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Byzantine Economic Growth: Did Climate Change Play a Role?

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By

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Abstract

Different chroniclers of the history of the Byzantine Empire have noted various economic data gleamed from historical documents and accounts of the empire at different periods of time. Research for this paper has not uncovered any estimates of long term, annual macroeconomic data (gross domestic product (GDP), national income (NI), etc.) for the empire during its existence. Such data has been estimated to one extent or another for other nations and societies that have existed during the middle ages. This paper attempts to provide conjectures on approximate real GDP per capita trends for the empire over its existence from AD 300 to 1453. Finally, some hypotheses on factors that would have affected Byzantine economic performance are tested using climate/environmental factors. The results of this paper appear to confirm some findings on how the Byzantine economy might have been affected by periods of regional climate change.

JEL codes: N13

Key words: Byzantine Empire, climate change, real GDP per capita, empire size

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Introduction

The field of cliometrics has developed over the last six decades or so to apply the statistical techniques of econometrics to questions of and research on historical issues or epochs of time in different societies and sometimes with different economic systems other than capitalism (Haupert and Diebolt 2020). Among the many studies that have used statistical techniques to explore and/or explain economic history some have included papers and books which have covered slavery in the antebellum southern US (Conrad and Meyer 1958); estimates of world economic growth and income since AD 1 (Maddison 2003); and economic growth in England and later the UK from the 13th to the 19th Centuries (Clark 2009, Broadberry et al 2015). Using data and estimates from Clark (2009) and Broadberry, et al (2015), Lambert (2020a, 2020b) has estimated the economic surplus accruing to land and property owners and levels of investment in Britain from the 1200s to the 1860s.

The Byzantine Empire was one that was beset by many challenges including conflicts with hostile and powerful neighboring nations and tribes (Treadgold 1997 and 2020); internal warring religious and aristocratic factions (Treadgold 1997 and 2020); recurring plagues (Treadgold 1997, Stathakopoulos 2004); frequent famines (Treadgold 1997 and Stathakopoulos 2004); and according to some climatologists, periods of adverse climate change which hindered the empire in a way that made it difficult to attain previous levels of political and economic power (Haldon, et al 2014). One purpose of this paper is to see if any approximations of the climate factors are correlated with estimated Byzantine real output trends from the 4th to 15th Centuries.[1]

[1] The main purpose of this paper is to develop and analyze general real GDP trends and not to establish precise estimates for year to year output fluctuations. All data developed in and used by this paper can be provided by the author upon request.

In the course of doing research for this paper, no literature has been found which gives estimates of imperial revenues or economic output of the Byzantine Empire over an extended period of time. This paper attempts to fill this gap in the literature by using reliable sources of data to construct different conjectures of consecutive real GDP per capita from AD 300 to 1453.[2] The paper proceeds as follows. The next section outlines the methods used to develop the estimates and some analysis of results. After that, a discussion and conclusion section on the results and key findings follows. This last section also outlines the limitations of the findings, provides some ideas on the implications of the conjectures, and gives suggestions for further research.

Methods and Analysis

Treadgold (1982, 1997 and 2020) gives estimates of Byzantine imperial budgets for the years 300, 457, 518, 540, 565, 641, 668, 775, 842, 959, 1025, 1143, and 1320, and Milanovic (2006) claims that any Byzantine budget is probably 5 to 8% of the amount of the Byzantine economy or gross output.[3] This would not be unusual given that most scholars have written that tax revenues usually would be the equivalent of around 5% of a medieval economy, and as a system on which most of the tax burden fell on peasants and laborers (Brown 2017, Lambert 2020a and 2020b). For the Byzantine Empire, it appears that most tax rates usually never exceeded and averaged 10% of land values, sales of goods, etc. and that if there were any surcharges, these usually never exceeded 20% for an overall average rate of 12% at the most (Treadgold 1982, 1997 and 2020, Harvey 1989, Le Goff 2012, Herrin 2013). By comparison, in the US today government spending, if transfer payments such as social security are not included,

[2] The empire ended in 1453 with the Ottoman Turks conquering Constantinople, yet the last good year of reliable estimates for imperial finances is for the year 1320 (Treadgold 1997 and 2020).
[3] The data in the table from page 258 of his 2020 book is displayed in the appendix.

makes up around 20% of GDP annually on average, and marginal individual income tax rates can be up to around one-third of one's income (Colander 2017).

According to Treadgold (1982) in the 8th and 9th Century of Byzantium only 5 to 10% of state revenues came from commerce and activities outside of agriculture (page 93), and land and hearth taxes made up the bulk of agricultural revenues at around 88% or so (pages 52-58). Land taxes mostly came from agricultural lands according to their fertility/productivity which meant that government finances were heavily influenced by the economic condition and size (in total square kilometers) of the agricultural sector of the economy. Hendy (1985) wrote that 80-95% of all Byzantine revenues came from land and 5-20% from trade (page 157). Treadgold (1982 and 2020) believed these estimates to be close to other time periods of the empire and thought most economic expansion or contraction in the empire depended upon demographic and territorial gains and losses through war victories and losses (page 94).[4] Laiou (1977) and Laiou and Morrisson (2007) claimed that agriculture usually made up 67% to 75% of Byzantine economic activity.

