce region winter rainfalls are crucially needed after the seeding during the growth period of the wheat and barley, which lasts four to five months. Long breaks between rainfalls are likely to harm the young plants and often require new seeding of the fields. On the other hand, the dry late springs and summers ensure – unlike in parts of Europe – that the harvest stays dry and would not be ruined by showers.

[7] Touchan, R., Meko, D.M. & Hughes, M.K. (1999). "A 396-year reconstruction of precipitation in southern Jordan". *Journal of the American Water Resources Association*, 35. pp:49-59.

early seventeenth century onwards.[8] However, there are some reasons to doubt the validity of these tree ring series as proxies for the climate in sixteenth century Gaza: First, Gaza is distant from the trees' sites. Second, the *Juniperus Phoenicia* is not an ideal proxy for past climate. As other Mediterranean-subtropical trees, this species may produce multiple rings in one year or no rings at all in another year; analysis of such rings may yield false or misdated indications for past climate. Third, some *Juniperus Phoenicia* trees exhibit different growth patterns, even though they were located virtually in the same site. Plausible explanations for these differences are competition between trees and sensitivity to microclimate. Finally, the *Juniperus Phoenicia* does not grow symmetrically and may produce different chronologies from different sides of the very same tree.[9] These features of the tree rings series data shed doubt on their validity as proxies for climate, in general and for the climate of sixteenth century Gaza in particular. Hence, most of the current section is dedicate to examining the validity of these tree ring series as proxy for Gaza’s historical climate.

The main corroboration for the validity of the tree rings as proxy for Gazan climate is provided by the following examination of the statistical relations between these tree rings and modern precipitation in Gaza –Yibna – Jerusalem area. The modern precipitation data was generally collected in standard weather stations located along the area of the district and in Jerusalem. The data were compiled by the Israeli Metrological Service that has also managed the stations in Israel in the last six decades. The tree ring series examined here include both the de-trended integrated chronology computed by Touchan et al. and series of individual sixteenth century trees that lasted until the second half of the twentieth century (BAR21, WDD04 and WDD09).[10]

Table A1 in appendix A presents the coefficients of the South Jordanian tree rings series (β) in regressions of the modern precipitation data on the tree-rings series and time trend[11] ($rain_t = \alpha + \beta \cdot tree\text{-}ring_t + \gamma \cdot t + \varepsilon_t$), and table A2 reports the correlations between the tree ring series and modern precipitation. All the coefficients, except one coefficient of WDD04 are positive, and the vast majority coefficients of series with more than 45 observations are statistically significant. The vast majority of the correlations of the integrated chronology, BAR21, and WDD09B are in the range (0.2, 0.4). It is evident from both tables that WDD04

[8] Touchan et al (1999).

[9] Nili Liphschitz (2007). *Timber in Ancient Israel: Dendroarchaeology and Dendrochronology*. Emery and Claire Yass Publications in Archaeology. Tel Aviv: Institute of Archaeology, Tel Aviv University. pp: 146-165.

[10] It should be noted that the integrated chronology of the twentieth century is based on both 'old' trees, as well as younger trees. Thus the statistical relations between the modern chronology and precipitation data from Gaza area can only indicate that trees in southern Jordan could approximate for climate in Gaza. It does not imply that this index is a good predictor for the sixteenth century climate.

[11] The time trend is needed to clear trends in the tree ring raw measurements. For instance, the rings become narrow as a tree grows older.

provides a weak signal for modern precipitation probably because it ends in 1962, shortly after beginning of widespread and regular collection of precipitation data in this area. On the other hand both BAR21 and WDD09B are reasonable proxies for the modern precipitation. The integrated chronology provides a signal that is somewhat stronger than any individual series.

Due to the north-south monotonicity of precipitation in rural Gaza, the tree rings in southern Jordan are also able to capture the excess vulnerability of the southern locations. Table 2 presents the results of the estimation of the likelihood of a location to get more than 200 mm of rain in a year as a function of its latitude, the above tree rings, and the interaction between the two:

(1) $pr(rain_{i,t} > 200) = \beta_0 + \beta_1 Tree\_Ring_t + \beta_2 Tree\_Ring_t * Latitude_i + \gamma X_i + \varepsilon_{i,t}$

A positive β_1 suggests that the tree rings approximate a positive climatic sock, and a negative β_2 suggests that the tree tings approximate a greater increase in likelihood of southern locations to receive more than 200mm of rain than the increase in the parallel likelihood in northern locations.

Table 2: Probability of Annual Rainfall Exceeding 200 mm (1950-2003)

	Dependant Variable: pr(Rain>200)					
Tree Ring Series	**Unified Chronology**			**WDD09B**		
Tree-Ring* 10^3	0.84 (0.156)***	0.830 (0.162)***		9.33 (1.17)***	9.13 (1.43)***	
Tree-Ring* Latitude*10^5	-0.533 (0.122)***	-0.527 (0.125)***	-0.525 (0.130)***	-5.84 (1.12)***	-5.73 (1.16)***	-5.74 (1.30)***
Latitude*10^3	8.82 (1.97)***			7.19 (1.61)***		
Location F.E.	**N**	**Y**	**Y**	**N**	**Y**	**Y**
Time Dummies	**N**	**N**	**Y**	**N**	**N**	**Y**
R^2	**0.19**	**0.24**	**0.41**	**0.16**	**0.22**	**0.40**
Observations	**559**			**625**		

Robust S.E. in parentheses; location and time dummies are not reported.
The dataset includes annual rainfall in Abba Hillel, Beit Guvrin, Bror Hayil, Gan Shelomo, Hulda, Nizanim, Palmahim, Revadim, Ruhama, Shoval, Urim, Yad Modekhay, Yavne, and Yesodot between the years 1950 and 2003. **Excludes Bayt Jimal and Latrun in the hilly area.**
* 10%, ** 5%, ***1% significance level.
The units in these regressions are the actual measurements for the tree rings, and a growth index (average 1000) for the unified chronology).

The results presented in this sub-section suggest that the tree rings are acceptable proxies for the modern precipitation, and that they capture the excess vulnerability of southern location. However, corroborating the validity of these tree rings as proxy for sixteenth century climate fluctuations also requires historical evidence.

Official Prices of Rural Goods in Sixteenth Century Jerusalem

The official market prices in Jerusalem were announced by the local *kadi* (Islamic judge) and were recorded in the court records as part of regulation of the market. Amnon Cohen extracted these price quotes and published the prices of wheat, olive oil, and meat products.[12] The following analysis assumes that even though one of the aims of announcing official prices was to smooth price fluctuations the local *kadi* could not completely ignore significant scarcities or surpluses caused by droughts or bountiful years and had to adjust the official market prices accordingly.

The *kadi*s in sixteenth century Jerusalem announced these prices usually few times a year at irregular intervals.[13] There is no clear indication why local *kadi*s announced the official prices several times in some years and did not announced them even once in other years. Sometimes the official price lists provide additional qualitative indications regarding climate conditions. Notably, the 1544 and 1589 official price quotes of *simud* flour ground from imported wheat suggest that sufficiently large quantities of wheat were imported to require the announcement of separate prices of imported wheat.

At any rate, the wheat prices are an imperfect proxy for climate, as they were influenced by non-climatic factors, such as demographic changes, wars, trade, and monetary instability from the mid 1580s onwards. Therefore, grain prices are not used as proxies by themselves, but rather as corroboration for the validity of the tree-ring data as a proxy for sixteenth century Gaza: a negative correlation between the prices of an agricultural product and the tree ring series suggests that the region supplying this product to Jerusalem suffered from adverse supply shock when the above tree rings were thin, and benefited from a favorable supply shock when the tree rings were thick.

As different products were produced in different regions the price-tree rings correlations have spatial interpretations: Meat prices in Jerusalem reflect climate in a large area because herds of sheep and goats were brought to the holy city from a vast region including the Galilee, the Golan, Transjordan, and sometimes even from northern Syria. Prices of olive oil

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[12] Cohen also describes the process of setting the prices. See: Cohen (1988) p. **XXX**. The impact of climate on prices of agricultural products was examined in numerous studies of historical climate. An example for the Bauernfeind W. and Woitek U. "The influence of climatic change on price fluctuations in Germany during the 16th century price revolution" *Climatic Change*. 1999; 43(1): 303-321.

[13] Jerusalem is an exception to the Pamuk's observation that Ottoman kadis rarely announced official prices in periods of monetary stability. For more details about the official prices see Şevket Pamuk. *A Monetary History of the Ottoman Empire*. Cambridge: Cambridge University Press, 2000.

reflect climate in the hilly and mountainous district of Jerusalem (east to Gaza), and Nablus. Grain prices in Jerusalem were influenced by the climate in the coastal plains – including the Gaza district – which supplied grains to the city.[14] Therefore, the best corroboration for the validity of the south-Jordanian tree rings as proxies for the climate of Gaza is the correlations between the tree rings and the prices of wheat products: *simud* flour and *kmaj* (pita bread), *mawi*, and *tabbuni* breads.

The analysis of the time series properties of both the annual averages of prices and the tree-ring series for the years 1530-79, for which we have both types of data, is presented in appendix B. It shows that *simud* flour, kmaj bread and other products had positive and significant autocorrelation (eg. *simud* flour 0.53; kmaj bread 0.41) but the unit root hypothesis is rejected, usually after a time trend is included. Similarly, the raw tree ring series have positive and significant autocorrelation (0.29-0.46), while the filtered chronology does not have significant auto-correlation by construction. Once again the unit root hypothesis for the tree ring series is rejected. Therefore, the correlations between the tree rings and prices, when a time trend is controlled, are not spurious correlations resulted by their time series properties.

The following analysis of the statistical associations between the sixteenth century tree ring series and contemporary price data uses the price quotes, which began at 1530. I chose to analyze the price quotes published before 1579 to avoid the price fluctuations caused by the monetary instability of the 1580s and 1590s. The following table (3) presents the coefficients of the tree rings series (*β)*, when the log prices are regressed on log of the tree rings, time trend and dummy variables for the solar months:[15]

$$\ln(p_t) = \alpha + \beta \cdot \ln(tree\_ring) + \sum_{month=2}^{12} \delta_{month} \cdot d_{month} + year_t + \varepsilon_t$$

The vast majority of the coefficients are negative but not statistically significant. The most important result of these regressions is the negative and statistically significant *β* coefficients when the dependant variable was the *simud* flour; it indicates that all the tree rings series, except then young tree WDD01, are negatively and significantly correlated with the climate prevalent in the coastal plains that specialized in grain production. Specifically, an increase of 10% in width of the tree rings included in the unified chronology corresponded with an average decrease of 4.6% in the prices of wheat flour. The prices of *mawi* and the

[14] Analysis of the composition of production according to the Ottoman tax surveys show that the costal planes, including the Gaza district, specialized in grain production, while the grain production in the hilly and mountainous district of Jerusalem was limited. For this reason the Ottomans tried to ease the flow of grains from the costal planes to Jerusalem by exempting grains from road tolls on the way between Jaffa and Jerusalem. See Cohen, 1989, p. 119. Another example for supply of grain to Jerusalem is the Imperial soup kitchen, that collected tax in kind from villages in the Ramla *nahiye*.

