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# Spatial Propagation of the Economic Impacts of Bombing: The Case of the 2006 War in Lebanon

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**Abstract:** This paper assesses the economic effects of the July 2006 War in Lebanon. We estimate the economy-wide impacts on the Lebanese regions resulting from the reduction of physical capital stocks using the estimated damages associated with the bombing events. In doing that, we are able to derive the estimates of the short-run economic costs of the War related to the structural break in the availability of economic infrastructure in the country. A discussion on resiliency is also introduced showing how the lack of redundancy in the country's infrastructure is associated with stronger higher-order negative effects. Moreover, we show how international trade can act as a shock absorber.

**Keywords:** Middle East, Lebanon, disasters, July 2006 War, impact analysis, resiliency

JEL Classification: Q54, R13

## 1 Introduction

On July 12, 2006, the conflict between Israel and Lebanon started and lasted for 5 weeks. By the time the war ended, after the August 14 UN-brokered cease-fire came into effect, Lebanon had sustained enormous economic losses (Darwish, Farajalla, and Masri 2009; Raphaeli 2009; Harris 2012). Not only direct economic damages took place in the form of destruction of the physical capital, other severe damages to human and social capitals also directly resulted from the

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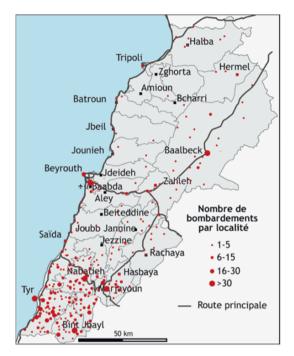


Figure 1: Locations bombed during July/August 2006.Source: Verdeil, Faour, and Velut (2007).

conflict, known in Lebanon as the July 2006 War.<sup>1</sup> Damage to the economic infrastructure of the country happened mainly in the southern regions, where most of the bombings were concentrated (Figure 1). However, public and private properties were also damaged in other parts of the country, where strategic bombing from Israel took place.

The main targets of the bombings were associated with important links and nodes in the transport infrastructure of the country, as well as key industrial facilities (Figures 2 and 3). Information on the bombed locations in July–August 2006 reveals not only a spatial pattern of localized disruption in infrastructure that covers the entire country but also a concentration of scattered bombing in the southern governorates of Nabatieh and South Lebanon.

<sup>1</sup> The July 2006 War resulted in more than 1,187 deaths, 4,398 injuries, and large-scale destruction of infrastructure (roads, bridges, and water and electricity supplies), disruption of essential services, and displacement of over one million persons. In addition, 27 people were killed and 234 injured by unexploded ordnances (UXOs) after the war ended, as a consequence of the estimated 1.2 million cluster bombs that were scattered over the country during the final days of hostilities (CDR 2008). Concerns with long-lasting environmental damage deserve also to be mentioned (Farajalla and El-Khoury 2007).

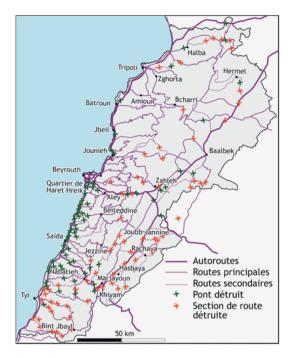


Figure 2: Transport infrastructure affected during July/August 2006. Source: Verdeil, Faour, and Velut (2007).

Capital stocks were severely ravaged. Bombing actions by the Israeli forces caused an estimated USD 1.1 billion of direct damage to the economic infrastructure of the country, in addition to USD 1.7 billion of damage in housing. Thus, total reconstruction costs were estimated by the government to be in the order of USD 2.8 billion (Table 1). However, the overall impacts of the war on the economy, social indicators, and employment were much greater. Based on the level of various indicators, the economy would have achieved an annual growth of at least 7% and 8% in the years 2006 and 2007, respectively (Council for Development and Reconstruction – CDR 2008). However, these significant higher-order effects were not properly estimated.<sup>2</sup>

<sup>2</sup> In a pioneering effort, Darwish, Farajalla, and Masri (2009) calculate that indirect losses may account for additional 80–90 % of any estimate of direct loss in the agriculture sector. They estimate the total – direct and indirect – cost of the war *specifically* to agricultural crop production, using an area of south Lebanon as a focal point. The indirect loss assessment viewed inter-temporal reductions in crop production values as the opportunity cost of not working fields due to the presence of unexploded ordnance (UXO). However, this partial equilibrium production function approach does not consider important general equilibrium higher-order effects.