Treadgold (1982) and Laiou and Morrisson (2007) note that around half of the Byzantine economy was non-monetized or not cash based, and some payments to the government could be in-kind, although land taxes usually could not be paid in kind. Treadgold admits that this means his estimates of government revenues for different years are only conjectures and only include cash payments to the government which means his estimates may be low. He also notes wide variations in estimates of government revenues by other writers (2020, pages 258-259), but his research is the only one found by this paper to give so many years of sequential data over the empire's life. Finally, it can be claimed that his estimates have been adjusted for inflation or

[4] On page 57 he writes that the Byzantine treasury lost substantial land tax revenues due to those farmlands having been ravaged by war often being exempted from taxes for 30 years after an attack or siege.

debasement in Byzantine currency value over the centuries since he puts budget values in terms of the of the original nomismata/solidus of 1/72 of an ounce of gold issued during the late Roman Empire. Finally, Milanovic (2006) and Laiou (2002) note that from around the 500s to the 1300s wages and prices did not change that much in Byzantium.[5]

At the same time, Treadgold (1997) does show changes in the pay of soldiers and sailors over time in the budgets, and these go up and down over the centuries. Morrison and Cheynet (2002) display wheat prices for different parts of the empire over the centuries and across regions, yet it is hard to use these to pinpoint an overall average empire-wide price of wheat over time. Wheat was an important food staple and ingredient for other food items. Pamuk (2007) claims that wages and prices went up dramatically in the Byzantine Empire after the Black Death and cites Morrison and Cheynet (2002) for evidence. Yet, the price and wage increases appear to mostly be confined to some regions versus others, and for wheat (see Table 5 in Morrisson and Cheynet (2002), prices actually go down in some regions after the Black Death rather than up.[6] Wine prices and wages for domestic servants show gains (servant pay went from 10 hyperpyra to 14 hyperpyra after the plague started), yet prices for horses remain stable before and after the pandemic. In Table 14 (Mossisson and Cheynet (2002)) the prices of slaves increase from 1300

[5] The concept of the time value of money is considered to have been not that important in ancient and medieval times, and there has been some debate over whether Church prohibitions against usury made some logical sense from an economic point of view in that since most of the medieval period saw little if any economic growth and capital investment, which would make the cost of money extremely low, so that charging interest for loans would not make sense much less be justifiable. Jacques Melitz (1971) evaluates the writings of different scholars on this issue and finds little support for this view. It appears that prohibitions against usury exclusively came from moral reasons. Additionally, much of Church teaching back then was based on the belief that business and market professions and transactions were, although not dishonorable, less than desirable and considered somewhat crass. There is also the concept of just price from Church teachings which often led to price controls and limits on pricing by medieval merchants. These beliefs and practices can be traced to the teachings of Aristotle who influenced the Catholic theologian Thomas Aquinas (Blaug 1991). Treadgold (1997 and 2020) writes that price controls were often used in Byzantium to control inflation and to insure "just prices."

[6] On pages 826 and 827 it is shown in Table 5 that in 1343 in Constantinople the price of a modius thalassius was greater than ¼ hyperpyron, and it ranged from 1/5 to 3/8 hyperpyron in 1366 in Constantinople after the Black Death had started.

to 1350, and this supports Pamuk's claim that these prices rose during and after the Black Death period, although slave purchases mostly would have been made by the Byzantine upper classes, which made up a very small segment of the population. Morrisson and Cheynet (2002) write on page 850,

> "When one takes the devaluation of the hyperpyron into account, slave prices are seen to have remained remarkably stable from the Justinianic period until the beginning of the fourteenth century. This stability was all the more remarkable in that these prices were the outcome of a real market, partly international in nature. Prices subsequently rose, particularly after 1350, perhaps due to the effect of the plague on the population, despite the pirate warfare in which Turks and Latins were actively engaged."

Next, to come up with an accurate price or inflation index is complicated by the fact that the Byzantine Empire was often subjected to price controls imposed by the government in accordance with the concept of "just prices" and due to the fact that many markets in Byzantium and in most medieval societies were localized so that food shortages and famines could exist in one part of the empire whereas surpluses could exist in others. Additionally, currency was often debased in order to help the government pay its bills, although periods of inflation could be followed by deflation during times of bountiful harvests or the issuance of new coinage. Finally, many medieval transactions were non-monetized and goods were often not sold on markets but bartered instead or used as payment in kind for debts or tax payments or rental payments on theme lands. This fact also makes estimating inflation difficult. Nonetheless, given the claim that there are few overall price changes during the course of most of the history of the empire and Treadgold's use of the value of the nomismata (N) from around AD 300 as a base currency, the real GDP per capita trend estimates developed for this paper should be rough but somewhat legitimate conjectures.[7]

[7] Milanovic (2006) calculates that during the 11th Century subsistence levels were no less than 3.5 to 3.7 N with an average minimum expenditure of around 6.3 N per year. He calculates average income levels of 6 N per person

Dividing the budget totals in nomisma[8] (the main Byzantine currency throughout most of the history of the empire) given by Treadgold by 6.5% (the average of 5 and 8%), and then dividing these numbers by his population estimates (2020), one gets the results in Table 1 for GDP per capita for various years in the empire.[9] Using these values and developing a regression model from them, one can estimate GDP per capita trend values for the empire from 300 to 1453.[10] When the equation yielded from the scatter plot in Figure 1 is used to create estimated real GDP for each year from AD 300 to 1453, a diagram like that in Figure 2 is yielded.[11] The polynomial in Figures 1 and 2 is the one that best fits the plot/pattern with an r-square of around 89% and an equation of

$$\text{Predicted Real GDP} = -0.000000000000315x^5 - 0.00000000142x^4 + 0.0000024x^3 - 0.00187x^2 + 0.665x - 78.187 \quad (1)$$

Harvey (1989) claims that the Byzantine economy had a great expansion from around 900 to 1200 because of records indicating greater urbanization and population density during this time whereas Laiou and Morrisson (2007) write that it was from 800 to 1200. These notions are illustrated in Figure 2, and the accounts of this time period somewhat boost the possible validity of the estimates given in Figure 2. The decline in real output in Figure 2 that is shown during the

per year. If wages and prices did not change that much on average during the history of the empire, then an average of 6 N per year per person is plausible throughout the history of the empire.

