REGION

The Journal of ERSA
Powered by WU

Volume 1, Number 1, 2014, 9–24 journal homepage: region.ersa.org

Climate change in Lebanon: Higher-order regional impacts from agriculture*

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Received: 15 June 2014/Accepted: 31 July 2014

Abstract. In this paper, we analyze the susceptibility of agricultural outputs to future climate change in Lebanon, and the extent to which it propagates to the economic system as a whole. We use a methodological framework in which physical and economic models are integrated for assessing the higher-order economic impacts of projected climate changes. By using this integrated modeling approach, we are able to quantify the broader economic impacts in the country by considering not only the temporal dimension but also the regional disaggregation of the results. Our estimates suggest that there are high potential costs and risks associated with a burden to the poorer and more vulnerable regions of the country.

1 Introduction

Lebanon's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) (MoE 2011) made important advances in many areas. A major improvement over the Initial National Communication to the UNFCC (INC) (MoE 1999) refers to the climate modeling effort as the first time a specifically developed regional model that targeted Lebanon was used. This allowed for the development of climate change impact scenarios in various sectors. Data availability and a lack of scientific studies, however, precluded further advances in strategic topics. One such topic relates to the assessment of the impacts of climate change on the agriculture sector. The report relied mostly on the qualitative analysis of indicators of climate change impacts on vulnerable systems in agriculture. While the discussion did not include any effective effort to modeling the relationships between projected changes in climatic conditions and crop yields in Lebanese territory, it provided a targeted impact assessment that could potentially be measured in the future.

*This article was developed under the memorandum of partnership agreement between the *Issam Fares Institute for Public Policy and International Affairs at the American University of Beirut*, and the *University of São Paulo Regional and Urban Economics Laboratory – NEREUS*. The authors acknowledge financial support by the Brazilian Network for Global Climate Change Research – Rede CLIMA, and the National Institute of Science and Technology for Climate Change. Flavio Vieira acknowledges financial support from CNPq. Eduardo A. Haddad acknowledges financial support from CNPq and Fapesp; he also thanks Princeton University and Rutgers University for their hospitality.

> The analysis heavily relied on assumptions given the paucity of empirical studies and data in Lebanon. (...) Since the direct impact of climate change on yields and crop product quality is not taken into consideration in the agriculture census, and in research topics in Lebanon, we assumed that these parameters vary in the same way as mentioned in the literature. (MoE 2011 p. 2.17)

Agriculture is one of the economic sectors most vulnerable to climate change as it is directly affected by fluctuations in temperature and rainfall. Limited availability of water and land resources in Lebanon, together with increasing urbanization, puts additional challenges for future development in the country. In general, the direct effects of climate on agriculture are mainly related to lower crop yields or failure owing to drought, frost, hail, severe storms, and floods; loss of livestock in harsh winter conditions and frosts; and, other losses owing to short-term extreme weather events. Effects of climate on agriculture and rural areas have been extensively studied (IPCC WGII AR5 Chapter 9). Not many studies, however, have explored the higher-order systemic impacts of climate change on the agriculture sector within a country. Given productivity shocks that a region may face, backward and forward linkages will affect, to different extents, the local demand by the various economic agents. Spatial and sectoral linkages will also play an important role in the adjustment processes. The nature and extent of the impact will depend on the degree of exchanges with other regions. In an integrated interregional system, there is a need to address these issues in a general equilibrium framework by also including price effects. This broad regional view is essential to convey valuable insights to policy makers considering integrated approaches to production value chains.

A growing body of literature exists on the assessment of systemic effects of climate change on agriculture in the context of computable general equilibrium (CGE) models[1]. Modeling strategies attempt either to include more details in the agriculture sectors within the CGE-model structures (e.g., modeling of land use and land classes) or to integrate stand-alone models of crops yields agricultural land use with the CGE models, usually through soft links that may use semi-iterative approaches (Palatnik and Roson 2012). Most of such CGE applications are global in nature, providing economic impacts only at the level of regions of the world or countries. The detailed spatially disaggregated information on land characteristics that may be present in land use models is lost in aggregation procedures that are used to run the global CGE models, providing few insights on the differential impacts within national borders.

Within this context, the objective of this study is to analyze the susceptibility of agricultural outputs to future climate variations in Lebanon, and the extent to which it propagates to the economic system as a whole. We use a methodological framework in which physical and economic models are integrated for assessing the higher-order economic impacts of projected climate changes in Lebanon in the period 2010–2030. As the agriculture sector has important forward and backward linkages in the economic structure, as well as specific location patterns, climate change may entail economic effects for the whole country with distinct regional impacts. On one hand, physical models of crop yields can provide estimates of the direct impact of climate change on the quantum of agricultural production per unit of area. On the other hand, interregional computable general equilibrium (ICGE) models can take into account the associated productivity changes and generate the systemic impact of projected climate variables by considering the linkages of the agriculture sector with other sectors of the economy and the locational impacts that emerge. Thus, assessing the economic contribution of a part of a country's economic sector requires some consideration of the likely paths of interactions that are a consequence of the direct effects of climate on crop yields. Accordingly, the process adopted here is to estimate econometrically the initial correlation between climate variables and agriculture productivity, and then to feed the results into an ICGE model to capture the system-wide impacts of the projected climate scenarios for Lebanese regions.