[15] The results are virtually identical when one controls for lunar-Muslim months. It should be noted that the irregularity of the raw data and missing observations in the annual averages hamper a more sophisticated time series analysis that is required because of serial correlations in price data.

plain *kmaj* (pitta bread), are also negatively and significantly correlated with the unified chronology and two series of tree rings. But these correlations are smaller (in absolute values) probably because of the high labor input in their production.

Table 3: Regression Coefficients of Log Prices on log Jordanian Trees and Linear Trend Full Data (1531-1579)

	Wheat flour	Kmaj Bread	Mawi Bread	Tabuni Bread	Olive Oil	Goat Meet	Sheep Meat
Unified Chronology	-0.459 (0.117)***	-0.272 (0.114)**	-0.276 (0.156)*	-0.077 (0.121)	-0.290 (0.174)	-0.037 (0.036)	-0.018 (0.037)
WDD01A (1520-1888)	-0.113 (.087)	-0.034 (0.072)	-0.131 (0.108)	0.141 (0.105)	-0.126 (0.104)	-0.023 (0.032)	-0.035 (0.035)
WDD04 (1485-1962)	-0.432 (0.127)***	-0.283 (0.124)**	-0.292 (0.153)*	-0.071 (0.139)	-0.188 (0.171)	0.005 (0.028)	0.011 (0.032)
WDD09B (1469-1995)	-0.524 (0.131)***	-0.432 (0.130)***	-0.459 (0.179)**	-0.249 (0.139)*	-0.400 (0.149)**	-0.081 (0.028)***	-0.067 (0.031)**
BAR21 (1517-1995)	-0.184 (0.089)**	0.001 (0.117)	0.042 (0.138)	0.040 (0.107)	-0.100 (0.105)	-0.014 (0.027)	-0.004 (0.024)
Observations	133	95	83	92	84	198	207

Robust S.E. in parentheses; time trend and month dummies are not reported.
The observations from the 1580s and 1590s were dropped because of the monetary instability.
* 10%, ** 5%, ***1% significance level.
The units in these regressions are the actual measurements for the tree rings, and a growth index (average 1000) for the unified series calculated by Touchan et al. (1999).

Remarkably, the WDD09B series, the oldest series, is a good predictor of the prices of all the products but BAR21 is a relatively poor proxy for sixteenth century prices.[16] To sum up, the analysis of the statistical relationships of the Jordanian tree rings with both the historical data and the modern precipitation data suggest that the integrated chronology and the WDD09B are the best available – but not perfect – proxies for the precipitation in the sixteenth century Gaza. These tree ring series are used below as the quantitative indicators for the annual fluctuations in precipitations.

[16] This observation is opposite to the superiority of the BAR21 over WDD09B as a proxy for modern precipitation. It is plausible that the weak correlation between BAR21 and the sixteenth century price dada is related to the growth patterns of this tree at its early stages of development (BAR21 starts in 1520, while WDD09B starts in 1469).

Qualitative Evidence on Sixteenth Century Climate

Historical documents provide additional indications for climatic events, even though these indications are qualitative and are likely to be biased by the subjective perceptions and the interests of the authors of these documents. Evidence on trade, such as export and import of grains, are good indicators for good and bad years (respectively) because they reflect average supply in an area instead in specific locations, but they also depend on the economic and climatic conditions prevailing in other locations. Despite these limitations, these records can provide additional corroboration for the quantitative proxies for the sixteenth century climate.

The historical evidence on the climate in sixteenth century Jerusalem, and Jaffa and the corresponding tree ring values are presented appendix D and figure 6. They show that the qualitative indications on the climate in Jerusalem and Jaffa generally fit the tree rings from southern Jordan. For instance, both the qualitative evidence and the tree rings provide indications for droughts in the 1544-6, 1589-91, and 1998-9. The correlation between south Jordanian tree rings and climate in Jerusalem and Jaffa is probably the result of the westerlies that transfer rain systems from Jaffa and Jerusalem area to southern Jordan. At any rate, the qualitative indications provide further corroboration for the validity of the south Jordanian tree rings as a proxy for the climate in area of Jerusalem and Jaffa, which are adjacent to Gaza.[17]

I would like to focus on the qualitative evidence on the climate prevailing in the years preceding the Ottoman tax surveys (ca. 1519, 1532, 1548, and 1557), which are summarized in table 4 below. Unfortunately, I have not found such evidence regarding the years preceding the first two surveys, perhaps because the lack of suitable sources.[18] There are, on the other hand, few indications for bad climate in the mid-1540s, shortly before the 1548 survey was taken. In 1544 the official price list included the price of flour ground from imported wheat. This unprecedented announcement repeated only in 1589. Naturally, it indicates that large quantities of wheat were legally imported to Jerusalem. The wheat imports occurred when the the price of *simud* wheat flour soared from an average level of about 4.5 *hallabiya* in the years 1541-3 to a level of 11 *hallabiya* in the years 1544-5. Only after the harvest of 1546 did the price of *simud* return to the level of 4-5 *hallabiya*. Similarly, the price of olive oil doubled from 15-18 *hallabiya* in the years 1541-3 to 36 *hallabiya* for about two years starting September 1544.

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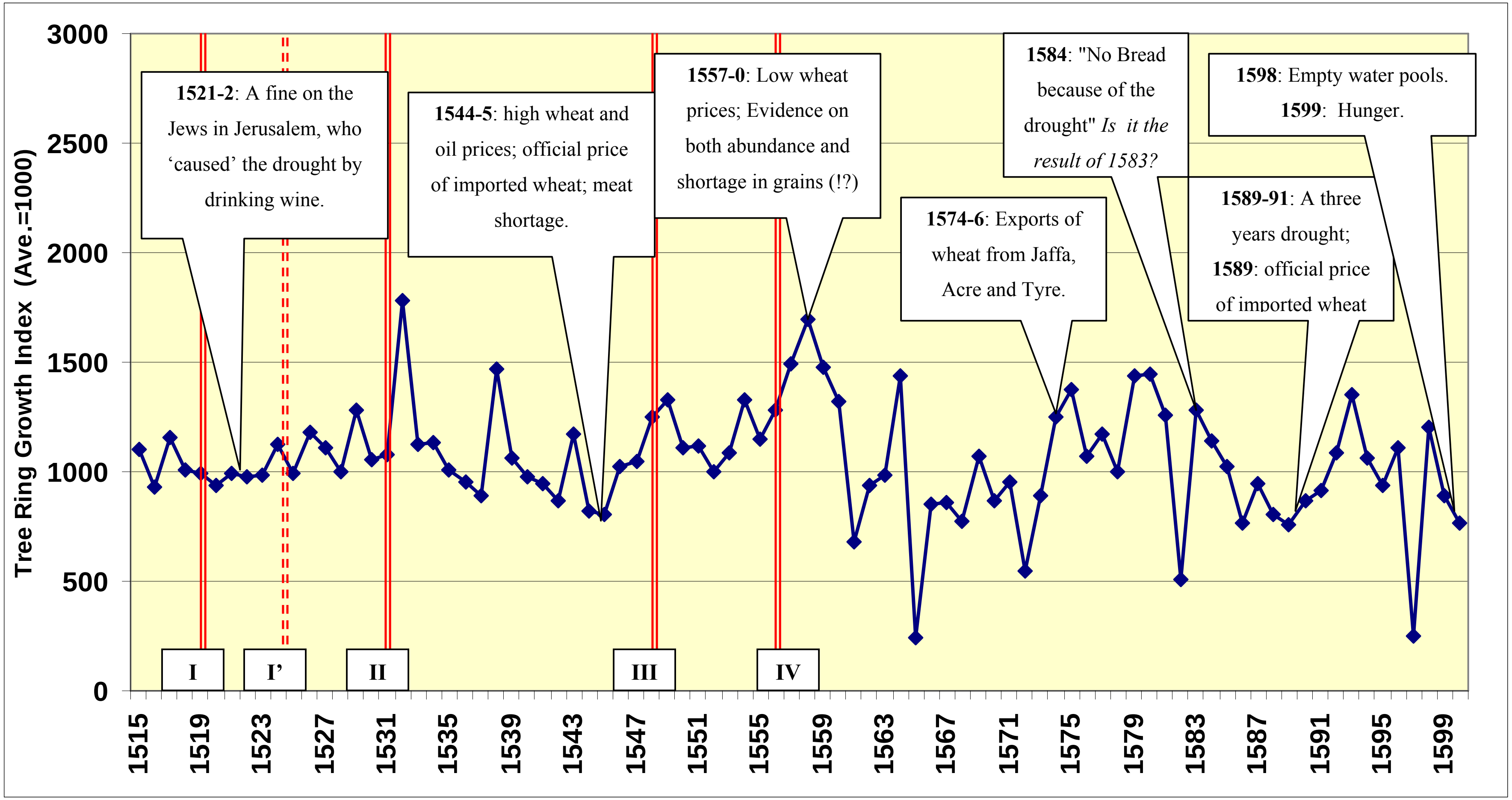
[17] Notably, qualitative indications for Galilee north to Gaza, which are excluded from this study, do not match the tree ring data. This finding matches the conclusion of Touchan et al. that the south Jordanian tree ring chronology does not match tree ring chronologies in Mount Carmel and northern Jordan. However, the two northern chronologies do match each other. See: Ramzi Touchan and Malcolm K. Hughes. "Dendrochronology in Jordan" *Journal of Arid Environments*, 42:4, August 1999, 291-303.

[18] The two main sources for sixteenth century Gaza and Jerusalem do not cover this period. The surviving court records of Jerusalem start from 1530, and the *Mühime defter*s from 1552.

Figure 6: Sixteenth Century Climate According to Tree Rings and Qualitative Indicators



Note: The dates of tax surveys are denoted with double lines and roman numbers: I - ca. 1519 (I' - 1525 Lewis' dating); II – 1532; III – 1548; IV – 1557.

Meat prices, on the other hand, exhibited only a modest increase, but the guild of the butchers was accused of neglecting its duty to supply meat to the holy city in 1546. This evidence coincided with very low levels of the standard tree ring index, 793 and 751 for the years 1544 and 1545 (respectively) in comparison to an average of 1086 in the period 1530-79.[19] All these qualitative and quantitative indications suggest that third survey was conducted after a few climatically difficult years.