[8] For the last two years the Byzantine currency of the hyperpyron was converted to nomismata by Treadgold.

[9] The per capita income estimate of 1453 may appear very low, yet as Treadgold notes in the second to the last chapter of his 1997 book, the last few decades of the empire would be those in which inequality levels went to extremes as land holdings became more and more concentrated, and the number of those living in poverty dramatically increased (pages 838-844). When apply the polynomial regression equation, the predicted value for 1453 is actually between 2 and 3 N.

[10] There are various estimates for the population and the size of territories of the empire at the time of its fallin 1453. The best estimate by this paper is an empire size in territory of around 600,000 square kilometers; population of around 500,000; and government revenues of 45,000 N. Treadgold (1997) writes that at the time of the fall of the empire, Constantinople had a population of just 50,000 residents, and Treadgold (1997 and 2020) and Laiou and Morrisson (2007) note that by 1453 the empire had lost gradually at least half and probably more of its land size and population from 1320 onward.

7th Century is reflective of dramatic losses in territory by the empire due to the rise of Islam and Arab conquest. Surprisingly, if economic fortunes are linked to territorial size, there are declines in real GDP during the 6th Century when Byzantium took many territories that had been part of the Western Roman Empire. At the same time, however, there are claims that a Late Antique Ice Age existed during the 6th and part of the 7th Centuries in Europe due to volcanic eruptions and cooler temperatures, and this could have hindered agricultural production resulting in lower real output during these times despite gains made from conquest (Buntgen et al 2016). Finally, the 6th Century also is when the Plague of Justinaian occurred in the empire which possibly killed up to 30% of the empire's population (Laiou and Morrisson 2007, page 38).

(Insert Table 1 and Figures 1 and 2 around here)

Did Climate Factors Affect Byzantium Real GDP?

In addition to estimating Byzantine GDP per capita, it would be interesting and useful to know what factors influenced the Byzantine economy. Especially useful would be to know what external or exogenous factors had effects on output. Finding some type of evidence of such effects could also help to establish some type of validity for the real GDP trend conjectures developed in this paper. Some scholars, such as Haldon, et al (2014), give evidence that the empire suffered from climatological problems which caused problems in agricultural production and famines in different parts of the empire or throughout the empire in different epochs. Others (Bertrand, Loutre, Crucifix, and Berger 2002, Jones and Mann 2004) have created historical climate databases that go back to antiquity and that possibly demonstrate the existence of a "Medieval Warm Period" (10th to 13th Centuries) and a "Little Ice Age" (14th to 19th Centuries).[12]

[12] Kelly and O Grada (2014) cast some doubt on the existence of a Little Ice Age in Europe by claiming that estimated temperature trends showing a cooling period are not accurate due to a Slutsky-Yule effect of making random variation fit a pattern of cyclicality that follows a trend. That is, since moving averages are often used to

Historical climate databases are published on the website of the US National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA) and contain estimates of greenhouse gas (GHG) forcing in watt per square meter (based on Crowley 2000); solar irradiance (sun energy) in watt per square meter (based on Crowley 2000); and regional volcanic ash estimates based on work by Ammann and Naveau (2010) for the Mediterranean and Europe according to longitude and latitude; and estimated above or below normal/trend temperatures of degrees Celsius from AD 1 to 2001 (Luterbacher et al 2016).

Above trend greenhouse gas (GHG) forcing could dampen crop production if they are a result of volcanic eruptions, forest clearings through burning trees, or activities which can hinder or reduce carbon absorption and cause warmer than normal growing seasons. Volcanic ash circulating either globally or regionally can block sunlight necessary for agricultural production. Too little energy or radiance emitted by the sun can reduce agricultural output or cause crop failures, and temperatures too far above average can also harm farming efforts if they help to cause drought.[13] The trends over several centuries for these variables for Europe and the Mediterranean are shown in figures 3 to 6. There appears to be increases in absolute terms in each of these factors except for the volcanic ash measure during what is known as the Medieval Warm Period in Europe from around 950 to 1250 (Jones and Mann 2004, Goose, et al 2006).[14] At the same time, there are slight to moderate absolute decreases in these during the period of the Late Antique Ice Age (536 to 660 AD) and the Little Ice Age (1300 to 1453 for the purposes of

create the estimates, such averages sometimes make random variations fit a pattern that may not really exist. Yet most of the research found for this paper asserts that it did exist.

[13] Ch. Stathakopoulos (2004) writes about the "Dust-Veil" event of 536-537 which darkened the skies of the empire from 536 to 537. He notes that some believe that this phenomenom originated from volcanic activity.