We will examine how projected changes in climate variables — specifically temperature and precipitation — could impact growth and welfare in Lebanese regions through

[1] CGE models are based on systems of disaggregated data, consistent and comprehensive, that capture the existing interdependence within the economy (flow of income).

changes in productivity in the agriculture sector. This paper adds to the SNC in different ways. First, it develops a quantitative study relating climatic factors to agricultural production in Lebanon, helping to narrow one of the gaps identified in that report. Second, it goes one step further by generating a first attempt to compute higher-order impacts of climate change for Lebanon, despite focusing on the initial effects in only one specific sector. Third, and most important, it quantifies the broader economic impacts considering not only the temporal dimension but also the regional disaggregation of the results. In this regard, the paper also contributes to the literature on multiregional modeling of the impacts of climate change.

The remainder of the paper is structured as follows: in the next section, we discuss some of the broad features of agriculture in Lebanon. The climate scenario is then briefly introduced, followed by a discussion of estimates of the direct effects of climate change derived from econometric crop yields models. The next section provides an overview of the integrated approach to derive the economy-wide impacts of the climate change scenario in the period 2010–2030, presenting the baseline simulation and the main results of the impact assessment. Final remarks follow.

2 The study region

Despite its small size, Lebanon presents diverse geographical features. Located on the eastern part of the Mediterranean, it occupies an area of 10,452 km^2 with a coastline nearly 220 km long. Two parallel mountain ranges running north-northeast to south-southwest — Mount Lebanon on the west and Anti-Lebanon on the east — are separated by the elevated upland basin of the Bekaa, the main agriculture region of the country. The Mount Lebanon range is separated from the Mediterranean by a narrow coastal plain, where fruits, horticulture and vegetables are the main cultivated crops (Figure 1).

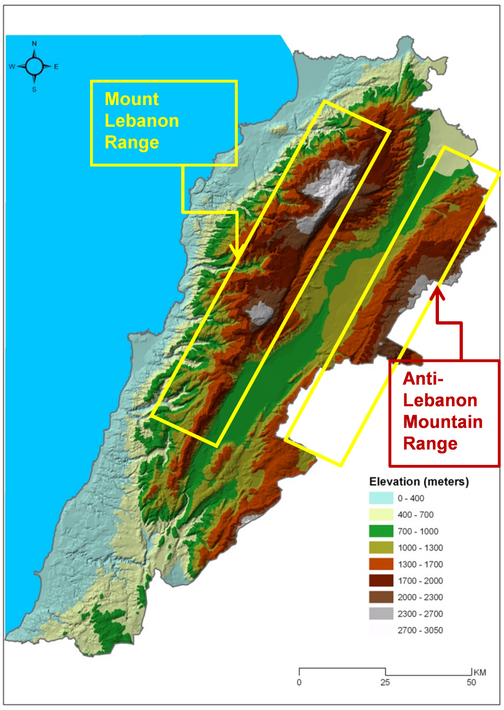

Figure 1: Digital elevation model for Lebanon showing the Lebanon and Anti-Lebanon Mountain Ranges

Lebanon's diverse agro-ecosystems have enabled the existence of a diversified agriculture sector, whose main crops range from semi-tropical produce in coastal areas to orchards in high mountains, with a wide range of different crops in between (CDR 2005).

Topography is largely a determining factor for potential crop types and agricultural techniques (see Saade 1994). Table 1 and 2 use data on crop areas to illustrate the regional differences related to the agriculture sector in Lebanon. The tables highlight not only the differences in the types of crops that prevail in each governorate[2] (table 1), but also the main producing regions for each crop group (table 2).

Approximately half of the 270,000 hectares that are cultivated in Lebanon are irrigated. Areas under cultivation are mainly concentrated in the Bekaa and Northern Lebanon (42.1% and 27.2%, respectively), with Southern Lebanon accounting for 12.6% and Nabatieh and Mount Lebanon accounting for 9% each (Ministry of Agriculture 2013). In spite of this, land dedicated to agriculture has been declining over the past twenty years, having represented nearly 18% of Lebanon's total land in 1990, declining considerably to about 13% in 1999, and further to below 11% in 2011 (World Bank 2013).