The historical sources regarding the climate prevailing when the fourth survey was taken (1557) are somewhat confusing. In 1559 Istanbul sent a couple of decrees to that allowed the manager of an imperial *waqf* (pious foundation) to sell *old* grains stored in Ramla (40 Km North to Gaza) to traders from Rhodes and Dubrovnik because "living is cheap and supply is plentiful."[20] A seemingly contradictory decree from April 1560 mentions that during the preceding three-four years, i.e. 1558-60, no grain was produced in the district of Gaza because of the locust invasion and the lack or rain.[21] At any rate, the very high values of the tree ring index for the years 1556, 1557, 1558, and 1559 (1392, 1508, 1703 and 1470, respectively; average is 1056) as well the low wheat flour prices in Jerusalem, fit the first description of plentiful supply of grain, and not a grim depiction of shortage.

Climate Fluctuations in Sixteenth Century Gaza

To summarize, this section has presented quantitative and qualitative indications on the climate in sixteenth century Gaza – Jerusalem area. It shows that the tree rings from Southern Jordan are positively correlated with modern precipitation in the area of the historical Gaza *nahiye*. In addition, the tree ring data are negatively correlated with grain prices from sixteenth century Jerusalem (1530-79). Finally, the qualitative indications for the climate in Jerusalem and Jaffa generally fit the tree rings data. These results provide corroboration for the validity of the south Jordanian tree rings as a reasonable, but not ideal, proxy for the climate fluctuations in sixteenth century Gaza.

The aim of the inquiry into the climate fluctuations in sixteenth century Gaza is to explain the patterns of demographic growth in the *nahiye* as recorded in the tax surveys of the same period. Hence, it is crucial for this study to provide indications for the climate prevalent in the in few years before each one of the surveys. The tree ring chronology together with the main qualitative indications for climate fluctuations are presented in figure 6 and summarized in table 4. The tree ring chronology indicates that the climate in the first decade and a half of the Ottoman rule, when the first two surveys were taken, was quite stable and varied slightly above the long-term average (1000 points). The climate probably improved somewhat

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[19] The misery caused by the dry years was escalated with the 1546 earthquake that destroyed many houses in Ramle, Nablus, Jerusalem and probably in Gaza as well. Cohen (1989) p.23

[20] Heyd (1966) p. 131.

[21] Heyd, (1966) 131-2 n.5

between the first and the second surveys (1519-32).[22] The climate in the period between the second and the third surveys (1532-48) was drier and included two or three series of few successive dry years. Specifically, 1544/5 and 1545/6 were dry years that saw the doubling of wheat and oil prices in Jerusalem, complaints on shortage in meat, and importation of wheat, while the corresponding tree rings were quite thin. Both the tree ring and the price data suggest that the period between the third and fourth surveys (1549-57) was bountiful, but the qualitative indications seem to contradict themselves. Finally, the last four decades of the sixteenth century were characterized with switches from dry to wet years with indications for a few droughts in the last two decades of the century.

Table 4: Indications for Climate Prevailing Before The Dates of The Tax Surveys

	Year	Chronology 5 year MA	WDD09 5 year MA	Other Indications
I	**1519**	1036.6	82.0	N.A.
I'†	**1525**	1015.6	73.2	N.A.
II	**1532**	1237.8	84.2	N.A.
III	**1548**	988.	64.6	**1544:** Official price of imported wheat flour in Jerusalem. **1544-5:** High wheat and oil prices in Jerusalem. **1546:** Shortage of meat in Jerusalem.
IV	**1557**	1134.0	78.2	**1553-7:** Low wheat prices. **1559:** Permission to sell grain from previous years, because supply is plentiful. **1560:** Request to import grain because "no grain was produced in the Gaza district during the last three years".
Notes: the 5 year moving averages are for the years before the surveys were taken. † This study follows Singer's dating of the first defter, i.e. ca. 1519. Lewis dated the first defter to 1525. The empirical results below hardly change when the analysis is made according to Lewis' dating.				

This study conjectures that climate fluctuations – a minor improvement (ca. 1519-32), a sizable deterioration (1532-48), and a significant improvement in the prevailing climate (1548-57) – were the cause for the differential demographic growth in Gaza – somewhat higher southern growth (ca. 1519-32), higher northern growth (1532-48), and higher southern growth. In other words, it contends that the population of taxpayers in semi-arid southern villages was more sensitive to climate fluctuation than the same population in Mediterranean northern villages. The next section (IV) discusses the sources for the demographic data, and section V presents estimates of the impact of climate fluctuations on the demography of northern and southern villages.

[22] Lewis dated the first survey to 1525. The results of the empirical analysis do not change much when Lewis; dating is assumed.

IV – Main Data Source: *Tahrir Defter*s

The primary source for the demographic data (taxpaying males) analyzed in this paper is the *tapu tahrir defter*s, the Ottoman tax surveys. These surveys were initiated by Istanbul, which sent survey teams to its provinces in order to collect data. These teams included a high ranking Ottoman official, often a governor or a judge, a scribe from the Ottoman chancery, and military escort when needed. The aim of these documents was to enumerate the taxable units, estimate the revenues each one of these units was expected to yield, and allocate these revenues to various tax recipients: the sultan, the governor, local military officers, pious foundations (*waqf*s) etc. Indeed, the *tahrir defter*s were the blueprint of fiscal planning of the relevant district/s. The permanently population tax units listed in the *tahrir defter*s include towns (*qasba*), and villages (*qarya*), but agricultural production also took place in other tax units, such as grain fields (*mezra`a*), orchards (*bustan*) parcel of land (*qit'a ard*). The current analysis focuses on the demography of taxpayers in villages in the Gaza *nahiye.*

The *nahiye* was surveyed four times during the first four decades of the Ottoman rule. While the dates of the second, third and fourth *defter*s (1532, 1548, and 1557) are determined either by a date written in the document or by a clear cut outside evidence, the date of the first defter is not completely clear. Bernard Lewis, who was the fist scholar to examine this *defter* dated it to 1525.[23] Singer reviewed this issue and dated it with the other surveys the Ottomans conducted according to Sultan Selim's (d.1520) order after his conquest of the Mamluk Empire (1516-7). Therefore she dated the *defter* to ca. 1519.[24] The empirical analysis below follows Singer's dating but the results are not sensitive to changes in the date. A fifth defter was compiled in the 1590s. However, as other late sixteenth century *defter*s its reliability is doubtful and it seemed to be, at least partly, copied from the 1557 *defter*. Thus, this last *defter* is not used in this study.[25]

Typically, a record of a village in the Gazan *tahrir defters* includes the name of the village and its administrative affiliation; names, number and classification (by marital status and religion) of the adult male taxpayers; quantity and value of the crops paid in kind by the village (wheat, barley, beans, sesame etc.); the village specific tax rate levied on crop production (20-50%); tax on orchards, some summer crops and domesticated animals (sheep, goats and beehives). A record of a villages is presented in appendix C. The aims of recording the names of the taxpayers were to collect personal taxes and to prevent them from moving to other locations, and thus ensuring that the relevant village remained populated and productive. Assuming that unregistered males could move more easily than registered males,

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[23] Lewis 1952.
[24] Singer 1996. The prime minister's archives in Istanbul also dates this defter to ca. 1519.
[25] I analyse the evidence for copied entries in the last *defter* in my forthcoming dissertation. Heath highlighted the doubts on the reliability of late sixteenth century *defter*s in general. See **XXX**

the changes in the number of the registered taxpayers were probably smaller than the changes in the total male population.

It is important to stress that the *defter*s have several limitations as a source for demographic and economic history. The most relevant limitations for the current study of the spatial patterns of demographic growth are: First, as any administrative data source, it is influenced by the aims of the data collection and recording. Specifically, these tax records suffered from taxpayers' attempts to avoid the surveyors. Peasants were likely to try to avoid the census takers. Second, the surveys did not include population that did not pay tax, such as Ottoman and few Mamluk soldiers, nor demographic details on nomad tribes. These two limitations imply that the demographic data in the *tahrir defter*s is downward biased.

Third, the agricultural production recorded in the *defter*s is the *expected* production – according to once source the three years average – as estimated by the survey takers. Therefore. Mehmet Öz claımed that changes in the recorded production reflect mid-term and long-term changes not short term fluctuations.[26] In addition, not all the agricultural production was recorded in the village entries; some production took place in separate unpopulated tax units such as *mezra`a*s and and *bustan* for grain and fruits (respectively) production. In many cases, however, it impossible to link these tax units to the villages that cultivated them. Hence, any spatial analysis of the rural production cannot reflect shot-term fluctuations and it suffers from a considerable problem of incomplete information.

Fourth, the quality of the tax surveys – as the blueprint of the fiscal planning of the district – depended on the effective Ottoman control over the district, which varied from period to period. Thus, it is impossible to distinguish between real demographic growth, and an improvement in the Ottoman ability to record population. The analysis below assumes that the accuracy of the data within each survey is uniform, but could have changed between surveys. The assumption is justified by the fact that the same team conducted the survey throughout the district, which was administrated by the same governor, and probably had the same military escort etc. Under this assumption, differences in the growth of the population recorded in different villages do represent actual differences in the growth demographic.

Finally, there are several problems in identifying the names and locations of villages in the Gaza *nahiye*. The *tahrir defter*s are written in *siyakat* script, which was used for internal communications within the Ottoman administration. This script is difficult to decipher as the dots for the Arabic script are often missing[27] and it is easy to confuse between village names. The locations of the villages, mainly determined by Abdulfattah and Hütteroth and completed

[26] Öz.
[27] Usually one could not distinguish between letters such 'ب' (Ba), 'ت' (Ta), 'ن' (Nun), and 'ي' (Ya), when they appear between other letters. Similarly, there are other letter that only dots distinguish between them such as 'ق' (ka) and 'ف' (fa).

by the author,[28] are based on names of villages as recorded in British maps from the 19th and 20 centuries. Matching sixteenth century names written in *siyakat* by Ottoman officials with names recorded in Latin script by British map makers is liable to produce mistakes. It is also reasonable to assume that some names of locations 'migrated' during the three centuries between the compilation of the Ottoman tax surveys and the modern maps.

The locations of about 81% of the villages were identified on the modern British maps. A comparison between the located villages and the un-located villages suggests that the latter were demographically smaller and had relatively low wheat/barley ratio. As located southern village were demographically smaller, and had lower barley/wheat ratios than located northern villages, it seems that most of the not located villages were in the semi-arid south.[29] The selection of villages out of the group of villages that bore same name throughout the four Ottoman centuries is a plausible result of their presumed location in the semi-arid zone.

Despite these limitations, the *tahrir defter*s are a valuable unique primary quantitative source for the study of the demographic and economic history of the Ottoman lands, including the *nahiye* of Gaza. A careful application of modern statistical methods that addresses the biases and limitations of these data can provide reliable indications about *actual* demographic changes, and not only on changes *recorded* in the surveys. The following empirical strategy offers remedies for most of the above limitations.

V - Empirical Analysis

This section estimates the differential impact of climate fluctuations on the population of Mediterranean and Semi-Arid villages in the sixteenth century Gaza sub-district. The focus is on the number of taxpayers recorded in the *tahrir defter*s. The climate fluctuations are approximated by tree ring series from southern Jordan. The climate zone (the transition from Mediterranean to semi-arid) is approximated by two alternative variables: the longitude, and the ratio of wheat over barley in 1557.