[14] Mann, et al (2009) write that the Medieval Warm Period only occurred in some areas of the globe such as Europe during the middle ages while other parts of the planet exhibited normal or cold climate conditions in contrast to modern global warming which is occurring across the globe.

this paper, although the Little Ice Age supposedly lasted to 1850) in Europe except for the ash measurement.

(Insert Figures 3 to 6 around here)

These climate forcing variables are used as independent variables to predict imperial real GDP per capita trend estimates from 300 to 1453 and to see if climate may have been correlated with Byzantium economic activity. Additionally dummy variables for each period—Antique Ice Age (AIA), Medieval Climate Anomaly (MCA), and Little Ice Age (LIA)—are used where if a year is in one of the periods, the variable is coded "1", otherwise it is coded as "0". The Late Antique Ice Age is estimated to have existed from around AD 536 to 660 (Buntgen, et al 2016); the Medieval Climate Anomaly, aka the Medieval Warm Period, is estimated to have been from around AD 950 to 1250 (Lamb 1965, Diaz and Hughes 1994); and the Little Ice Age is supposed to have been from around 1303 to 1860 (Lamb 1995, Fagan 2001 among others). These variables are used to see if the empire's economy was influenced in general by different climate epochs. If the Byzantine economy is considered to have been mostly agricultural, then abnormal climate factors would matter more than in a modern economy where there is a greater mix of industries and where some of these industries are not so vulnerable to weather extremes as with agriculture. Laiou (1977) and Laiou and Morrison (2007) claim that most of the empire's output was agricultural, and around half of this output was not sold on markets but was for personal, familial or community consumption.

Other Factors Affecting the Byzantine Economy

Next, the approximate size of the Byzantine Empire in millions of square kilometers from 300 to 1453 is used to predict real GDP per capita (Treadgold 1997 and 2020). This variable is used to approximate territory gains and losses over time due to war victories and losses or

through treaties with rival nations. The hypothesis is that this variable should matter to real GDP per capita in that if the empire loses important lands that have key ports or fertile and productive agricultural lands, then overall GDP per capita would suffer. This variable is both exogenous and endogenous to real output due to imperial conquests or losses helping GDP growth, but at the same time, a healthier economy helps to make military provisions and conquest easier.

Estimates of the empire's size is made from Treadgold's data for the years that correspond to his estimates of empire's budgets (different years from 300 to 1320) and presented in his 1997 (a figure on page 8) and 2020 (Table 8.1 on page 258) books. Figure 7 illustrates the changes in the empire's size over time using Treadgold's table (2020) and in trying to replicate his figure as closely as possible, and in general the figure is similar in shape to a figure he presents in his book.[15] The empire gained some territory in the 6th century but then lost vast amounts of land in the 7th and 8th Centuries due to the rise of Islam and Arab conquests. Under the leaders Nicephorus Pfocas and Basil II, the empire regained some lost territories and gained some new ones in the 10th Century and early 11th Century but then lost these and more land in subsequent centuries until the empire fell in 1453.

(Insert Figure 7 around here)

Finally, a dummy variable that indicates the years in which a cataclysm occurred (1=yes, 0 =no) is used as a predictor variable of real GDP per capita to see if external "shocks" to the economic system have any substantive effects. The cataclysmic events include famine, plagues,

[15] Unfortunately, the data upon which the figure is based no longer exists apparently. They appear to be Treadgold's estimates. The only actual numbers found are the 13 years of area estimates from his 2020 book. The appendix contains an email note from Dr. Treadgold in which he explains that he no longer has the notes or data upon which the figure is based. In the note he states that his estimates are based upon maps showing the size of the empire at different points in time, his knowledge of Byzantine historical events, and a useful atlas. The use of Geographic Information Systems (GIS) software to generate data is limited by the fact that there are large gaps in time periods between the dates for different maps. Therefore, Treadgold's estimates may be the best available ones to use for continuous data. Dr. Treadgold's note can be provided by the author upon request.

and sieges of different cities that happen in large areas of the empire (e.g., Egypt or Mesopotamia) or throughout the empire as mentioned in Treadgold (1997 and 2020), Ch. Stathakopoulos (2004), and Haldon, et al (2014). A siege of several cities is seen as a cataclysmic event rather than an event or outcome of war in that civilian and worker lives are lost in addition to military ones, and the former losses may be more relevant to estimating GDP per capita. Cataclysmic events that happened in just one city are ignored, and for some years, more than one type of event occurred. However, since it is difficult to assess the impacts of each type of disaster event, only a value of 1 is to indicate that at least one type of adverse event occurred. This variable, similar to territory size, can be both an endogenous and exogenous factor to the empire's economy in that these cataclysms can be both internal by having famines caused by crop failures, plagues exacerbated by poor health policies, and sieges caused by poor defense planning); and they can be external in that population losses from these events can lower subsequent economic output.

Table 2 below shows the results of the multivariate regression analysis. The adjusted r-square of 0.8589 indicates that the variables explain around 86% of the variance in real GDP per capita trends. Diagnostics of the regression output show no problems with multicollinearity (variance inflation factors < 10.0 (Berenson, Levine, and Szabat 2015, page 608), but there are problems with serial correlation, and so Newey-West standard errors are used to correct for this. All variables are statistically significant at $\alpha = 0.05$.