Table 1: Regional distribution of major types of crops in Lebanon (% of total crop area)

	Cereals	*Fruit trees*	*Olives*	*Industrial crops*	*Vegetables*	*TOTAL*
Mount Lebanon	1.0	4.2	18.9	10.0	2.2	9.5
Northern Lebanon	13.0	27.6	21.4	49.0	14.6	27.2
Bekaa	74.0	57.6	37.5	6.0	48.9	42.1
Southern Lebanon	5.0	5.6	18.3	18.0	9.3	12.6
Nabatieh	7.0	5.0	3.9	17.0	25.1	8.6
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Source: Ministry of Agriculture

Table 2: Major types of crops distribution within regions in Lebanon (% of regional crop area)

	Cereals	*Fruit trees*	*Olives*	*Industrial crops*	*Vegetables*	*TOTAL*
Mount Lebanon	2.4	8.2	63.0	25.8	0.6	100.0
Northern Lebanon	10.8	18.8	24.8	44.0	1.5	100.0
Bekaa	39.8	25.3	28.1	3.5	3.3	100.0
Southern Lebanon	9.0	8.2	45.8	34.9	2.1	100.0
Nabatieh	18.4	10.7	14.3	48.4	8.3	100.0
TOTAL	22.6	18.5	31.6	24.5	2.8	100.0

Source: Ministry of Agriculture

Although industrial crops account for about one-fourth of Lebanon's crop area, they represent two-thirds of agriculture output value (FAO 2014). Fruit trees account for 17% of total crop value, followed by vegetables (10%). While cereals and olives occupy over 50% of crop areas in the country, together they represent less than 10% of the total value of production. Overall, the agriculture sector (including livestock) is responsible for almost 5% of Lebanon's GDP.

3 Climate projections

Lebanon's climate is typical of the Mediterranean region with four distinct seasons that encompass a rainy period usually lasting from November to March, followed by a dry period during which very little precipitation occurs. Annual precipitation on the coastal

[2] Administratively, Lebanon is divided into six *mouhafazat* (governorates). See figure A1 in the Appendix.

plain ranges between 600 mm and 800 mm. Mount Lebanon may receive up to 2000 mm of precipitation annually, but a typical range is from 1000 mm to 1400 mm. Central and northern Bekka experiences approximately 200 mm to 600 mm of rainfall annually, while for the southern portions of the plain it is 600 mm to 1000 mm (Ministry of Environment/Ecodit 2010).

In its latest assessment report, the Intergovernmental Panel on Climate Change (IPCC) states that the frequency and intensity of drought in the Mediterranean region will likely increase into the early and late twenty-first century (IPCC 2013). The same report predicts that precipitation in the eastern Mediterranean from the period 1986–2005 to 2081–2100 will likely decrease on average between 20% and 30%, coupled with an increase in temperature of 2°C to 3°C.

According to climate predictions from the PRECIS model, by 2040 temperatures will increase by between approximately 1°C on Lebanon's coast to 2°C in its mainland; by 2090 these temperatures will be 3.5°C to 5°C higher, respectively. Rainfall is also projected to decrease by 10–20% by 2040 and by 25–45% by the year 2090, compared with the present. This combination of significantly less precipitation and substantially warmer conditions will result in an extended hot and dry climate. Temperature and precipitation extremes will also intensify. The drought periods, across the whole country, will become nine days longer by 2040 and eighteen days longer by 2090 (MoE 2011).

Table 3: Changes in temperature (Tmax, Tmin) and Precipitation (Prcp %) over Beirut, Zahle, Daher and Cedars from the PRECIS model for winter (DJF), spring (MAM), summer (JJA) and autumn (SON), 2025–2044

		Beirut	*Zahle*	*Daher*	*Cedars*
Prcp (%)	DJF	-7.95	-23.50	-0.99	-1.82
	MAM	-8.60	35.50	-0.38	-15.50
	JJA	-26.80	-84.20	-39.00	-49.80
	SON	-8.87	23.80	14.10	12.60
Tmax (degrees C)	DJF	1.08	1.23	1.92	1.77
	MAM	0.87	1.14	1.53	1.28
	JJA	2.15	2.14	2.28	2.13
	SON	1.48	1.64	1.67	1.70
Tmin (degrees C)	DJF	1.22	1.28	1.63	1.27
	MAM	0.90	1.09	1.36	1.06
	JJA	2.13	2.36	2.46	2.24
	SON	1.83	2.08	1.96	1.98

Obs. As changes from 2001–2010 averages

Source: MoE (2011)

Climate change scenarios for regions in Lebanon have been developed through application of the PRECIS model[3]. Details on the dynamic downscaling adopted in the projections are provided below:

> The PRECIS regional climate model (Jones et al., 2004) was applied in a 25 km x 25 km horizontal resolution whereby Eastern Mediterranean and Lebanon particularly are at the center of the model domain, ensuring optimal dynamical downscaling of this region of interest. The driving emissions scenario adopted is A1B, assuming a world with rapid economic growth, a global population that reaches 9 billion in 2050 and then gradually declines, and a quick spread of new and efficient technologies with a balanced emphasis on all energy sources. PRECIS's 25 km x 25 km grid spacing is a state-of-the-art horizontal resolution that captures the geographical features of Lebanon

[3]Model's projections were made available through Lebanon's SNC to UNFCCC, and as such we have no control over the running of the model and any resultant or subsequent error adjustment.

> and resolves coastal and mountainous topographic characteristics, although not the steep orographic gradient. The more detailed topography can be represented with even higher horizontal resolution which is still being developed in regional climate modeling research. (MoE 2011, 1.1-1.2)

Table 3 summarizes the projections for the period 2025–2043, considering the four different point references in the country for which information is reported in the SNC.