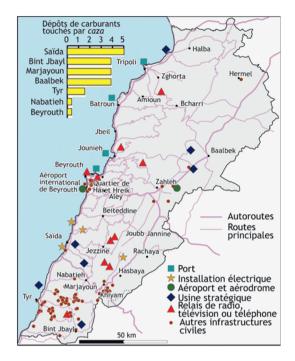


Figure 3: Other vital infrastructure affected during July/August 2006. Source: Verdeil, Faour, and Velut (2007).

From a regional perspective, based on the preliminary assessment made by the government, 117,661 housing and non-housing units, distributed over 354 villages and towns, were partially or severely damaged. The largest number of affected units was in the governorate of Nabatieh (50.5%), followed by South Lebanon (24.3%), Beirut area (20.6%), Bekaa (2.8%), Mount Lebanon (1.3%) and Northern Lebanon (0.6%).

Such estimates consider only the direct economic damage (value of lost assets) that led to interruptions of economic activities due to the destruction of capital stocks. Immediately after the war, resources for reconstruction were made available by foreign donors.<sup>3</sup> From an economic perspective, two different driving forces came into play: at first, damage in the economic infrastructure generated a reduction in the capital stock available for production, negatively impacting the potential national GDP and gross regional product (GRP) of Lebanese governorates; secondly, reconstruction efforts operated in the opposite direction, activating investment-oriented activities (e. g. construction sector), starting more vigorously in 2007. This paper aims to evaluate the short-run effects of the first of these two

**<sup>3</sup>** For further information on the recovery and reconstruction program, initiated in 2007, see CDR (2008).

Table 1: Estimated reconstruction costs.

Sector	Estimated direct damages (USD million)
Economic sectors	1,105
Transportation	120
Electricity	160
Telecommunication	135
Water & wastewater	40
Health	15
Education	45
Industrial & commercial	380
Agriculture & irrigation	210
Housing	1,700
Total	2,805

Source: CDR.

driving forces observed in Lebanon. We look at the economy of the country just before the war and estimate what would be the hypothetical economy-wide impact had the Lebanese regions faced a reduction of physical capital stocks in the same magnitude of the estimated damages associated with the bombing events. In doing that, we are able to derive the estimates of the partial economic costs of the war related to the structural break in the availability of economic infrastructure in the country. By deliberately not taking into account the effects of foreign transfers for reconstruction, we are also able to isolate the economic effects of the bombing and its spatial propagation providing a better approximation of the regional consequences of the targeted destruction.

# 2 Issues in the Modeling of Spatial and Economic **Impacts of Bombing**

Economic impacts of disasters caused by natural or man-made hazards are complex and difficult to assess and evaluate, due to the features and uniqueness of disasters; however, some methodologies have been employed to analyze their impacts. There is considerable research addressing the persistent problem of natural disasters, such as floods, storms and earthquakes (Okuyama and Chang 2012). However, human-induced or man-made disasters have not received similar attention from economic impact analysts until recently.

From the perspective of social science, insights are needed into several fundamental questions at the intersection of economics and public policy, particularly in the context of massive bombing events. Carl von Clausewitz claimed that "war is a mere continuation of policy by other means" (Clausewitz 1832). The consequences of a war would surely become a disaster (for the definition of the term "disaster", see Okuyama and Chang 2012); hence, the economic impact of the disaster by a war should be considered for it's (public) policy consequences. In this regard, social science research has a critical role to unfold the extent and significance of the economic impact by a war.

Pelling, Özerdem, and Barakat (2002) set out a conceptual framework that allows a more holistic accounting for the macroeconomic impacts of disasters. They argue for a methodological approach that goes beyond the accounting for the replacement value of physical infrastructure by incorporating the potentially larger systemic impacts of disasters on regional and national economies. While it is recognized that disasters are felt on different spatial scales, by focusing on the units of development planning (i. e. a nation state or national sub-regions) one can move toward a deeper integration of disasters and development. The authors use the methodology designed by the Economic Commission for Latin American and the Caribbean (ECLAC) for appraising the impacts from natural trigger events to frame a broader discussion on the economics of disaster impacts (Box 1).