The cataclysm variable shows that for each year when at least one cataclysm is noted with a value of 1, real GDP per capita goes down by 0.332 N on average. For the empire territory size, a gain/decline of 1 million square kilometers in the empire's domain results in an increase/decrease in real GDP per capita or around 1.32 N. The temperature variable shows that

a one unit or one standard deviation above normal temperature score results in a 0.26 N decrease in real GDP per capita. The GHG variable shows that a one unit increase in above normal greenhouse emissions yields a decrease in real per capita output of around 13 N, and the solar irradiance variable indicates that a 1 unit above average measurement of irradiance or sun energy increase is associated with a 0.213 N increase in real GDP per capita. The volcanic ash measure coefficient suggests that a 1 unit change in this measurement is associated with a 0.05 N change in real GDP per head. The average of real GDP per capita over the centuries examined is around 6.30, so one-unit changes in the variables can have substantive impacts as a share of the predicted amounts.

The dummy variables for each climate epoch show negative associations between the period of the AIA and real GDP per capita and the LIA and real per head output. The AIA years decrease real output per head by 1.95 N on average, and the LIA period decreases real GDP per capita by 1.53 N on average. On the other hand, the MCA era is associated with a boost of 1.8 N per year on average.

Discussion and Conclusion

The limits of this paper include the use of other conjectures in order to create further estimates. No conclusions can be made with a very high degree of certainty. There are also other variables, endogenous and exogenous, related to real GDP per capita that could have been used as predictors in a more developed model. To have actual numbers or estimates of the lives lost for various cataclysms would have helped with the precision of the regression models rather than having to use a dummy variable. Therefore, the results displayed are only partial and general ones regarding Byzantine per head output, and they are submitted as general trends of Byzantine economic activity and not as exact, year-by-year estimates.

Yet the estimates for annual GDP per capita, and empire size are reasonable as general trends based on the sources used and how they follow patterns exhibited in historical accounts. The results of the regression analysis show a strong degree of correlation between climate forcing factors with real per capita output estimates, and this is not surprising given that Byzantine society's major industry is noted as agriculture. Too high of temperatures and GHG result in a loss of output probably because of too much heat for agricultural output whereas greater energy provided by the sun is useful for output. The positive sign for the volcanic ash measure shows that higher scores or those closer to zero are associated with higher output, most of which would be agricultural. That is, less or no volcanic ash present helps production whereas otherwise its presence and magnitude can be detrimental.

For the three climate epoch dummy variables, the AIA and LIA variables have their expected signs in that colder weather is supposed to have lowered agricultural output in Europe and the Mediterranean during these time periods according to different climatologists. However, for the MCA period, the regression results show this variable to have a positive sign, which is contrary to expectations given what has been written about how a medieval warming era could have impacted the region. Yet, this era is noted by historians as one of conquest and good economic growth in the empire due to increases in population, territory and greater urbanization (Treadgold 1997 and 2020, Laiou and Morrisson 2007). Xoplaki et al (2016, page 248) conclude that despite bad climate conditions, Byzantium was able to overcome the adverse conditions of the MCA. The results in Table 2 somewhat support their conclusion. Of course, some of the reasons for conquest could have been to make up for poor performing agricultural output within the empire's existing boundaries. At the same time, any adverse effects of crop failures or poor agricultural output by conquered opponents could have helped to make them easy and weakened

targets for conquest by the Byzantines during the MCA era. Finally, warmer weather could be a benefit to growing some types of crops versus others, and Lüning, Gałka, and Vahrenholt (2017) claim that the eastern Mediterranean region (the "Levant") of what would have been part of the empire might have actually not have had that warm of weather during the MCA period.

The fortunes of the empire also seem to have rested on the amount of territorial holdings it had. During medieval times, historians have often noted Malthusian economic conditions in which agricultural production often could not keep up with population growth with the subsequent result often being periods of famine. To make up for this, conquest of foreign lands which would provide more farmland is noted as an objective pursued by different kingdoms and nations. As a society would gain more land, its economic fortunes also usually would rise. The same is probably true for Byzantium. But as the empire began to shrink, so did its income and wealth. Over time the empire lost many of its major assets such as key ports (e.g. Alexandria), trading routes and centers (e.g. Damascus), and best agricultural lands (e.g., Egypt, Anatolia, etc.). The fact that the estimates of real GDP trends used in this paper are drawn from government revenue estimates based on a tax system that mostly relied upon land tax receipts make the link between empire size and economic performance unavoidable. As the size of the empire shrank, so did government coffers even after some tax rates could have been raised or other taxes could have been employed in order to make up for lost tax revenues.

Having peace, good climate, and avoiding famine and pestilence can be the keys to the survival of any nation. Losing too many battles and perhaps suffering from the adverse climate conditions may have hastened the end of the Byzantine Empire from the 11th Century and onward. This paper provides some tentative support for these factors as impacts on Byzantine economic viability.

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Table 1—Estimated Real GDP per Capita using Treadgold data (1997 and 2020)

Year	Real GDP per Capita in Nomismata
300	6.89
457	7.50
518	6.71
540	6.69
565	6.71
641	5.42
668	3.08
775	4.18
842	5.96
959	6.67
1025	7.56
1143	7.54
1320	3.85
1453	1.38