4 Crop yields

We have analyzed how climate variables affect the average yield of five main types of crops: cereals, fruit trees, olives, industrial crops, and vegetables. Data limitations constrained the specification of models that could take into account variation at the regional level. We have relied on time series data of national crop yields and climate variables to extract the conditional correlations of the latter with seasonal temperature and precipitation observations for the period 1961–2001. This procedure allows the measurement of crop yield variation (direct effects), which will be further used as a physical measure of output change.

The empirical strategy was to define a common specification that would maximize the use of the limited information and could be supported by the existing empirical literature on yield effects of temperature, precipitation and technological progress. A broader specification could also include output and input prices[4]. The general form of a crop yield model using the restricted time series data set can be written as:

$$Yield_{it} = f(Climate_t, Prices_{i,t-1}, Technology_{it}) + \epsilon_{it} \tag{1}$$

where $Yield_{it}$ represents the yield of crop i in year t; $Climate_t$ are seasonal climate variables; $Prices_{i,t-1}$ refer to the price of crop i in year $t-1$; $Technology_{it}$ includes information on technical progress related to crop i in year t; ϵ_{it} is the error term. There are many alternatives to define these variables. However, in our parsimonious approach in which data constraints prevail, we relied on the following information. For each of the five main types of crop, we used data for yield and prices from FAOSTAT (FAO 2014); climate variables from archives at the American University of Beirut and from the national weather service refer to seasonal average precipitation and temperatures (max and min). All climate variables were normalized, taking into consideration the respective 40-year sample averages. Deviations from the sample averages are meant to capture long-term climate changes in the simulations. Note that, to maximize the use of regional variation in the simulations, we selected the same variables for which regional climate scenarios from the PRECIS model are provided (see table 3). The FAOSTAT database publishes additional information that could potentially be used to identify prices of inputs (e.g. oil price) and technology (e.g. use of fertilizers, irrigation). Given the lack of crop-specific technology and cost information for Lebanon, we opted to identify technical progress and aspects of the economic environment with a time trend variable (testing also for a quadratic form). The rationale is that crop yields are expected to increase over time because of technological advances such as the adoption of new varieties, greater application of fertilizers and irrigation, and expansion or contraction of crop acreage.

The econometric estimates of equation (1) are presented in the Appendix. Overall, the general specification adopted under the set of variables described above has shown a good fit for four out of the five crops. Time trends and specific seasonal climate variables are the main determinants of crop yields in the models.

The total direct impacts on productivity of the agriculture sector in each Lebanese governorate were then calculated from the estimates of the crop yields models by using Laspeyres indices whose weights were given by the shares of crops in regional output value[5]. In the simulations, we have assumed that the projected scenarios of climate change in table 3 would prevail in 2040. The accumulated effects on regional productivity

[4] For a review, see Huang and Khanna (2010).

[5] Climate projections for Beirut were associated with Mount Lebanon; Zahle with Bekaa; Daher with Southern Lebanon and Nabatieh; and Cedars with Northern Lebanon.

in the agriculture sectors in Lebanon are presented in table 4. The agriculture sector would potentially be more affected in the southern part of the country due to the stronger vulnerability of its crop mix (a high share of industrial crops — the most vulnerable crop type — in the sectoral output).

Table 4: Accumulated productivity changes in the agriculture sector due to climate change, Lebanese governorates, 2010–2030 (in percentage change)

	2010–2030
	Accumulated (%)
Mount Lebanon	-5.72
Northern Lebanon	-8.44
Bekaa	-3.10
Southern Lebanon	-9.66
Nabatieh	-9.98

5 Higher-order impacts

Results from table 4 were translated into productivity shocks that change the production functions of the agriculture sector in each governorate. We have assumed monotonic changes from 2010 until the accumulated changes reached the simulated values, generating a magnification effect over time. These productivity shocks only account for the direct impact of climate changes in the agriculture sector. As the agriculture sector is integrated with different agents in the economy, it is naturally expected that the effects on productivity will spread to the entire economic system, generating higher-order impacts.

An ICGE model[6] was used to simulate the systemic impacts of changes in crop yields by governorate, owing to climate variation. According to Haddad (2009), the general equilibrium approach treats the economy as a system of many interrelated markets in which the equilibrium of all variables must be determined simultaneously. Any perturbation of the economic environment can be evaluated by re-computing the new set of endogenous variables in the economy. Moreover, interregional models consider explicitly the location of such markets. This methodological feature of general equilibrium analysis is very attractive to our case. It allows us to define a baseline scenario that does not incorporate climate change, and to re-estimate the model with the changes in the exogenous variables that may be attributed to the expected changes in regional temperature and precipitation, thus identifying the economic impacts associated with the changes in climate variables.

The departure point was the ARZ model, a fully operational ICGE model calibrated for the Lebanese economy (Haddad 2014a). The ARZ model was recently developed for assessing regional impacts of economic policies in Lebanon. The theoretical structure and the database of the ARZ model are documented in Haddad (2014ab).