The latitude is virtually vertical to the modern isohyets, the lines of equal average precipitation. This measure captures the gradual switch from Mediterranean climate zone to semi-arid climate zone as one moves from *Yibna* southward: high latitude (north) implies that the climate of the specific location is more similar to Mediterranean climate while low latitude (south) suggests that the village's climate is akin to semi-arid climate. The wheat over barley ratio in 1557 [30] reflects the composition of grain production between the drought

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[28] Abdulfattah and Hütteroth (1977).

[29] Haggay Etkes. "The Tahrir Defters as a source for economic and demographic history" a chapter in a forthcoming dissertation.

[30] Another chapter in my dissertation analyses tributes that villages made to nomads. It shows that villages that did no pay off the nomads reduced their wheat production in ca. 1519 and 1531. However, by 1548 the wheat/barley ratios of the paying off and non-paying off villages converged. Thus, the wheat-barley rations of 1548 or 1557 are the more suitable as proxies for the climate zone.

sensitive wheat, and the drought resilient barley. High wheat/barley ratio implies that the peasants expected relatively wet climate, and preferred to sow the more lucrative wheat. Conversely, low wheat/barley ratio suggests that the peasants preferred the safer but cheaper barley for they expected relatively dry climate.[31]

The merit of the latitude is its very high correlation with the average modern precipitation (0.95 in 1557, N=109). However, the sub-sample of the geographically located villages is not randomly selected, and some of the locations of villages are likely to be misidentified on the modern British maps. The wheat over barley ratio, on the other hand, is based only on data collected by the contemporary Ottoman officials. Thus, the observations included in the analysis based on this climate proxy are not selected. Moreover, this proxy does not bring about measurement errors, which are likely to attenuate the results based on the latitude. Yet, it is hard to interpret the results that are based on this measure. At any rate, the analysis below uses both the latitude and the wheat/barley ratio in 1557 as alternative and complementing proxies for the climate zone of the villages.

The focus of the following analysis is on the interaction between the proxy of the climate prevalent (tree rings) in the five years before the surveys were taken and the proxy for the climate zone of the village (latitude or wheat-barley ratio). It captures the differential impact of the wet/dry short periods on northern Mediterranean and southern semi-arid villages. The regression analysis is based on two basic specifications that capture the climate zones in different ways: A dummy variable specification, and a linear specification. The dummy variables specification assigns dummy variables to five groups of villages divided according to their longitude: 80-89, 90-99, 100-109, 110-119, and 120-129; the base group is the northern villages located between latitude 130 and 142. It uses the interaction between these dummy variables and the tree-rings for estimating the impact of the changing climate on different groups of villages. Formally, I estimate the regression:

$$(*) \qquad \ln(Y_{i,t}) = \alpha + \sum_{Latitude=80}^{120} \beta^{Latitude} \cdot l_i^{Longitude} + \sum_{Latitude=80}^{120} \delta^{Latitude} \cdot l_i^{Latitude} \cdot tree\_rings_t + + \gamma \cdot X_{i,t} + \sum_{t=2}^{4} \phi_t \cdot d_t + \varepsilon_t$$

where $Y_{i,t}$ is the number of taxpayers in village *i* at time *t*; l^{80}, l^{90}, l^{100}, l^{110}, and l^{120} are the dummy variables that designate the above groups, $tree\_rings_t$ is the five years moving averages of the tree rings series at time *t*; $X_{i,t}$ are village *i*'s characteristics including tax rate of village *i* at time *t*, longitude, and fixed effects; and d_t are time dummies. The interpretation of

[31] Wahbi, and Sinclair provide a through analysis of the comparative advantages of wheat and barley in Syria when precipitation changes. See: Wahbi, and TR Sinclair "Simulation analysis of relative yield advantage of barley and wheat in an eastern Mediterranean climate" Field Crops Research 91 (February 2005) 287–296

the results of this specification is straight forward: the coefficients of the interaction terms (δ^{80}, δ^{90}... δ^{120}) reflect the difference between the sensitivity of the average $Y_{i,t}$ in the relevant group to changes in the tree-ring chronology and the parallel sensitivity of the base group, i.e. the villages in the northern edge of the Gaza *nahiye*. For instance, δ^{90} is the additional sensitivity of villages located between longitudes 90 and 100, on top of the sensitivity of the villages located between longitudes 130 and 142. The primary merit of the dummy variable specification is that it does not impose a structure on the interaction between the average demographic growth of villages in the latitude groups and the proxy for the weather fluctuations.

The linear specification explicitly estimates the average change in the sensitivity to climate fluctuations (approximated by tree rings) of villages' taxpayers population as one switches from semi-arid to Mediterranean climate. The linear specification is:

(**) $$ln(Y_{i,t}) = \beta_1 + \beta_2 \cdot climate\_zone_i + \beta_3 \cdot tree\_rings_t + \beta_4 \cdot climate\_zone_i \cdot tree\_rings_t + \gamma \cdot X_{i,t} + \sum_{t=2}^{4} \phi_t \cdot d_t + \varepsilon_t$$

where $Y_{i,t}$ is the number of male taxpayers in village *i* at time *t*; $climate\_zone_i$ is one of the two continuous proxies for the climate zone (latitude or wheat over barley ratio) of village *i*, $tree\_rings_t$ are the five years moving averages of the tree rings series at time *t*; $X_{i,t}$ are village characteristics including village fixed effects, tax rate; and d_t are time dummies. A negative coefficient of the interaction between the proxy for climate-zone and the tree rings (β_4<0) implies that the impact of wet years is larger for semi-arid (southern) villages than for Mediterranean (northern) villages. The linear specification is virtually identical to the specification used in table 2, which demonstrates that the tree rings series capture the differential likelihood of Gaza villages to get over the 200 mm rain threshold.

Notably, these specifications address the above-mentioned deficiencies of the *tahrir* data. They obviate the problem caused by temporal changes in the quality of the *tahrir defter* data by looking at the differences in the growth rates of Mediterranean and semi-arid villages. Under the assumption of uniform quality of the data within each survey these specifications "cancel out" temporal changes in the Ottoman ability to record population. In addition, the selection bias caused by the difficulty to identify village locations in modern maps in about 19% of the villages to is addressed by using the alternative proxy for climate zone, the wheat/barley ratio, that is based solely on data recorded in the in the *tahrir defter*s. By the same token, this specification also solves the measurement errors caused by misidentification of village locations.

Estimation Results

Table 5 (p. 26) presents the results of the estimations of impact of climate fluctuation on demographic growth in few variations of the dummy variables specification (*). Columns (i) and (ii) use the full sample without and with location fixed effects (respectively). Column (iii) excludes outliers i.e. villages, whose taxpayers population grew by more than 200% or shrank by more than 50% between two surveys. Column (iv) controls for the villages' tax rate and location fixed effects. Columns (v)-(viii) analyze balanced panels of four and three periods, and columns (vi) and (viii) further restrict the sample to balanced panel of villages whose tax rate on crops did not change between surveys. Specifications (iv)-(viii) allow to test whether the results of the full sample estimations are not driven by either by the inclusion or dropping out of villages from the Ottoman tax records, or by changes in the tax rates on crops.

The pattern that persists in all of the regressions is a monotonic decrease in the sensitivity of the male population of villages to the proxies for the climate fluctuations as one moves northwards. The only exception is the higher sensitivity of the villages located between longitudes 90 and 99 than more southern villages locates between longitudes 80 and 89 (see figure 7). The reasons for this exception could be misidentified village locations or economic activity that is not directly related to climate.[32] At any rate, the persistence of the pattern – greater southern sensitivity to climate fluctuations in than northern sensitivity – in all the specifications suggests that this pattern is not resulted by selection into the sample or by changes in the tax rates. In fact, the results of columns (v) – (viii) indicate that these selection biases attenuated the estimated differences in the estimated sensitivities. Table 5 also reports the F-statistic and the p-values for the test of the hypothesis that all the coefficients are equal zero (H_1: $\delta^{80} = \delta^{90} = \delta^{100} = \delta^{110} = \delta^{120} = \delta^{130} \equiv 0$), against the hypothesis that they are not equal. In all the specifications, except the one without the outliers (column iii), the hypothesis is easily rejected.

Figure 7 presents the estimated impact of an increase of one standard deviation in the proxy of the climate (tree ring chronology) on the growth in the number of taxpayers. This estimation is based on the full sample fixed effect specification (column ii). It demonstrates that when the tree ring chronology increased by one S.D. the average demographic growth rates of villages located between latitude 110 and 119 was higher by 13.2% than the base group (latitude 130-142), while the growth rate of the villages located between longitudes 90 and 99, was higher by 25.8% than the based group.

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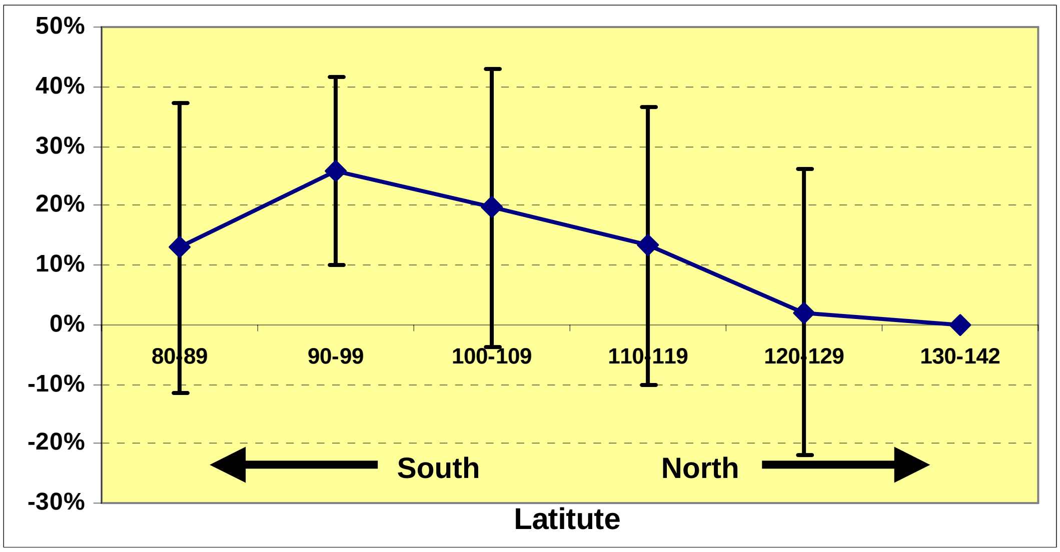
[32] An example for such non-agricultural activity is providing services to traders on their way to Egypt. This vivid trade left its traces in the form of a toll station in Khan Yunis and Gaza itself. The total expected toll revenues was between 50,000-100,000 akçe between ca. 1519 and 1557. The latter sum was equivalent to the tolls levied from 25,000 camel loads per year. See: Cohen and Lewis. p. 129.