#### Box 1: The ECLAC methodology for disaster impact appraisal

#### Direct damages:

All damage to fixed assets, capital and inventories of finished and semi-finished goods, raw materials and spare parts that occur simultaneously as direct consequences of the phenomenon causing a disaster. Includes expenditure on relief and emergency response.

#### Indirect damages and flow losses:

The effect on flows of goods that will not be produced and services that will not be provided after a disaster. Indirect damages may increase operational expenditure following the destruction of physical infrastructure, or inventories. They incur additional costs from the alternative provision of services (additional costs are incurred because of the need to use alternative means of production and/or distribution for the provision of goods and services), losses of income resulting from the non-provision of goods and services, losses of personal income in the case of total or partial loss of the means of production, business or livelihood.

#### Secondary effects:

The impact on the overall performance of the economy, as measured through the most significant macroeconomic variables. Relevant variables may include overall and sectoral gross domestic product, the balance of trade and balance of payments, levels of indebtedness and monetary reserves, the state of public finances and gross capital investment. The effect of a disaster on public finance, such as a decline in tax revenue or an increase in current expenditure can be particularly important. Secondary effects are usually felt during the calendar or fiscal year in which the disaster occurs but may spill over a number of years.

Source: Zapata-Marti (1997) and Pelling, Özerdem, and Barakat (2002).

This conceptual framework guides our modeling strategy that deals explicitly with the computation of these compounding effects. Nonetheless, as mentioned in the introduction, we deliberately disregard expenditures on relief and emergency response in order to isolate the extent of economic disruption caused by the bombing events. As we will make it clear, the propagation of the effects is greatly influenced by the structure of the productive system.

The guidance provided by the ECLAC framework recognizes that higherorder impacts of disasters are usually concentrated in the short-run but may also be felt in the long-run. Bozzoli, Brück, and Sottsas (2010) provide a critical assessment of studies assessing the economic costs of conflict, considering both short- and long-term measurable impacts from mass violent conflicts. The cost of a conflict is defined as some measure of welfare loss between the current situation in a given country and the welfare that the country would have achieved in the absence of conflict. Results coming from these comparisons tend to differ depending on the methodology of the study, the time period analyzed, and the geographical context.

The spatial scale of a disaster is another important dimension to be considered in the estimation of the economic impacts of disasters (Jensen and Gleditsch 2009; Bozzoli, Brück, and Sottsas 2010; Caruso et al. 2016). In the case of the 2006 War in Lebanon, geography has played an important role since the spatial pattern of the direct damages was heavily influenced by geographical proximity to Israel. However, when taking into account indirect damages and flow losses, as well as secondary effects, the regional structure of the Lebanese economy has also influenced the spatial propagation of the impacts. Though small, the Lebanese economy is not internally homogenous (Table 2). It presents

	Population	%	GRP/ GDP*	%	Per capita GRP/ GDP**	Share of national
Beriut	361,366	9.61	4,169	13.70	11,537	1.43
Mount Lebanon	1,484,473	39.49	13,578	44.62	9,147	1.13
Northern	763,713	20.32	5,329	17.51	6,978	0.86
Lebanon						
Bekaa	489,866	13.03	3,154	10.36	6,439	0.80
South Lebanon	242,877	6.46	2,535	8.33	10,436	1.29
Nabatieh	416,842	11.09	1,668	5.48	4,001	0.49
Lebanon	3,759,137	100.00	30,433	100.00	8,096	1.00

Table 2: Basic socioeconomic indicators for Lebanon, 2004-2005.

Notes: \*In LBP billions; \*\*In LBP thousands.Source: National Economic Accounts and Haddad (2014b).

variations across both industries and regions. Thus, it is expected that the impact of economic disruptions will vary across different governorates.

The concepts and methodologies for analyzing the economic impact of disasters caused by natural hazards have progressed considerably in the recent decades. Meanwhile, there had been a growing but still limited number of studies on the economic impacts of catastrophic events, such as war, terrorism, and man-made disasters triggered by violence. This dearth of research may have been changed since the occurrence of the 9/11 terrorist attacks in the USA in 2001. In those researches, the costs of countermeasures against such terrorist attacks are often compared with the economic impacts of such events. Therefore, a series of hypothetical estimations have been performed using similar methodologies employed for disasters by natural hazards.