Fig. 1: Estimated Real GDP per Capita Trend, N

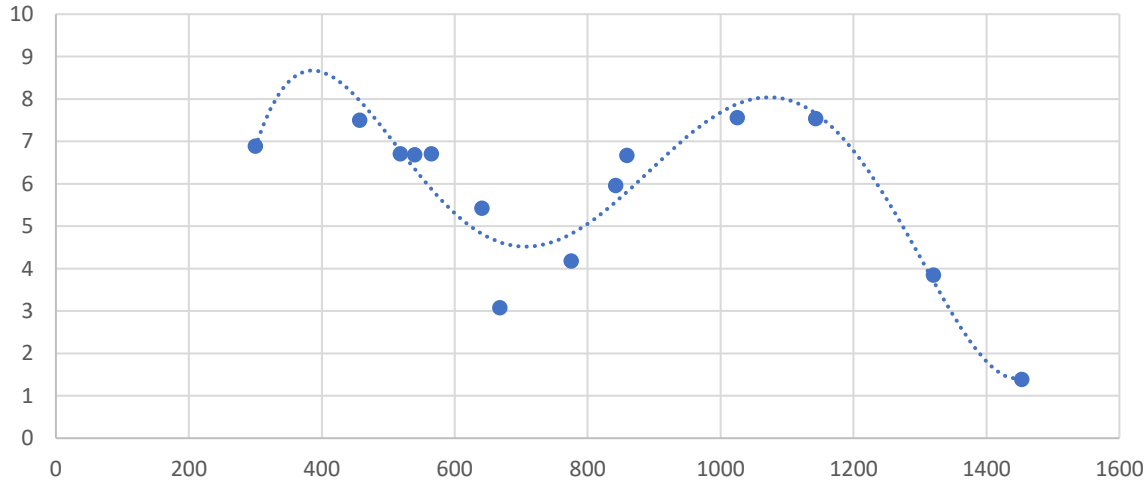


Fig. 2: Estimated Real GDP per Capita Trend, N, AD 300 to 1453

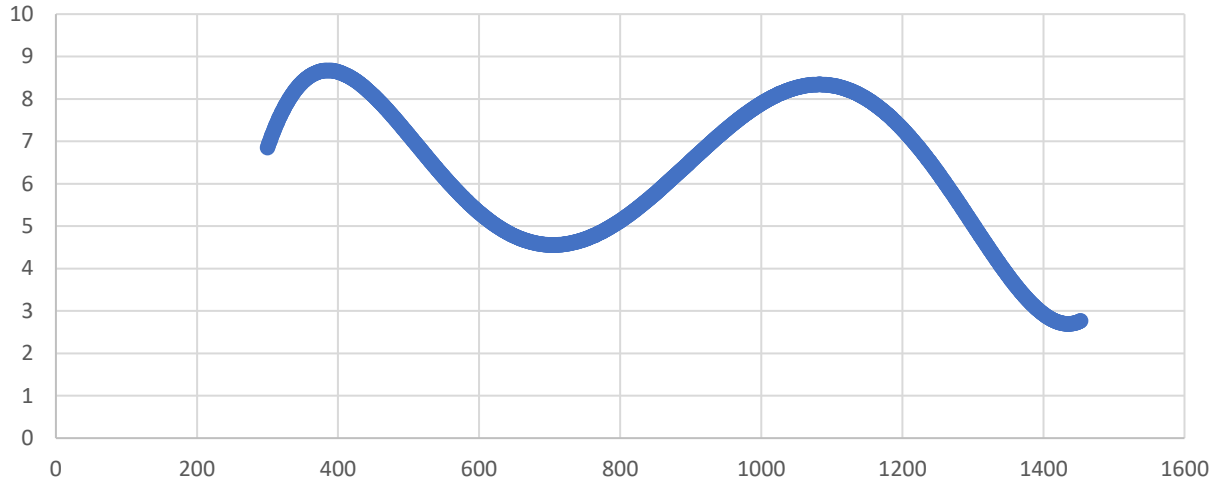
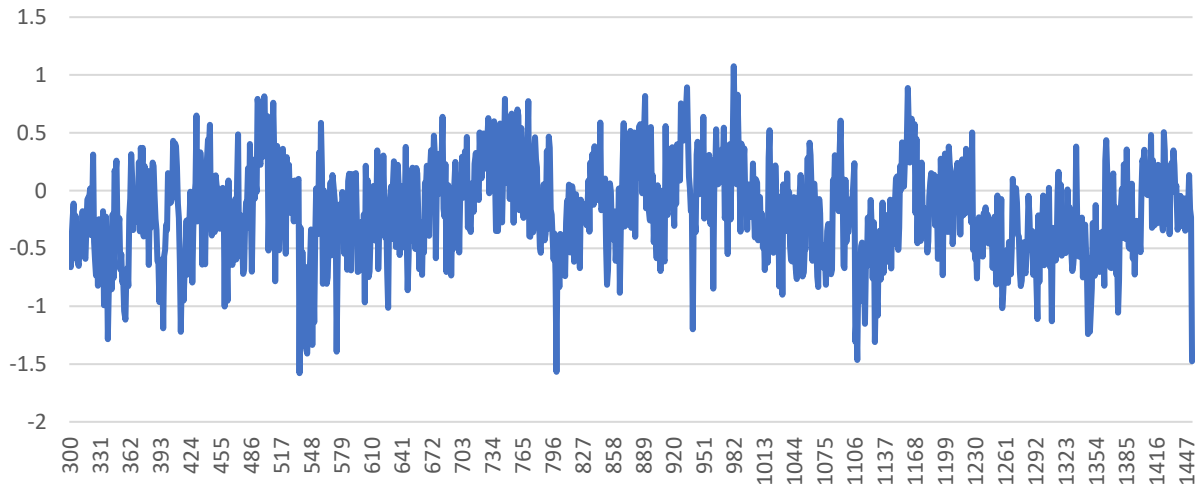