Table 5: Estimated Impact of Climate Fluctuations on Rural Taxpayers Population - Dummy Variables Specification

		Dependant variable: ln(males)							
		Full Sample		**No † Outliers**	**Controll-ing for tax rate**	**4 period Balanced**		**3 period Balanced**	
						All	**Fixed Tax %**	**All**	**Fixed Tax %**
		i	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**
Interact-ions between Latitude dummies and Tree Ring Chronol-ogy	**D(80-89)* Tree ring*10^4**	8.40 (10.38)	8.57 (8.06)	14.37 (9.48)	11.79 (9.27)	11.72*** (2.36)	N.A.	10.59 (10.44)	21.94* (11.51)
	D(90-99)* Tree ring*10^4	20.32** (10.38)	17.06*** (5.17)	18.53* (9.42)	21.10** (9.09)	18.10*** (4.63)	26.85*** (3.35)	22.86** (10.88)	32.90*** (11.01)
	D(100-109)* Tree ring*10^4	15.34 (9.68)	12.98* (7.69)	14.86* (8.02)	15.47* (8.14)	14.21*** (2.83)	16.73*** (2.92)	15.02 (9.19)	24.07*** (8.56)
	D(110-119)* Tree ring*10^4	13.39 (9.68)	8.76 (7.68)	10.78 (8.02)	10.36 (8.11)	7.56*** (2.68)	7.38* (4.29)	10.61 (9.08)	20.67** (8.47)
	D(120-129)* Tree ring*10^4	0.86 (9.67)	1.34 (7.94)	7.44 (8.75)	4.40 (8.55)	7.45** (3.52)	4.48** (2.32)	2.99 (9.64)	10.10 (8.47)
Tax Rate *10^5					9.62 (9.09)				
F. E.		N	Y	Y	Y	Y	Y	Y	Y
Obs.		389	389	262	354	284	132	279	219
R^2		0.05	0.91	0.95	0.90	0.91	0.90	0.92	0.91
F-Stat $\delta^{80}=\delta^{90}=\delta^{100}=\delta^{110}=\delta^{120}=0$		**3.27*** (5,110)**	**2.63** (5,110)**	**1.10 (5,107)**	**2.41** (5,106)**	**15.6*** (5,70)**	**25.5*** (4,32)**	**1.95* (5,92)**	**3.28*** (5,72)**

Notes:
Robust standard errors.
* 10%, ** 5%, *** 1% significance level;
Period dummies are not reported
† Outliers – growth of taxpayer population >200% or <-50%.

Figure 7: Estimates of the differences in the Impact of One S.D. Increase in Tree Ring Chronology on Taxpayers Population by Latitude



- Te northern villages (latitude 130-142) are the base group.
- The estimates are based on the Full Sample F.E. results (Table 4, Culumn ii)

Table 6: Estimated Impact of Climate Fluctuations on Rural Taxpayers Population Linear Specification – Latitude as Proxy for Climate Zone

	Dependant variable: ln(males)							
	Full Sample		No‡ Outliers	tax rate Control	4 period Balanced		3 period Balanced	
					All	Fixed Tax %	All	Fixed Tax %
	i	ii	iii	iv	v	vi	Vii	viii
Chronology† $*10^{-3}$	4.80*** (1.62)	5.59** (1.31)	2.58 (1.79)	5.33*** (1.56)	4.53*** (1.29)	8.47*** (1.43)	3.61*** (1.69)	5.35** (2.21)
Chronology* Latitude$*10^{-5}$	-4.01*** (1.52)	-3.45*** (1.21)	-3.24*** (1.61)	-4.05*** (1.39)	-3.22*** (1.18)	-6.56*** (1.24)	-4.43** (1.69)	-5.99** (1.92)
Latitude$*10^{-2}$	4.72** (0.190)							
Tax Rate $*10^{5}$				9.91 (9.25)				
Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Observation	389	389	262	354	284	132	279	216
R^2	0.03	0.91	0.95	0.90	0.90	0.89	0.92	0.91

Robust s.e.; * 10%, ** 5%, *** 1% significance level; Period dummies are not reported
† Tree ring chronology in southern Jordan as calculated by Touchan, Meko, &. Hughes (1999)
‡ Outliers – growth of males population >200% or <-50%.

Table 6 presents the estimation results of varieties of the linear specification. The sub-samples in table 6 are the same sub-samples used in table 4 above. In all of the estimations the coefficient of the interaction between the tree-rings and the latitude is negative and statistically significant. It is statistically significant even for the 'no outliers' specification (column iii), for which the hypothesis of equal coefficients of the dummies specification was not rejected (see table 5, column iii). The interpretation of the full sample fixed effects specification (column ii) is: the sensitivity of a village to an increase of one s.d. in the proxy for the climate is on average larger by 5.2 % than the sensitivity of a similar village located 10 Km to the north.

As mentioned in the discussion of the limitations of *tahrir defter* data, the locations of only 81% sixteenth century villages were identified on modern maps. Moreover, the identified locations of some villages are likely to be erroneous. The characteristics of un-located villages, small population and low wheat/barley ratio, indicate that they were mostly located in the semi-arid area. Hence, the analyses presented in tables 5 and 6, which are based on the latitude as a proxy for climate zone is likely to suffer from both selection bias, in addition to attenuation caused by measurement errors. The alternative proxy for climate zone – the ratio of wheat over barley in 1557 – is not based on matching sixteenth century names with modern geographic data but rather solely on data collected by Ottoman officials. It reflects the decisions of local peasants, whether to increase the production of lucrative wheat or drought resilient barley: a high wheat/barley ratio fits Mediterranean climate and a low ratio fits semi-arid climate.

Table 7 presents the estimated results of the linear specification based on the 1557 wheat-barley ratio as proxy for climate zone. Naturally, these regressions include larger sub-samples than the above regressions presented in tables 5 and 6 for they include villages whose location was not identified. The persistent negative interaction between the proxy for the climate fluctuation (tree rings) and the proxy for climate zone (wheat/barley in 1557) is reproduced in these estimations and suggests that the population of semi-arid villages grew faster than the population of Mediterranean villages when climate was favorable. This regularity matches the results presented in tables 5 and 6 that demonstrate that southern villages were more sensitive to climate fluctuations than northern villages. Therefore, table 7 confirms that the estimated greater sensitivity of semi-arid villages to climate fluctuation was neither the result of selection in the compilation of the modern dataset nor of misidentified village locations.

Table 7: Estimated Impact of Climate Fluctuations on Rural Taxpayers Population Linear Specification – Wheat/Barley (1557) as Proxy for Climate Zone

	Dependant variable: ln(males)							
	Full Sample		No‡ Outliers	tax rate Control	4 period Balanced		3 period Balanced	
					All	Fixed Tax %	All	Fixed Tax %
	i	ii	iii	iv	v	vi	vii	viii
Chronology † $*10^{-3}$	1.16*** (0.34)	1.51*** (0.29)	-5.33* (3.08)	1.54*** (0.32)	1.51*** (0.29)	1.41*** (0.39)	-0.34 (0.30)	-0.13 (0.38)
Chronology * $W/B_{1557}*10^{-4}$	-7.95*** (2.55)	-7.79*** (2.38)	-8.11*** (2.38)	-7.62*** (2.42)	-6.12*** (2.02)	-5.52* (2.96)	-10.8*** (2.72)	-13.4** (0.29)
W/B_{1557}	1.09** (0.31)							
Tax Rate $*10^5$				5.74 (8.48)				
Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Observation	459	459	314	439	352	196	339	276
R^2	0.06	0.91	0.95	0.91	0.90	0.89	0.93	0.92

Robust s.e.; * 10%, ** 5%, *** 1% significance level; Period dummies are not reported;
† Tree ring chronology in southern Jordan as calculated by Touchan, Meko, &. Hughes (1999)
‡ Outliers – growth of males population >200% or <-50%.

To sum up, this section demonstrated that the taxpayer population of semi-arid / southern villages was more sensitive to climate fluctuation than the population of Mediterranean / northern villages. This greater sensitivity of southern population is robust to the selection of the proxy for *climate zone* (latitude or wheat/barley), and various specifications that control for the location fixed effects, village's tax rate, or those that are based on balanced sub-samples. Thus, these results are not artificial results of the deficiencies of the *tahrir defter* data: villages that dropped from and entered the sample; changing tax rates; unidentified or misidentified locations of villages. The greater sensitivity of the southern villages is also robust to the choice of the proxy for *climate fluctuations*. The tree ring series WDD09 was shown above (section III) to be a reasonable alternative proxy for sixteenth century climate. Appendix D replicates tables 5-7 using the WDD09 ad proxy for climate. It also demonstrates the greater southern sensitivity to climate fluctuation. Therefore, this statistical analysis provide substantial evidence that climate fluctuations as approximated by tree rings had stronger impact on the population of taxpayers in semi-arid village than on the population of Mediterranean villages. Plausible interpretations of this greater sensitivity to climate fluctuations of population of semi-arid villages, and its implications are discussed in the concluding sections.

V - Interpretations of the Differential Demographic Growth Rates

This paper provided evidence that differences in the growth of taxpayer population between northern and southern villages are related to greater sensitivity of population in semi-arid south to climate fluctuation in comparison to the Mediterranean north. Climate volatility could influence the demography through a few channels: fertility, mortality, and migration. Good climate could enhance rural production, nutrition, and hence fertility of a population that lives of low-calorie diet. By the same token, good climate can reduce mortality and enhance longevity because improved nutrition benefits health and the ability to endure diseases. However, as the demographic data used here includes only adult male taxpayers, presumably older than fourteen years,[33] and as the time gaps between the *tahrir* surveys are relatively short (13, 16, and 9 years), fertility is not a plausible explanation for the growth patterns examined here. Mortality of adults, on the other hand, is a possible explanation for the phenomena examined in this study.[34]

Migration is another possible reason for the differential north-south growth of taxpayer population. Good climate may attract population to southern and sparsely populated areas that can be cultivated in wet periods. The impact of a sequence of a few dry years could be even greater as residents of southern areas are likely to move to wetter areas in the north to find food. However, migration of peasants was prohibited by the Ottoman law, which aimed at securing tax revenues for the legal tax recipients. A decrease in the population of a village implied a decline in production, i.e. a diminution of the tax revenues of certain tax recipients. Thus, the Ottoman regulations authorized the tax recipients to bring migrant peasants back to their village of origin, or to collect from them fines. Only if the peasant resided in the new location more than ten years, he was not any longer legally bound to his previous location.[35]

Indeed, the very registration of the names of peasants in the *tahrir defter*s – which is the source for the demographic data analyzed above – was the main legal mean for binding a taxpayer to a location. Hence, the above analysis of demographic growth does not include

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[33] David Geza. "The age of unmarried male children in the tahrir, *Acta Orientalia* 1977. 347-357.