In their survey article on the global economic costs of conflict, Bozzoli, Brück, and Sottsas (2010) review around 30 studies that considered the economic cost aspect of mass violent conflicts explicitly. They point that, from a methodological and data perspective, the most practical way to calculate the economic costs of conflict given the state of the art is the use of well-articulated regression model informed by insights from micro-level analyses and accounting for constraints on the data side. As an alternative to econometric model, the use of general equilibrium model would allow a stronger connection between microand macro-level studies. According to the authors, focusing on basic economic principles to understand the link between welfare and war may help to broaden our understanding of welfare in war-torn countries.

Input-output (IO), social accounting matrix (SAM), and computable general equilibrium (CGE) models are the usual tool kits that have been employed more often - as alternatives to econometric models - to estimate the higher-order effects of a disaster. Detailed comparison of these methodologies can be found in Rose (2004) and Okuyama (2007, 2009). By and large, with the fixed coefficients hypothesis, IO and SAM models derive the system-wide impact of an event but inherently overestimate the impact, while CGE models endogenize price changes, substitution possibilities, and other flexible adjustment mechanisms, sometimes leading to the underestimation of the impacts. CGE models have been one of the most popular modeling frameworks in recent years (e. g., Rose 2009, 2013), because of their aforementioned advantages and their inherent simulation features. On the other hand, CGE models have been criticized as tools for disaster impact analysis, as they rely on optimization behavior and not (empirically) observed elasticities of various adjustment mechanisms (or changes thereof) under disaster situations (Okuyama 2009; Albala-Bertrand 2013).

As proposed by Rose (2004), "higher-order effects" should cover all flow losses beyond those associated with the curtailment of output as a result of disaster-induced property damage in the producing facility itself, including input-output linkages and general equilibrium price effects. In an integrated interregional system, it should also cover spatial interdependence effects.

Rose (2004) also observes that the size of higher-order effects can be guite variable depending on the resiliency of the economy, i. e. the ability an economy has to cushion potential losses from a hazard. Resiliency is considered in our modeling exercise in two ways: (i) it is embedded in the possibility of importing more goods and services from other domestic regions and also from abroad, in the event a long-standing supplier going temporarily out of business and (ii) in the modeling of the optimal mix of inputs in the regional production functions. A sector or region is considered to be more resilient to post-disaster higher-order effects, the easier the access to alternative suppliers outside the damaged areas and the more flexible are the production functions in terms of input substitution possibilities.

Rose and Liao (2005) modeled economic resiliency successfully in a CGE framework, in which inherent resiliency, i. e. the ability to substitute inputs and/ or reallocate resources under normal circumstances, is embodied in the production functions, while adaptive resiliency, i. e. the substitution ability in crisis situations with extra effort, is set as the changes in the parameters. Whereas the extent of resiliency across economic sectors has been studied empirically by Kajitani et al. (2005a, 2005b), further studies on theoretical and empirical foundations of economic resiliency need to be carried out so that more comprehensive impact estimates of disasters, taking into account resiliency mechanisms, can be produced.

As for the estimation of the impact of conflicts, IO models have a long history of use that dates back to strategic bombing studies during the World War II (Rose 2004). In addition, recovery from war destructions has also been examined in different econometric studies. The literature on the regional economic impacts of bombings has focused so far on longer run issues, such as long-run development (Miguel and Roland 2011), regional distribution of population and city-size (Davis and Weinstein 2008), and long-run city growth (Brakman, Garretsen, and Schramm 2004). Studies looking at the relationship between war and trade have examined different aspects of the impact of various forms of conflict on bilateral and multilateral trade flows (Barbieri and Levy 1999; Glick and Taylor 2010; Bah 2013). Survey articles are also available in Bozzoli, Brück, and Sottsas (2010) and Brück and De Groot (2013). While most of these studies investigate the long-run effect of particular wars, it is also essential to evaluate the very short-run impact of a war in order to understand the systemwide impacts with flow measures, such as immediate changes in output due to disruptions in the value chain, and in order to improve the design and focus of mitigation actions.