We provide a very brief verbal description of the model's key features, drawing on Haddad (2014a), where the details of the model can be found. Agents' behavior is modeled at the regional level, accommodating variations in the structure of regional economies. Regarding the regional setting, the main innovation in the ARZ model is the detailed treatment of interregional trade flows in the Lebanese economy, in which the markets of regional flows are fully specified for each origin and destination. This model recognizes the economies of the six Lebanese governorates. The model is standardized in its specifications, drawing on previous experiences with the MONASH-MRF and the B-MARIA models[7]. Results are based on a bottom-up approach — i.e. national results are obtained from the aggregation of regional results. The model identifies eight production/investment sectors in each region producing eight commodities, one representative

[6]Reviews of ICGE models are found in Partridge and Rickman (1998), and Haddad (2009).
[7]Peter et al. (1996) and Haddad (1999).

household in each region, one government, and a single foreign area that trades with each domestic region. Two local primary factors are used in the production process, according to regional endowments (capital and labor). Special groups of equations define capital accumulation relations. The model is structurally calibrated for 2004–2005; a comprehensive data set is available for 2005, of which the last national input-output tables — that served as the basis for the estimation of the interregional input-output database — were published. Additional structural data from the period 2004–2005 complemented the database[8].

In order to examine the higher-order effects of changes in productivity in agriculture related to climate change projections, we conducted two sets of simulations, following standard procedures described in Giesecke and Madden (2006). The first set of simulations is undertaken to produce a baseline forecast for the Lebanese economy for the period of 2010 to 2030. These ARZ forecasts incorporate information on trends in sectoral TFP growth, forecasts of commodity prices and growth of the world economy, estimates of regional population growth, and trends in sectoral investments. Using this information, the model generated forecasts for a wide range of variables (see table A2 in the Appendix).

We repeated our forecasts under the assumption that the productivity in agriculture would grow slower over the period to 2030. This involved the same set of shocks imposed to generate the baseline forecast, plus an additional set of shocks that incorporate the direct effects of the slower productivity growth. The new forecasts were then compared with the baseline forecasts. Results are reported as deviations (in either change or percentage change terms) of the lower productivity growth scenario for 2010 to 2030 from the baseline forecasts. Thus, the results show the effects on the economy of a scenario in which the productivity of the agriculture sector grows at a slower rate than under a "business as usual" scenario.

One difference between the two closures (baseline and "policy") is that we have swapped the regional population growth variable (exogenous in the baseline) with the regional utility change variable (endogenous in the baseline). Thus, the population change impact reported below should be interpreted as the population movements necessary to keep the baseline utility levels unchanged in the regions.

Tables 5 through 7 present results for selected macroeconomic, industry and regional variables. The accumulated results presented in the last two columns of table 5 are simply the sum of the annual marginal flows related to the differences between the two scenarios, shown in LBP and percentage of the baseline values in 2010. In order to calculate annual GDP losses that are accrued until 2030 at their present value, taking into account the value of time, three different discount rates were used: 0.5%, 1% and 3% per year (table 6).

Regarding the impacts of climate change on the economy through changes in crop yields, the simulations revealed a permanent loss for Lebanon GDP by 2030 of approximately 0.55% when the scenarios with and without climate change are compared.

Present values of losses range between 5.50% and 7.75% of the GDP for 2010. Therefore, if the costs from climate change in Lebanon by 2030 were brought forward to today, at an intertemporal discount rate — for example — of 1.0% per year, the cost in terms of the GDP would be LBP 4,140 billion, which would account for 7.22% of the GDP for 2010. In terms of welfare, the average Lebanese citizen would lose around LBP 504,000 (US$ 336) in terms of the present value of the reductions in household consumption accumulated to 2030, representing 4% of current per capita annual consumption.

These economic impacts would be experienced in different ways across the sectors and regions. For example, agriculture would be the sector most directly sensitive to climate, with a permanent decline in production of LBP 105.9 billion by 2030, which is equivalent to 1.9% of the baseline sectoral value added at that year. The total accumulated losses in the period would account for almost half of the sectoral GDP for 2010 (without taking into account any discount factor over time).

From the regional perspective, the greatest threat exists for the poorest regions in the country. It is fair to conclude from GRP results in table 5 that the effects of climate change on crop yields will potentially exacerbate regional inequalities in Lebanon. The

[8]See Haddad (2014b) for a detailed description of the database.