[34] The above discussion assumes that climate influenced rural demography through the direct effect of climate on agricultural production. However, analysis of the grain production does not reveal a similar robust impact of climate on the recorded grain production. In other words, the recorded grain production in southern villages does not seem to be more sensitive to climate fluctuations than production in northern villages. There are few possible explanations for this result: first, as Öz claimed the production data is expected, not *actual*, production, and analysis of this data reveals mid-term or long-term changes, not short term fluctuations. Secondly, much of the agricultural production, possibly the marginal production, took place in separate units such as grain fields (*mezra`a*s), and parcels of land (qit`a ard). Unfortunately, it is impossible to link the majority of these units to the villages that cultivated them. I also was not able to identify the locations of the majority of *mezra`a*s on modern maps. Hence, any spatial analysis of the agricultural production ought to be biased by unrepresentative data.

[35] Gümüsçüç provides details on the legal framework and the levels of the fines. Further details appear in David and Singer referred in the f.n. 39. See: Osman Gümüsçüç "Internal migrations in sixteenth century Anatolia" *Journal of Historical Geography* 30 (2004) 231–248

males, who were not recorded in the *tharir defter*s, either because of their young age or because they managed to avoid the census takers in two successive surveys, and presumably could migrate more easily. Therefore, migration is assumed to be somewhat under-represented is this analysis.

Despite the legal prohibitions, migration of peasants took place in various Ottoman provinces. Singer examined cases of migrant peasants whose cases were brought to the court in the Jerusalem district, which bordered the Gaza district. She mentions natural disasters, including droughts, as possible reasons for migration, but focuses on migrations that were result of oppression by the tax recipients such as *sipahi*s (cavalrymen). Singer shows that the *kadi* in Jerusalem applied the above-mentioned ten years criterion and demanded from migrating peasants to return to their original village or to pay extraordinary fines. However, she added that the Ottoman policy both in Jerusalem and in other locations was characterized by pragmatism and it allowed some migrants to avoid strict application of the anti-migration law. The latter observation coincides with Islamoğlu-İnan's conclusion regarding Anatolia that while migration to the towns was restricted, movements between villages were common.[36] Unfortunately, due to the limitation of the sources it is impossible to quantify the share of migrants in the districts of Gaza, Jerusalem in or any other adjacent district.[37]

Such quantifications were made for other Ottoman provinces. Gümüsçüç uses names of locations and personal nicknames that designate origin for studying migration in sixteenth century Anatolia. He claims that migration at the beginning of the century was insignificant, but increased to 3-5% in the second half of that century because of increasing population pressure.[38] These estimations are probably lower bounds because migration was not necessarily reflected in the names of all the migrants or in the names of their new neighborhoods. Additionally, naming a person is a social practice that could change from time to time, and thus it is difficult to interpret Gümüsçüç results. David, on the other hand, used a rare surviving draft of the local *tahrir defter* of Buda (Hungary). The survey takers tried to track down the migrating taxpayers, and explicitly marked those who left their village since the previous survey (1546). He found that 8.1% of the rural males recorded in the 1546 *defter* migrated by 1559.[39] Thus, even though the Ottoman law prohibited migration, historical

[36] Huri Islamoğlu-İnan's. p. 143.
[37] Singer A. "Peasant migration: Law and Practice in Early Ottoman Palestine *New Perspectives on Turkey* 8 (1992) 49-65. Faroqhi addressed the rural-urban migration and claim that it was difficult to trace the migrants, and that the "the only city where the Ottoman state intervened against new migrants on a significant scale was Istanbul." see: Suraiya Faroqhi. "Towns, Agriculture and the State in Sixteenth-Century Ottoman Anatolia" *Journal of the Economic and Social History of the Orient*, Vol. 33, No. 2 (1990), pp. 125-156
[38] Gümüsçüç. Ibid.
[39] David, G. "Data on the continuity and *migration* of the population in 16th century *Ottoman* Hungary" *Acta Orientalia* (Academiae Scientiarum Hungaricae), vol. 45, no. ii, pp. 219-252, 1991

studies provide solid evidence that it occurred both in a district adjacent to Gaza (Jerusalem) and in remote (Anatolia and Hungary) Ottoman districts. Consequently, we may posit that it was an important factor in the demographic patterns of sixteenth century Gaza as well.

In fact, two historical factors were likely to smooth migration of Gazan villagers. First, the population density in the *nahiye* of Gaza was quite low: between 3,086 and 7,091 adult male villagers, which are equivalent to about 15,000 and 35,000 people, on about 2,100 sq Km.[40] Ottoman historiography suggests that the first half of the sixteenth century was characterized by low population pressure in other, if not most, Ottoman provinces. Low population density could have eased migration because land was relatively abundant and the competition for land, even during droughts, was not very intense. Second, Gazan villagers did not own the land they cultivated. Most of the land was formally owned by the Sultan. The Ottoman bureaucracy allocated the rights to collect taxes-rents to various recipients. In fact, the primary sources of this study, the *tahrir defter*s, are the deeds of these allocations. The peasants had the right to cultivate the land in exchange to paying taxes. The above-mentioned laws against migration were needed because peasants did not loose much property when they moved to another location.

One indication for internal migration – within the boundaries of the Gaza *nahiye* – is the contrast between the 5.6% decline in the population of northern tax payers residing in villages located between longitudes 120 and 130 and the 16.1% growth of the same population in villages located south to latitude 110 when the climate improved between 1548 and 1557 (see table 8). Assuming that the favorite climate did not inflict direct damage to northern villages, their demographic decline was most likely the result of migration from northern villages to southern villages within the Gaza *nahiye*.

Table 8: Total Population by Year and Latitude Groups

	← South		Latitude		North →	
	78-89	**90-99**	**100-109**	**110-119**	**120-129**	**130-142**
ca. 1519	139 [6]	465 [16]	489 [15]	1049 [28]	427 [16]	80 [6]
1532	133 [5]	572 [17]	729 [17]	1619 [31]	659 [24]	183 [7]
1548	178 [6]	799 [17]	962 [17]	2364 [36]	**1183** [25]	364 [8]
1557	291 [7]	883 [17]	1078 [17]	2382 [36]	**1117** [25]	400 [8]

Source: See section III.

[40] There is no information the population of the nomad tribes.

Clearly, the above small internal migration cannot account for all the growth in the population of taxpayers in southern villages. The majority of this growth was probably the result of migration from outside the *nahiye* or registration of local peasants who were not recorded in the pervious survey. Anyhow, this indication for internal migration, adds to the above suggestive evidence: the frequency of migration in other Ottoman districts, the low population density, and the lack of peasant ownership on the land they cultivated. Together, they support plausibility of migration as the main explanation for the differential south-north growth rates of the taxpayer population. I contend that these migrations were induced by climate fluctuations.

I would like to draw on the current research literature to illuminate the interpretation of the demographic patterns in Ottoman Gaza. In the last two decades the economics and the development literatures on migration tend to stress the benefits of voluntary migration both to the migrants and to the areas they came from. These benefits include mainly the generation of higher income and greater income security by diversification the sources of income. The increasingly dominant view in the development literature contends that migration is "… the norm rather than the rule, as an integral part of societies rather than a sign of rapture – an essential element in people's livelihood, whether rich or poor."[41] This attitude is echoed in Moch's historical study of migration in early modern and modern Western Europe: "Migration is present in every level of historical study. ... On the village and regional levels, it constitutes a part of the 'social glue' of subcultures and responds to economic and social change."[42]

One relevant case of drought induced migration is the Sahel. This semi-arid area, located south to the Sahara, is characterized by comparable levels of precipitation to those in Gaza and it is vulnerable to droughts. In fact, it mirrors Gaza's precipitation pattern: the north is closer to the desert and drier and the south is wetter. The Sahel gained its 'fame' during the prolonged drought in the early 1970s, which led to a widespread famine, and consequently numerous studies were conducted in this area in the last three and a half decades. For instance, Henry et al. used census data from Burkina Faso (West Africa) to analyze internal migration. One of their main finding is that in the drier northern provinces of the environmental variables has greater explanatory power than socio-economic variables. This observation is not true for the wetter southern provinces.[43] This result from the Sahel

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[41] Arjan de Haan, (1999) "Livelihoods and poverty: The Role of Migration - a Critical Review of the Migration Literature", *Journal of Development Studies*, 36:2, p. 30. this article contains a survey of the migration literature in the context of developing countries.

[42] Leslie Page Moch, *Moving Europeans,* Indiana University Press, 2003. p. 23.

[43] Sabine Henry, Paul Boyle and Eric F. Lambin**. "**Modelling inter-provincial migration in Burkina Faso, West Africa: the role of socio-demographic and environmental factors" *Applied Geography*, Volume 23, Issues 2-3, April-July 2003, Pages 115-136.

corresponds to the greater sensitivity of semi-arid southern villages in Ottoman Gaza; it highlights the similarity between these two desert bordering regions.

In the Sahel, migration of both nomads and villagers is often depicted as a traditional survival strategy. Indeed, in modern period *Sahilians* migrated, temporary or permanently, to oversee destinations such as France. Internal migration, however, has being used to alleviate droughts both at the colonial period and recently. The impact of the 1983-5 droughts on Rural Mali, for instance, was examined by Findley. She concluded that the drought increased the levels of *circular* migration within the region from 22% to 42%, while reduced the level of migration abroad by a similar magnitude.[44] David Rain also depicted internal circular migration as a traditional survival strategy in his field study.[45]

A similar drought induced circular migration is the explanation this study offers to the greater sensitivity of the population of semi-arid villages to climate fluctuations than Mediterranean villages. It conjectures that villagers migrated from semi-arid villages to northern wetter villages during droughts, and returned to the sparsely populated southern areas when climate was more favorable. Such migrations are a plausible result of living in a volatile region. An increase in the volatility of

V – Conclusion

The current study explores the impact of moderate climate fluctuations on the population of rural taxpayers in sixteenth century Gaza. It focuses on the differences between demographic growth rates in villages located in semi-arid areas and in villages located in Mediterranean areas, and documents the greater sensitivity of semi-arid villages to climate fluctuations. Specifically, it shows that after few dry years the demographic growth in southern villages in the Gaza *nahiye* was lower than the parallel growth of northern villages, while an improvement in the climate was followed by higher southern growth rates.

The sources used in this study – the Ottoman tax records – do not allow us to distinguish between demographic changes that are caused by migration and those caused by mortality. The evidence for significant rural migrations in other Ottoman provinces, which took place despite numerous legal prohibitions, as well as other historical factors suggest that migration is indeed the plausible explanation for most of the differential demographic growth rates documented by this study. Similar circular migration is common as a survival strategy in another climatically volatile region at the desert frontier – the Sahel in Africa. Indeed, such

[44] Surprisingly, there was no significant increase in the total levels of migrations during the drought, only in the destinations. Sally E. Findley. "Does Drought Increase Migration? A Study of Migration from Rural Mali during the 1983-1985 Drought" *International Migration Review*, Vol. 28, No. 3 (Autumn, 1994), pp. 539-553.