The event of the Israeli bombing in Lebanon in the summer of 2006 is a unique example of a recent man-made disaster. The bombing actions were concentrated in time - they roughly lasted for a month so that the time frame is still considered short in an economic modeling sense. They were also spatially focused – they reached not only various targeted infrastructure points across the country, but also scattered locations in the south of the country. Additionally, due to the strategic nature of bombing in this war, the direct damages were spatially uneven, and higher-order impacts may have had a very complicated spatial distribution via inter-industry relationships. Even in the case of natural disasters, attention to spatial distribution of impact is critically important, since the total impact can be oftentimes localized (Albala-Bertrand 2007). Hence, for understanding the more comprehensive picture of the regional economic impacts within Lebanon, it is critical to investigate more carefully the localized damages and their propagation to other regions, i. e. interregional effects. Thus, the impact analysis of the July 2006 War provides an opportunity to address some of the issues raised above. It also adds to the literature as regional economic impacts of bombings have received relatively little attention from research communities.

This paper is a case study that still does not meet the criteria of comprehensiveness and consistency advocated by Bozzoli, Brück, and Sottsas (2010) to be used as the benchmark for research on the global economic costs of conflicts. On the contrary, our focus is concentrated in time and space. Nonetheless, we believe we are able to address some of the important aspects associated with the immediate economic impacts of a war in a small country.

## 3 The ARZ Model

In this paper we use the ARZ model, a fully operational ICGE model calibrated for the Lebanese economy introduced in Haddad (2014a).4 The ARZ model was recently developed for assessing regional impacts of economic

<sup>4</sup> ARZ is the Arabic word for cedar, the symbol of Lebanon. It is also a pseudo-acronym in Arabic standing for Analytical Regional System.

policies in Lebanon. In what follows, we draw on Haddad (2014a) to provide the description of the theoretical structure and the database of the ARZ model.

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. To our knowledge, this is the first attempt to model the Lebanese economy in an interregional framework. The model recognizes the economies of the six Lebanese governorates. The model is very standard in its specification, drawing on previous experiences with the MONASH-MRF and the B-MARIA models.<sup>5</sup> Results are based on a bottom-up approach – i. e. national results are obtained from the aggregation of regional results. The model identifies 8 production/investment sectors<sup>6</sup> in each region producing 8 commodities, one representative 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, providing a picture of the economic structure of Lebanon just before the 2006 War.<sup>7</sup>

The ARZ model qualifies as a Johansen-type model in that the solutions are obtained by solving the system of linearized equations of the model, following the Australian tradition. A typical result shows the percentage change in the set of endogenous variables, after a policy is carried out, compared to their values in the absence of such policy, in a given environment. The schematic presentation of Johansen solutions for such models is standard in the literature. More details can be found in Dixon and Parmenter (1996).

<sup>5</sup> Peter et al. (1996) and Haddad (1999).

<sup>6</sup> Sectors in the ARZ Model: 1. Agriculture and livestock; 2. Energy and water; 3. Manufacturing;

<sup>4.</sup> Construction; 5. Transport and communication; 6. Other services; 7. Trade; and 8. Administration.

<sup>7</sup> See Haddad (2014b) for a detailed description of the database.

## 3.1 Overview

The basic structure of the ARZ model is very standard and comprises three main blocks of equations determining demand and supply relations, and market clearing conditions. In addition, various regional and national aggregates, such as aggregate employment, aggregate price level, and balance of trade, are defined. Nested production functions and nested household demand functions are employed.

Figure 4 illustrates the basic production technology adopted in the ARZ model, which is a common specification in regional models. Dotted-line boxes represent functional forms used at each stage. Two broad categories of inputs are recognized: intermediate inputs and primary factors. Producers in each regional industry choose input requirements per unit of output through optimizing behavior (cost minimization). Constraints are given by the nested production Leontief/CES technology. Firms are assumed to use fixed proportion combinations of intermediate inputs and primary factors in the first level while, in the second level, substitution is possible between domestically produced and imported intermediate inputs, on the one hand, and between capital and

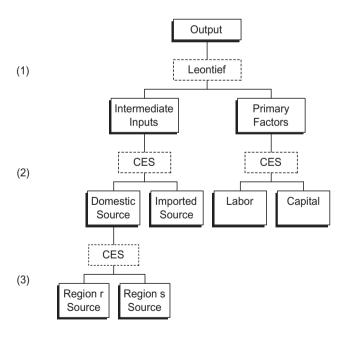


Figure 4: Nesting structure of regional production technology.