Table 5: Systemic impacts of productivity changes in agriculture due to climate change on selected variables (deviations from base case)

	2010	*2015*	*2020*	*2025*	*2030*	*2010–2030*	
						Accumulated	*% of 2010 values*
Macroeconomic indicators (Billions LBP 2010)							
GDP	**-28.6**	**-110.7**	**-228.7**	**-401.7**	**-522.0**	**-4770.9**	**-8.33%**
Household consumption	-22.3	-75.0	-132.0	-200.0	-223.6	-2457.4	-4.85%
Government expenditure	-3.0	-8.2	-12.6	-17.4	-17.9	-221.3	-3.12%
Investment	1.4	-5.0	-36.1	-103.6	-181.7	-1129.0	-7.94%
Exports of goods and services	-8.3	-29.8	-55.6	-86.1	-95.7	-1041.2	-5.01%
Imports of goods and services	3.5	7.3	7.7	5.4	-3.2	77.9	-0.22%
Sectoral value added (Billions LBP 2010)							
Agriculture	-6.2	-29.3	-62.2	-97.8	-105.9	-1169.1	-47.59%
Manufacturing	-2.1	-7.1	-12.9	-20.0	-22.2	-241.3	-4.80%
Services	-20.3	-74.4	-153.6	-284.0	-394.0	-3360.5	-6.75%
Gross Regional Product (Billions LBP 2010)							
Beirut	-2.8	-29.3	-62.2	-97.8	-105.9	-246.4	-3.24%
Mount Lebanon	-9.8	0.5	1.3	2.3	2.7	-1097.5	-4.32%
Northern Lebanon	-6.3	-7.1	-12.9	-20.0	-22.2	-1262.2	-12.33%
Bekaa	-3.6	-26.3	-72.3	-166.9	-274.2	-680.6	-11.15%
Southern Lebanon	-3.2	-3.3	-5.6	-8.4	-8.9	-807.2	-16.26%
Nabatieh	-2.9	-26.7	-46.1	-69.3	-75.4	-677.1	-22.64%

Table 6: Present value of marginal flows associated to the impacts of productivity changes in agriculture due to climate change, 2010–2030

	Discount rate		
	0.5	*1.0*	*3.0*
GDP (LBP billion 2010)	-4,442.2	-4,139.8	-3,150.5
GDP (% of 2010 value)	-7.75%	-7.22%	-5.50%
Per capita HH consumption (LBP 2010)	-538,873	-504,412	-391,022
Per capita HH consumption (% of 2010 value)	-4.28%	-4.00%	-3.10%

Table 7: Systemic impacts of productivity changes in agriculture due to climate change on regional population (net migrants)

	2010–2030	
	Accumulated	*% of 2010 values*
LEBANON	**-128,336**	**-3.19%**
Beirut	-18,137	-4.28%
Mount Lebanon	-52,798	-3.27%
Northern Lebanon	-21,772	-2.65%
Bekaa	-14,863	-2.94%
Southern Lebanon	-13,698	-3.22%
Nabatieh	-7,069	-3.07%

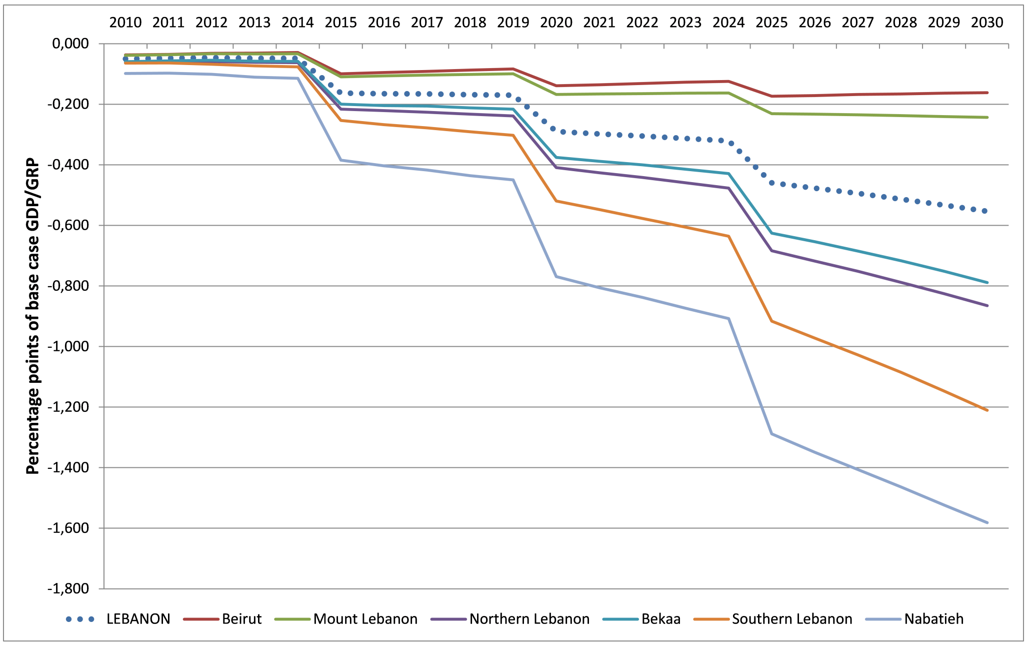

Figure 2: Regional impacts of productivity changes in agriculture due to climate change on GRP (% deviations from baseline)

most significant discrepancy can be found by comparing the systemic effects of climate change in Nabatieh and Southern Lebanon (accumulated losses in relation to the 2010 baseline's values of 22.64% and 16.26% by 2030, respectively) to the effects in Beirut and Mount Lebanon (losses of 3.24% and 4.32%, respectively). Moreover, as we analyze the annual GRP impacts as deviations from the baseline, we notice that regional inequality is potentially magnified over time (figure 2).