Fig. 3: Standard Deviations of Temperature above Trend/Norm



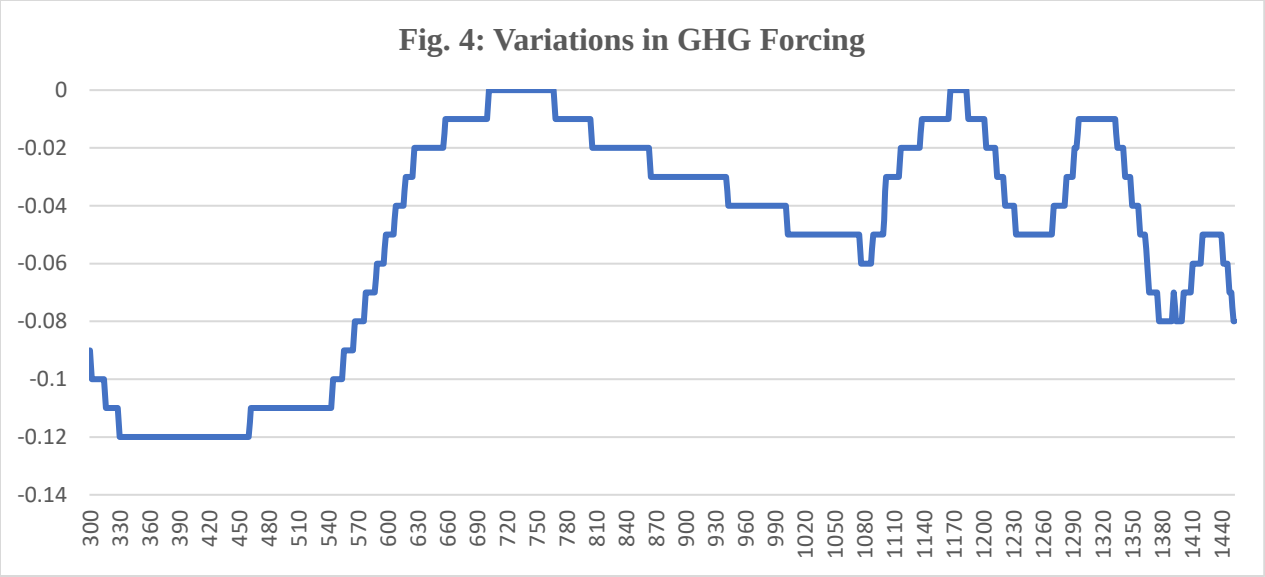


Fig. 4: Variations in GHG Forcing
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900 930 960 990 1020 1050 1080 1110 1140 1170 1200 1230 1260 1290 1320 1350 1380 1410 1440

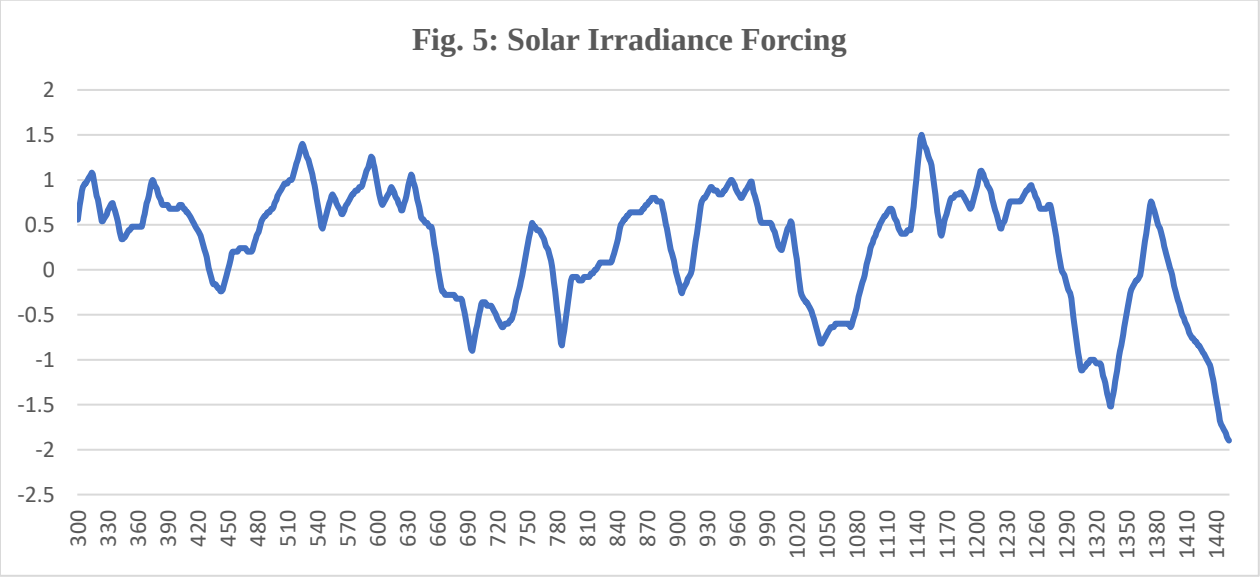


Fig. 5: Solar Irradiance Forcing
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900 930 960 990 1020 1050 1080 1110 1140 1170 1200 1230 1260 1290 1320 1350 1380 1410 1440

Fig. 6: Volcanic Ash Index Europe & Mediterranean (Ammann)