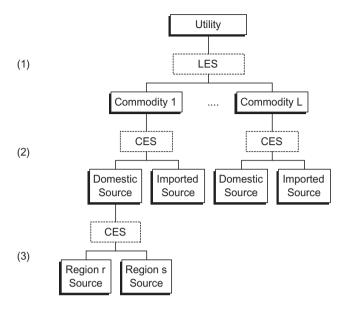


Figure 5: Nesting structure of regional household demand.

labor, on the other. At the third level, bundles of domestically produced inputs are formed as combinations of inputs from different regional sources.

The treatment of the household demand structure is based on a nested CES/ linear expenditure system (LES) preference function (Figure 5). Demand equations are derived from a Stone-Geary utility maximization problem, whose solution follows hierarchical steps. The structure of household demand follows a nesting pattern that enables different elasticities of substitution to be used. At the bottom level, substitution occurs across different domestic sources of supply. Utility derived from the consumption of domestic composite goods is maximized. In the subsequent upper-level, substitution occurs between domestic composite and imported goods.

Equations for other final demand for commodities include the specification of export demand and government demand. Exports face downward sloping demand curves, indicating a negative relationship with their prices in the world market.

The nature of the input-output data enables the isolation of the goods supplied by the government. However, "productive" activities carried out by the public sector cannot be isolated from those by the private sector. Thus, government entrepreneurial behavior is dictated by the same cost minimization assumptions adopted by the private sector.

An important feature of the ARZ model is the explicit modeling of the costs of moving products based on origin-destination pairs according to the allocation of trade margins. The model is calibrated taking into account the specific trade structure cost of each commodity flow. Such structure is physically constrained by the available transportation network, modeled in a stylized geo-coded transportation module.8

Following Haddad and Hewings (2005), the set of equations that specify purchasers' prices in the ARZ model imposes zero pure profits in the distribution of commodities to different users. Prices paid for commodity i from source s in region q by each user equate to the sum of its basic value and the trade costs associated with the use of the relevant margin-commodity.

The role of the margin-commodity is to facilitate flows of commodities from points of production or points of entry to either domestic users or ports of exit. The margin-commodity, or, simply, margin, includes trade services, which take account of transfer costs in a broad sense. The margin demand equations in the model show that the demands for margins are proportional to the commodity flows with which the margins are associated; moreover, a technical change component is also included in the specification in order to allow for changes in the implicit trade rate.<sup>9</sup>

Other definitions in the CGE core module include: basic and purchase prices of commodities, components of real and nominal GRP/GDP, regional and national price indices, money wage settings, factor prices, employment aggregates, and capital accumulation relations. 10

## 3.2 Structural Database

The CGE database requires detailed sectoral and regional information about the Lebanese economy. Haddad (2014b) reports on the recent developments in the construction of the interregional input-output system for Lebanon (IIOM-LIBAN) used in the process of calibration of the structural coefficients of the ARZ model. A fully specified interregional input-output database was developed, under conditions of limited information, as part of an initiative involving researchers from the Regional and Urban Economics Lab at the University of São Paulo (NEREUS).

<sup>8</sup> Spatial friction was approximated by distance measures, calculated for each pair of origindestination using Google Maps (see Haddad 2014b).

<sup>9</sup> In the case of international imported goods, the implicit trade margin may be interpreted as the costs at the port of entry, while for foreign exports it would refer to costs at the port of exit.

**<sup>10</sup>** The detailed system of equations of the ARZ model is available in an appendix.

## 3.3 Behavioral Parameters

Empirical estimates of the key parameters of the ARZ model are not available in the literature. We have thus relied on "best guesstimates" based on usual values used in similar models. Parameter values for international trade elasticities,  $\sigma$ 's in eq. [A2] in the appendix, were set to 1.5; regional trade elasticities,  $\sigma$ 's in eq. [A1], were set at the same values as the corresponding international trade elasticities. Substitution elasticity between primary factors,  $\sigma$ 's in eq. [A3], was set to 0.5. The marginal budget share in regional household consumption,  $\beta$ 's in eq. [A5], were calibrated from the input-output data, assuming the average budget share to be equal to the marginal budget share. We have set to -2.0 the export demand elasticities,  $\eta$ 's in eq. [A7].