[45] David Rain, *Eaters of the Dry Season: Circular Labor Migration in the West African Sahel*, Boulder, CO: Westview Press, 1999.

voluntary migration could improve the welfare of the migrants by increasing their expected income and by diversifying their sources of income.

Theoretically, exposure to uncertain climate should hamper location specific investment and production by risk avert agents. The Ottomans as well as other early modern states had limited policy tools to reduce the risks caused by climate fluctuations and specifically with unpredicted rainfall on desert frontier districts such as Gaza. During the 1960s, the Israeli government sought to solve this very same problem in the area of the sixteenth century Gaza *nahiye*, that is in the southern coastal plains. The state made large investments in the construction of “ha-movil ha-arzi” (The national water conduit) that was inaugurated in 1964. The main line of this large water conduit transferred water from the See of Galilee to the Israeli villages East to Gaza and reduced the dependence of local agriculture on rainfall. In addition, in early 1967 the state and the farmers' unions established an insurance company (Kanat Ltd.) that aims at providing cheap and reliable insurance. These two modern instruments supported the rapid growth of local agriculture despite the harsh ecology of this desert boarding area. Hypothesized increased climate volatility, due to the current climate change, may require similar investments in physical infrastructure and institutions in order to reduce the risks farmers face in desert bordering regions.

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Appendix A

Table A: Tree Rings and Modern Precipitation –Regression Coefficient

(S.E. in parentheses, Observations in Brackets)

$$rain_t = \alpha + \beta \cdot tree\text{-}ring_t + \gamma \cdot t + \varepsilon_t$$

	Index Standard	Bar21	wdd09b	wdd04
Miqwe Yisrael 128/159	0.145** (0.063) [70]	1.826*** (0.699) [70]	1.316* (0.699) [69]	-0.061 (0.722) [36]
Zrifin 135/152	0.145** (0.071) [58]	1.887* (0.836) [58]	1.873** (0814) [57]	3.429 (3.938) [24]
Palmahim 122/149	0.038 (0.063) [45]	0.352 (1.173) [45]	0.927 (0.827) [44]	Less Than 20 Obs.
Yavne 127/145	0.235 0.139 [41]	1.525 1.521 [41]	1.916* (1.049) [40]	Less Than 20 Obs.
Gan Shelomo 131/142	0.221*** (0.076) [56]	1.621*** (0.573) [56]	2.824*** (0.938) [55]	5.223 (5.408) [22]
St. Anna (Jerusalem)	0.321*** (0.000) [141]	1.979*** (0.479) [141]	1.003** (0.463) [141]	0.969* (1.281) [113]
Hulda 138/137	0.175** (0.076) [59]	1.913** (0858) [59]	1.843** (0.888) [58]	10.313* (5.381) [25]
Latrun 148/137	0.189** (0.082) [48]	1.452* (0.768) [48]	1.102 (0.871) [47]	5.977 (7.850) [20]
Yesodot 137/136	0.135* (0.076) [46]	2.274 (1.406) [46]	1.863* (0.992) [45]	Less Than 20 Obs.
Revadim 132/131	0.051 (0.067) [39]	1.131 (1.229) [39]	0.364 (0.927) [39]	Less Than 20 Obs.

	Index Standard	Bar21	wdd09b	wdd04
Beit Jimal 145/125	0.165*** (0.055) [71]	2.396*** (0.585) [71]	1.715*** (0.608) [70]	0.458 (2.553) [37]
Nizanim 115/124	0.191*** (0.069) 49	2.303** (0.992) 49	2.122** (0.873) 48	Less Than 20 Obs.
Abba Hillel 114/120	0.020 (0.075) [37]	1.175 (0.819) [37]	0.274 (0.789) [37]	Less Than 20 Obs.
Beit Jubrin 140/113	0.138*** (0.051) [44]	2.433** (0.958) [44]	1.306* (0.701) [43]	Less Than 20 Obs.
Yad Mordekhay 109/110	0.237*** (0.089) [36]	3.434*** (1.713) [36]	2.171* (1.089) [35]	Less Than 20 Obs.
Bror Hayil 116/107	0.126* (0.063) [43]	1.678 (1.189) [43]	1.646* (0.834) [42]	Less Than 20 Obs.
Ruhama 122/100	0.105** (0.050) [55]	1.457** (0.689) [55]	0.594 (0.596) [54]	3.399 3.634 [21]
Shoval 125/91	0.076* (0.042) [49]	1.737** (0.759) [49]	0.578 (0.557) [48]	Less Than 20 Obs.
Urim 104/79	1.710*** (0.380) [56]	1.710*** (0.380) [56]	0.594 (0.387) [55]	-0.571 (2.387) [22]

Note: WDD01 ends in 1888 before the beginning of systematic collection of most precipitation data.

Appendix B: Analysis of Time Series Variables: Tree Rings, and Prices.

Table B1: Descriptive statistics of time series variables (1531-79)

	Variable	Obs	Mean	Std. Dev.	Min	Max
Prices (Qita/Para)	ln_simud (wheat flour)	45	1.80	0.34	1.19	2.69
	ln_tabbuni (bread)	41	1.58	0.32	1.10	2.44
	ln_kmaj (bread)	40	1.76	0.28	1.29	2.77
	ln_mawi (bread)	37	1.38	0.35	0.16	2.00
	ln_oil (olive oil)	38	3.13	0.29	2.56	3.73
	ln_goat (meat)	47	2.62	0.15	2.37	2.87
	ln_sheep (meat)	47	2.76	0.17	2.49	3.13
Indicators for precipitation	Precipitation index (Jordan)	49	1085.70	233.07	606.20	1660.53
	bar21 (tree)	49	51.69	17.12	15	89
	wdd01a (tree)	49	118.63	47.88	14	271
	wdd04 (tree)	49	78.71	23.49	41	138
	wdd09b (tree)	49	59.12	19.73	12	92

Table B2: Auto-regression and Dickey Fuller Test of log Prices 1530-79

	Wheat flour	**Kmaj Bread**	**Tabuni Bread**	**Mawi Bread**	**Olive Oil**	**Goat Meet**	**Sheep Meat**
AR(1) 1530-79	0.53*** (0.139)	0.410*** (0.145)	0.187 (0.226)	-0.133 (0.319)	0.115*** (0.004)	0.311** (0.158)	0.304 (0.128)
Trend	0.009* (0.005)	Not Significant	0.0127*** (0.004)	0.125*** (0.003))	0.271 (0.215)	0.009*** (0.001)	0.010*** (0.001)
Obs.	45	40	41	37	38	47	47
Dickey Fuller †	-3.08** (0.03)	-5.60*** (<0.001)	-4.09*** (0.006)	-7.19*** (<0.001)	-3.98** (0.01)	-4.52*** (0.001)	-4.74*** (0.001)
Trend	Not Significant	Not Significant	0.010** (0.004)	0.012*** (0.004)	0.009** (0.003)	0.006*** (0.002)	0.007*** (0.002)
Obs.	41	31	35	28	32	44	44

S.E. in parentheses

The observations from the 1580s and 1590s were dropped because of the monetary instability.

* 10%, ** 5%, ***1% significance level.

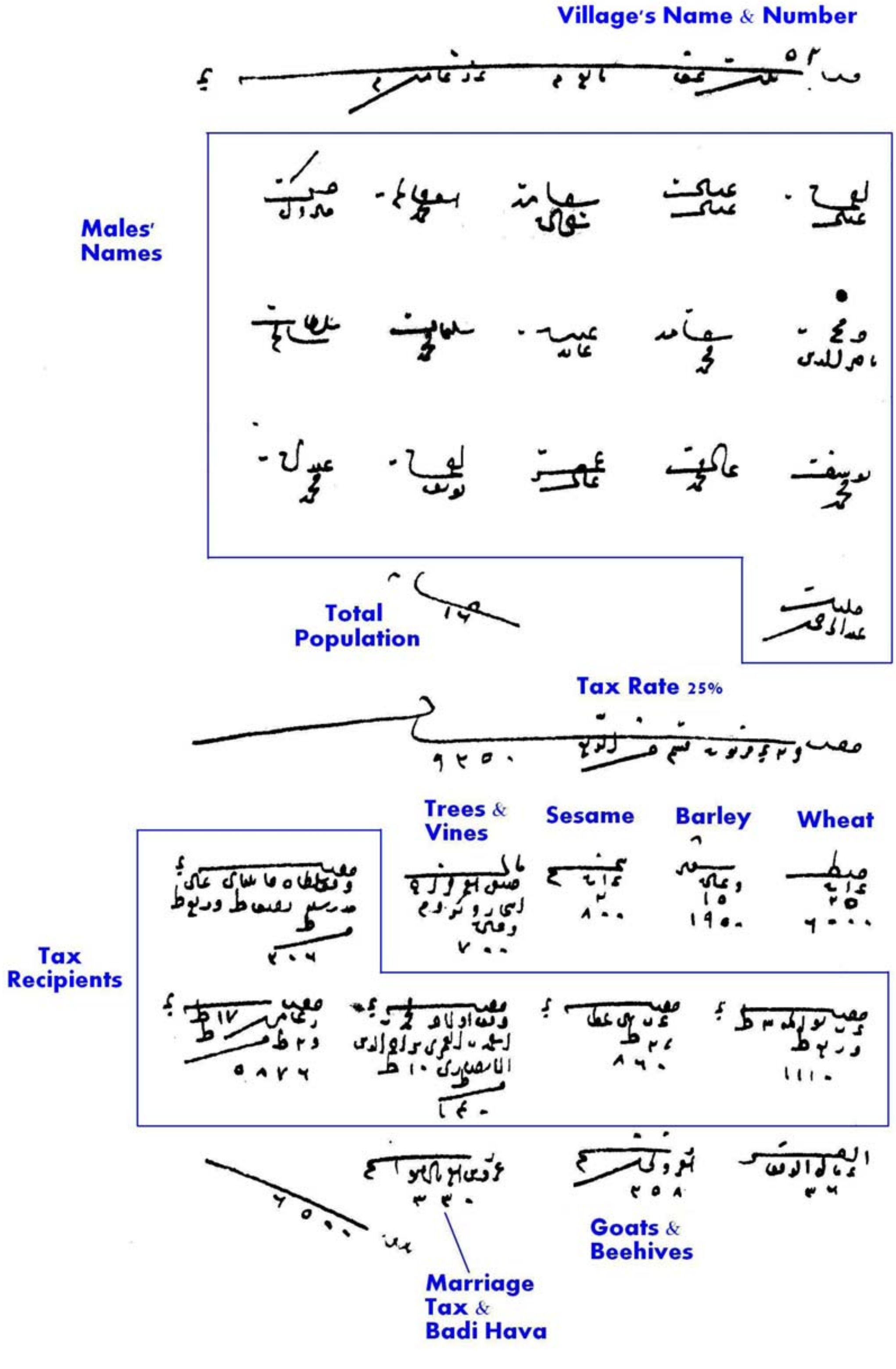
† The significance of the Dickey-Fuller statistic are marked with asterisks, and the MacKinnon p-value in brackets.