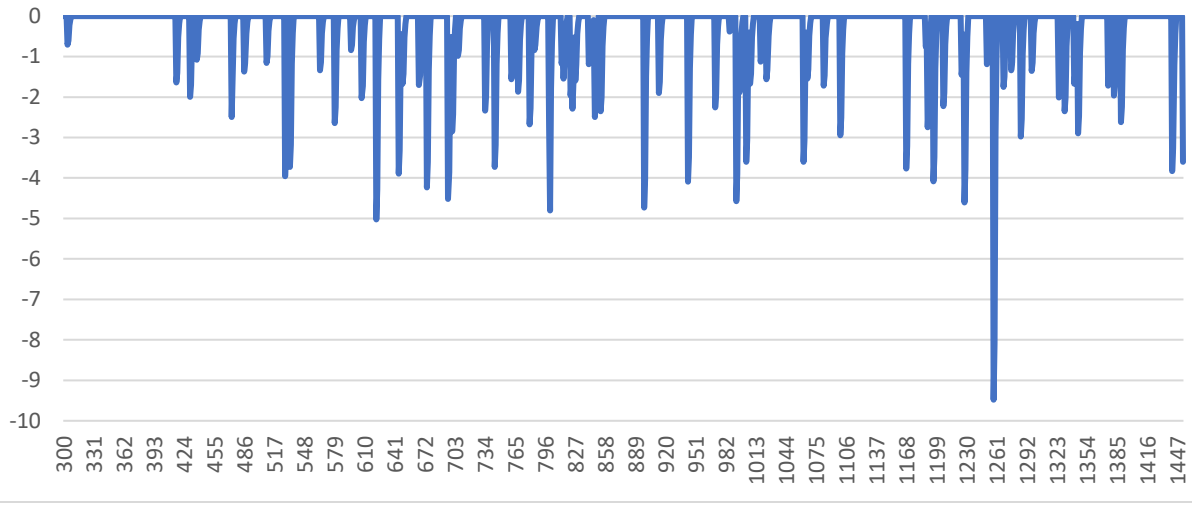


Fig. 7: Estimated Territory Sq Km, Millions

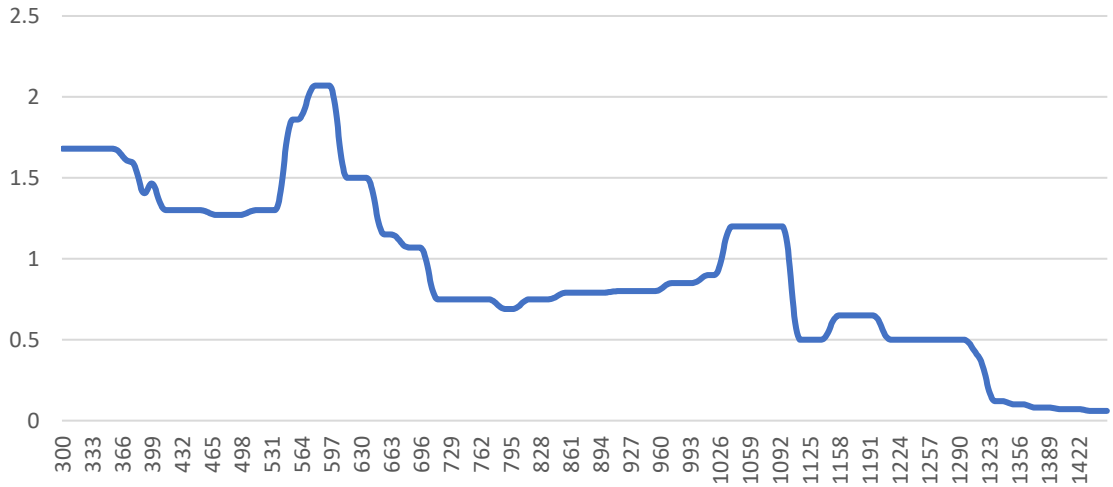


Table 2—Regression Results

Dependent Variable: Real GDP per Capita

Independent Variables:

	b (Newey-West SE)
Constant/Intercept	4.37
Cataclysm Dummy Variable (Yes = 1, No = 0)	-0.332** (0.05)
Size of Empire in Sq. Km. Millions	1.32** (0.115)
Temperature Deviation, Celsius	-0.261** (0.05)
GHG Measure	-13.004** (1.03)
Solar Radiance Measure	0.213** (0.04)
Volcanic Ash Measure	0.052** (0.022)
Antique Ice Age Dummy	-1.95** (0.095)
Medieval Climate Anomaly Dummy	1.8** (0.04)
Little Ice Age Dummy	-1.53** (0.015)

n=1154 years
Adjusted r-square = 0.8589
**p-value < 0.05
*p-value < 0.10

Appendix—Data from Treadgold's Table 8.1, page 258, of his *Concise History of Byzantium* (2020)

Year	Territory Millions Sq Km	Pop. Millions	Govt Rev Millions Nomismata	Army Size Soldiers Sailors Thousands
300	1.68	21	9.4	343
457	1.27	16	7.8	335
518	1.3	19.5	8.5	301
540	1.86	26	11.3	374
565	2.07	19.5	8.5	379
641	1.15	10.5	3.7	129
668	1.07	10	2	129
775	0.69	7	1.9	118
842	0.79	8	3.1	155
859	0.85	9	3.9	179
1025	1.2	12	5.9	283
1143	0.65	10	4.9	50
1320	0.12	2	0.5	7