A final point refers to regional welfare, as suggested by the results on net migration presented in table 7. Those estimates take into account endogenous population changes in order to maintain the baseline utility levels in the regions. The higher percentage changes in the population in Beirut and Mount Lebanon, required to keep residents as well off as in the baseline (no climate change), reveal important impacts on relative changes in the cost of living in the central areas of the country. This negative effect, common to all governorates, would be mostly due to the reduction in real income caused by the general increase in prices led by the increase in the prices of agricultural products.

6 Final remarks

The SNC has identified several gaps related to the assessment of vulnerability and impact of climate change on agricultural crops in Lebanon. Ways in which this has been achieved range from the use of a more accurate climate model, to the exhaustive application of GIS techniques to improve information available for agronomic variables (MoE 2011, 2.61). Accordingly, the assessment could have better invested into GIS techniques in order to strengthen the results and minimize assumptions. However, the limited availability of data and maps, in addition to time constraints, hindered the use of such tools (Ibid, 2.17).

We do recognize that, at this stage, there are still data limitations. However, do we wait until the data have improved sufficiently, or do we start with existing data, no matter how imperfect, and improve the database gradually? In this paper, we have opted for the latter, following the advice by Agénor et al. (2007) for approaches to quantitative modeling in developing economies.

With renewed interest by policymakers on regional issues in Lebanon after the publication of the National Physical Master Plan of the Lebanese Territory — NPMPLT (CDR 2005), the notion that there is little interest in spatial development planning and spatial development issues in small size countries has been challenged (Haddad 2014a). The NPMPLT has identified challenges for the future economic development of the country in different sectors in a context of increasing internal and external obstacles to the Lebanese economy. Climate change poses additional uncertainty to the future of Lebanese regions. Our study of the economic impacts from climate change on crop yields in Lebanon, despite its limitations, shows that there are potential high costs and risks associated with a burden to the poorer and more vulnerable regions of the country.

The great methodological challenge remains to establish a link between future climate projections and business sectors and several environmental and socio-economic features at local and regional levels. Additionally, a level of aggregation or disaggregation of analyses that makes research in this area relevant and a faithful reflection of the "local" reality at a minimum must be established, and it must be feasible from the perspective of information and data handling. This is a critical issue in studies involving a myriad of interconnected economic agents with different natures. The deterministic approach of our study, for instance, is just one of key limitations. We have explicitly omitted the risk and uncertainty by emphasizing expected average values[9]. Regional science has a central role to play in helping to narrow these gaps. There is plenty of existing experience with large-scale multi-regional and multi-sectoral models, including uncertainty and ways to handle it, from which the scientific community can learn to apply in interdisciplinary studies.

[9] As emphasized by one of the referees, there is a degree of uncertainty in the results of the climate models and thus the uncertainty within climate change further compounds the uncertainty of climate change impacts.