Table B3: Auto-regression and Dickey-Fuller Test of Tree Ring Series 1530-79

	Bar21	**Wdd01a**	**Wdd04**	**Wdd09b**	**Integrated Chronology**
AR(1) 1530-79	0.288** (0.132)	0.380** (0.152)	0.464*** (0.153)	0.328* (0.171)	0.293 (0.193)
Trend	Not Significant	Not Significant	Not Significant	-0.684*** (0.263)	Not Significant
Observations	50	50	50	50	50
Dickey Fuller †	-4.55*** (<0.001)	-4.34*** (<0.001)	-4.15*** (0.001)	-4.60*** (0.001)	-5.07*** (<0.001)
Trend	Not Significant	Not Significant	Not Significant	-0.323*** (0.188)	Not Significant
Observations	50	50	50	50	50

S.E. in parentheses
The observations from the 1580s and 1590s were dropped because of the monetary instability.
* 10%, ** 5%, ***1% significance level.

Appendix C: A Record from the *Tahrir Defter*: *Bayt ‘Afa* (1557)



Source: TT304, Prime Minster’s Archives (Istanbul).

Appendix D: Estimation Results of the Impact of Climate Approximated by Tree Ring Series WDD09B on Demographic Growth of Gazan Villages

Table D1: Estimated Impact of Climate Fluctuations on Rural Taxpayers Population - Dummy Variables Specification

		Dependant variable: ln(males)							
		Full Sample		**No † Outliers**	**Controll-ing for tax rate**	**4 period Balanced**		**3 period Balanced**	
						All	**Fixed Tax %**	**All**	**Fixed Tax %**
		i	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**
Interact-ions between Latitude dummies and Tree Ring Chronol-ogy	**D(80-89)* Tree ring*10^4**	8.15 (10.95)	12.50 (8.06)	16.22 (11.66)	15.69 (11.24)	21.55*** (4.70)	N.A.	13.68 (12.26)	27.07* (14.02)
	D(90-99)* Tree ring*10^4	26.20** (12.20)	24.57** (11.47)	19.24* (11.40)	28.94** (11.94)	31.81*** (7.79)	46.69*** (4.65)	27.44** (13.12)	38.78*** (13.73)
	D(100-109)* Tree ring*10^4	16.15 (10.76)	14.44 (9.23)	14.64 (9.53)	17.29* (9.89)	22.45*** (3.55)	25.88*** (3.44)	16.81 (10.48)	26.84*** (10.08)
	D(110-119)* Tree ring*10^4	16.82 (10.76)	10.95 (9.30)	10.16 (9.64)	13.58 (10.54)	13.95*** (3.65)	14.77** (5.65)	12.08 (10.54)	23.71** (10.30)
	D(120-129)* Tree ring*10^4	-0.21 (10.61)	10.3 (9.62)	5.48 (10.33)	5.02 (10.54)	13.69** (5.59)	8.69** (3.87)	2.31 (11.04)	10.34 (10.52)
Tax Rate *10^5						9.12 (8.89)			
F. E.		N	N	Y	Y	Y	Y	Y	Y
Obs.		389	389	389	262	354	284	132	279
R^2		0.05	0.05	0.91	0.95	0.90	0.91	0.90	0.92
F-Stat $\delta^{80}=\delta^{90}=\delta^{100}=\delta^{110}=\delta^{120}=0$		**3.27*** (5,110)**	**3.21*** (5,110)**	**2.39** (5,110)**	**1.97 (5,107)**	**2.06* (5,106)**	**17.15*** (5,70)**	**38.6*** (4,32)**	**2.04* (5,92)**

Notes:
Robust standard errors.
* 10%, ** 5%, *** 1% significance level;
Period dummies are not reported
† Outliers – growth of taxpayer population >200% or <-50%.

Table D2: Climate fluctuations Demographic Growth Gaza Sub-District (1519-57)
Linear Specification - Latitude as Proxy for Climate Zone, Explanatory Variable WDD09

	Dependant variable: ln(males)							
	Full Sample		No‡ Outliers	tax rate Control	4 period Balanced		3 period Balanced	
					All	Fixed Tax %	All	Fixed Tax %
	i	ii	iii	iv	v	vi	vii	viii
WDD09† $*10^{-2}$	6.25*** (2.05)	7.05*** (1.89)	2.85*** (2.04)	7.71*** (2.04)	7.93*** (2.08)	14.0*** (2.08)	4.54* (2.53)	6.55** (2.73)
WDD09† Longitude$*10^{-4}$	-5.03*** (1.95)	-5.07*** (1.75)	-3.89** (1.83)	-5.59*** (1.91)	-5.55*** (1.94)	-10.7*** (1.89)	-5.59*** (2.06)	-7.39*** (2.36)
Longitude$*10^{-2}$	4.07** (1.70)							
Tax Rate$*10^{3}$				9.35*** (9.03)				
Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Observation	389	389	262	354	284	132	279	219
R^2	0.03	0.91	0.95	0.90	0.91	0.90	0.92	0.91

Time dummies are not reported; Robust s.e.; * 10%, ** 5%, *** 1% significance level
‡ Outliers – growth of males population >200% or <-50%.
Dummy variables for years are not reported.
† growth index in southern Jordan as calculated by Touchan, Meko, &. Hughes (1999)

Table D3: Climate fluctuations Demographic Growth Gaza Sub-District (1519-57)
Linear Specification - W/B_{1557} as Proxy for Climate Zone, Explanatory variable WDD09

	Dependant variable: ln(males)							
	Full Sample		No‡ Outliers	tax rate Control	4 period Balanced		3 period Balanced	
					All	Fixed Tax %	All	Fixed Tax %
	i	ii	iii	iv	v	vi	vii	viii
WDD09† $*10^{-2}$	1.84*** (0.55)	2.52*** (0.46)	-0.76** (0.37)	2.56*** (0.51)	2.70*** (0.45)	25.5*** (6.17)	-0.52 (0.40)	0.25 (0.46)
WDD09† $W/B_{1557}*10^{-3}$	-11.3*** (3.08)	-11.6*** (2.87)	-9.36*** (2.80)	-11.7*** (2.95)	-10.6*** (2.68)	-9.70*** (4.12)	-12.9*** (3.16)	-16.2*** (3.38)
W/B_{1557}	1.07*** (0.27)							
Tax Rate$*10^{3}$				5.79 (8.42)				
Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Observation	459	459	314	439	352	196	339	276
R^2	0.06	0.91	0.95	0.91	0.90	0.89	0.92	0.92

Time dummies are not reported; Robust s.e.; * 10%, ** 5%, *** 1% significance level
‡ Outliers – growth of males population >200% or <-50%.
Dummy variables for years are not reported.
† Raw measurements of series WDD09B.

Appendix E – Qualitative Evidence on Sixteenth Century Climate

Year	Location	Fit Dana tree rings	Good/Bad qualitative indication	Tree Rings Standard Ave. 1052.	WDD09 Ave. 54.6	Indication	Source
30 Nov. 1521	Jerusalem	Y	Bad	889		The Jewish community had to pay a 200 ducats fine because 'their wine drinking caused a drought'.	יערי "שנות בצורת" ע 85
1544/5	Jerusalem	Y	Bad	793, 751	38, 56	Sharp increase in wheat and oil prices and official price of Egyptian wheat in Jerusalem.	Cohen. p.142, 158.
April 1545	Gaza	Y	Bad	793, 751	38, 56	A Gazan cavalryman complained that he got an estate yielding 1,800 akçe instead of 5,999 he was expected to get from his previous estate.	بيات (114)
1545/6	Jerusalem	Y	Bad	751, 994	56, 74	1546:Complaints on scarcity of meat in Jerusalem. Meat prices were fixed four times;	Cohen (1989) p. 23
1558-9	Ramle	Y	Good	1703, 1470	61, 75	Permission to sell grains to merchants from Rhode (June 1559) and old grain to traders from Ragusa (Nov. 1559) because "Supply is plentiful and cheap", there is "no demand" and prices are low.	Hyed. P.130-1 بيات 114
1558-60	Gaza and Jerusalem	N	Bad	1560: 1268		Drought and locust for the last few years.	بيات 196
1574-6	Jaffa, Acre and Tyre	Y	Good	1308 & 1448	40, 48, 44	1575 Export of Wheat to Istanbul through Jaffa. July 1576 Christian galleys attacked Muslim ships exporting wheat from Acre and Tyre.	Leonhart Rauwolff in Ray p.268 Heyd. P. 129

Year	Location	Fit Dana tree rings	Good/Bad qualitative indication	Tree Rings Standard Ave. 1052.	WDD09 Ave. 54.6	Indication	Source
July 1584	Jerusalem	N	Bad	1121	51	No water and no bread, and the fields are dry because there was no rain throughout the last winter.	שמשון בק . אגרות ארץ ישראל.
1584	Galilee	N	Bad	1121	51	The Galilee was in turmoil because of the famine.	בנטוב, ע' 218.
1589	Jerusalem	Y	Bad	785	28	Price of imported wheat	Cohen
1591	"whole country"	Y	Bad	932	44	Rabbi Josef Terani: The year 5351 (1590-1 BC) had a drought and there was not bread in the whole country.	בנטוב (תשל"ד) ע' 220.
October 1598	Bethlehem	(?)	Bad	1597-8: **247,**1153	51	The pools of Solomon were dry because of the long drought. (is it the result of 1597?)	Zippora S89
1598/9	Holy Land	Y	Bad	1597-8: 247,903	35	A ship imports wheat from Istanbul to the holy land.	יערי שלוחי א"י ע' 243
1598/9	Not Specified	Y	Bad	903	35	" in year 5359 (1598-9 AC) God inflicted a famine on the land"	הורויץ אברהם מרדכי הלוי. כבוד ירושלים ע' נ'.
1599/ 1600	Safed	Y	Bad	945	38	A letter sent from the Jewish community in Venice reports on famine in Safed	יערי, "שנות בצורת" ע' 86.
Jan. 1615	Safed	Y	Bad	1613-4: 979, 942	45, 39	Import by the sea of wheat and barley due to the drought and dreadth in Safed and its neighborhood.	Heyd p. 132

Most of the qualitative indications were collected by Zippora Klien, and verified by the author. Zippora Klien See: ציפורה קליין, "שינויי מפלס ים-המלח ותנודות אקלימיות בארץ ישראל בתקופה ההיסטורית," חיבור לשם קבלת תואר דוקטור לפילוסופיה, האוניברסיטה העברית. (1986)