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Appendix

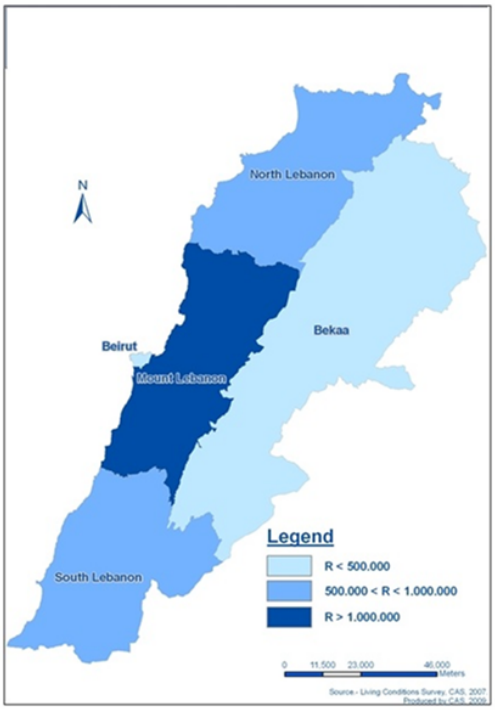

Figure A1: Lebanese governorates and their population

Source: CAS, 2013

Table A1: Econometric estimates

Variables/Productivity	prd_cereals	prd_fruit	prd_olive	prd_indus	prd_veget
time	0.0244	0.5559	0.0384	0.1484	0.2186
	(0.037)	(0.000)	(0.117)	(0.145)	(0.011)
time2		-0.0131			
		(0.002)			
p_cereals1	0.0078				
	(0.582)				
p_fruit1		0.0386			
		(0.184)			
p_olive1			2.2395		
			(0.109)		
p_indus1				-0.0020	
				(0.009)	
p_veget1					-0.1250
					(0.000)
winter_n	-0.0577	-0.6053	0.2251	-0.3244	0.1010
	(0.315)	(0.017)	(0.072)	(0.509)	(0.805)
spring_n	0.0702	0.4372	0.0089	-0.5671	0.2468
	(0.258)	(0.104)	(0.944)	(0.279)	(0.562)
summer_n	-0.0072	-0.0474	-0.1113	0.3504	-0.4723
	(0.903)	(0.851)	(0.376)	(0.485)	(0.252)
fall_n	0.0513	0.5917	-0.1108	0.2718	-1.2008
	(0.392)	(0.041)	(0.376)	(0.598)	(0.006)
winter_tem_max_n	-0.1400	-0.8466	0.1530	-0.0264	-0.4372
	(0.367)	(0.210)	(0.644)	(0.984)	(0.700)
spring_tem_max_n	0.1344	0.1275	0.2447	-1.8785	-1.7605
	(0.263)	(0.801)	(0.330)	(0.068)	(0.042)
summer_tem_max_n	-0.0114	-0.2612	-0.0399	-0.6323	-0.0561
	(0.891)	(0.452)	(0.822)	(0.376)	(0.927)
fall_tem_max_n	-0.0585	0.5741	-0.0824	1.3437	-0.4552
	(0.557)	(0.174)	(0.691)	(0.116)	(0.502)
winter_tem_min_n	0.0302	-0.2286	-0.4641	-0.1710	0.6329
	(0.876)	(0.781)	(0.267)	(0.918)	(0.656)
spring_tem_min_n	-0.1542	-0.2203	-0.6467	0.9328	2.2449
	(0.381)	(0.764)	(0.093)	(0.530)	(0.075)
summer_tem_min_n	0.2573	1.0862	0.4560	0.9984	1.2984
	(0.098)	(0.148)	(0.165)	(0.438)	(0.222)
fall_tem_min_n	0.1676	-0.1608	0.1076	-1.2030	0.4263
	(0.216)	(0.783)	(0.702)	(0.305)	(0.643)
constant	-0.0086	-8.4601	-2151.58	18.8068	57.1251
	(0.781)	(0.508)	(0.109)	(0.000)	(0.000)
R-Squared	0.8334	0.8267	0.4880	0.8747	0.9237

Note: p-value in parenthesis

Table A2: Baseline indicators, Lebanon 2010–2030

	2010	*2015*	*2020*	*2025*	*2030*	*Average annual growth 2010–2030*
Macroeconomic indicators (Billions LBP 2010)						
GDP	**57,299**	**67,847**	**78,839**	**87,454**	**94,324**	**2.52**
Household consumption	50,657	59,920	68,723	75,473	80,873	2.37
Government expenditure	7,083	7,237	7,401	7,483	7,531	0.31
Investment	14,226	14,577	15,840	16,909	17,803	1.13
Exports goods & services	20,777	25,189	29,055	31,936	34,042	2.50
Imports goods & services	-35,444	-39,077	-42,179	-44,346	-45,925	1.30
Sectoral value added (Billions LBP 2010)						
Agriculture	2,456	3,299	4,151	4,911	5,577	4.19
Manufacturing	5,022	6,095	7,191	7,982	8,535	2.69
Services	49,821	58,453	67,497	74,561	80,212	2.41
Gross Regional Product (Billions LBP 2010)						
Beirut	7,608	8,946	10,333	11,426	12,313	2.44
Mount Lebanon	25,398	30,288	35,254	39,122	42,197	2.57
Northern Lebanon	10,239	12,020	14,006	15,630	17,002	2.57
Bekaa	6,102	7,207	8,372	9,262	9,929	2.46
Southern Lebanon	4,963	5,883	6,821	7,517	8,015	2.43
Nabatieh	2,990	3,503	4,053	4,497	4,869	2.47
Population						
LEBANON	**4,021,367**	**4,158,521**	**4,252,732**	**4,300,625**	**4,328,435**	**0.37**
Beirut	423,613	442,500	454,292	461,353	466,629	0.48
Mount Lebanon	1,613,325	1,675,291	1,711,517	1,729,116	1,739,156	0.38
Northern Lebanon	822,745	836,638	855,451	864,840	869,815	0.28
Bekaa	505,370	520,992	532,262	537,632	540,217	0.33
Southern Lebanon	426,033	443,626	454,262	459,953	463,361	0.42
Nabatieh	230,280	239,474	244,948	247,731	249,258	0.40
Per capita GDP (Thousands LBP 2010)						
LEBANON	**14,249**	**16,315**	**18,538**	**20,335**	**21,792**	**2.15**
Beirut	17,960	20,218	22,744	24,767	26,386	1.94
Mount Lebanon	15,742	18,079	20,598	22,626	24,263	2.19
Northern Lebanon	12,445	14,367	16,372	18,073	19,546	2.28
Bekaa	12,074	13,833	15,730	17,227	18,380	2.12
Southern Lebanon	11,649	13,260	15,017	16,342	17,297	2.00
Nabatieh	12,986	14,627	16,545	18,153	19,534	2.06