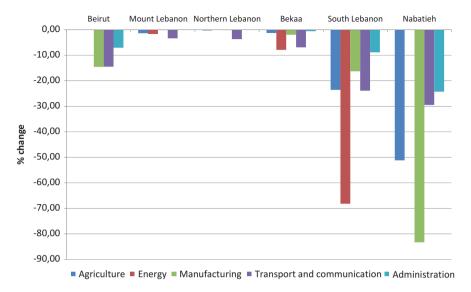
## 4 Simulations

In order to capture the impacts of the July 2006 War in Lebanon, the simulations are carried out under a short-run closure. 11 There is no dynamics in the model. The simulations with the ARZ model capture the effects associated with the static impact-effect question, i. e., given the structure of the economy, what-if questions can be addressed in a comparative-static framework. Structural changes are captured only through the evaluation of the re-allocation of resources.

The model was applied to analyze the effects of reductions in sectoral capital stocks in the regions according to official information on direct damages.<sup>12</sup> All exogenous variables were set equal to zero, except the changes in the affected capital stocks (Figure 6). South Lebanon and Nabatieh were the most affected governorates, with considerable damages in agriculture, manufacturing, transportation & communication, and public facilities. Beirut also

<sup>11</sup> The system of equations provides the theoretical structure of the model. In the implementation of the ARZ model, the linearized version of the model was condensed by eliminating some equations and variables, generating a reduced version with 33,454 equations and 34,248 variables. To close the model, values for 794 variables have to be set exogenously (the number of endogenous variables must equal the number of equations). The condensation procedure, i. e., the reduction of the size of the model, is carried out by substituting out variables that are to be endogenous and are of less interest to the analysis and presentation of the simulation results, and by omitting variables that are to be exogenous and not shocked in the simulations. The nominal exchange rate was set as the numéraire.

<sup>12</sup> Declines in regional sectoral capital stocks were computed based on information provided by CDR (2008) on the estimated damages in sectoral economic infrastructure, and the regional distribution of damaged transport and other vital infrastructure units.



**Figure 6:** Estimated damage of capital stocks, by sector and region (in percentage change from pre-war estimates).

presented significant damages, especially in the manufacturing, and transportation & communication sectors. The energy sector in South Lebanon and, to a lesser extent, in Bekaa, also suffered damages.

Results of the simulation were computed under a short-run closure (exogenous capital stocks). Uncertainty about key trade elasticities was also considered through qualitative sensitivity analysis, in an attempt to look at the potential range of the total costs under different degrees of resiliency (both technological and spatial). We have assumed a fixed low degree of technological resiliency (low values for the elasticities of substitution of primary inputs) consistent with a less complex and diversified economy - together with a spectrum of spatial resiliency (substitution of suppliers). We have altered the regional and international substitution elasticities to model the economy under different (uncertain) scenarios of adjustment following the bombings. Departing from the initial set of substitution elasticities used to calibrate the benchmark Lebanese economy, we have exogenously introduced different sets of elasticities to evaluate substitution possibilities for the regional economies in different resiliency settings. As suggested by Rose and Guha (2004), this procedure mimics the reaction of the economy with the assumption that resiliency is built in the adjustment process.

Table 3: Macro-regional effects: GDP/GRP effects (in percentage change).

Beirut	-4.61
Mount Lebanon	-2.44
Northern Lebanon	-2.05
Bekaa	-2.21
South Lebanon	-14.43
Nabatieh	-50.15
Lebanon	-6.26

We imposed the same reduction in capital stocks to reflect the supply losses under different sets of substitution elasticities. For the base case with the initial set of parameter values in the ARZ model, national GDP decreased by 6.26% (Table 3).<sup>13</sup> In regional terms, the Nabatieh region was the most affected, with a GRP decrease by over 50 %. South Lebanon region was second, with total losses accounting for a little over 14% of GRP. The least-affected regions were Mount Lebanon, Northern Lebanon and Bekaa, with GRP losses in the rough magnitude of 2%. Finally, total impact in the capital area was estimated in to be a loss of 4.61% of its 2005 GRP.

In money values, the total impact in the Lebanese economy was estimated to be USD 1,644 million in the base case simulation, for a direct damage of USD 1,105 million, so that the associated total impact-damage ratio was 1.49 in the short run.

The results presented in Table 4 indicate the simulated sectoral impacts. The largest impacts occurred in the production of the energy and water sector, whose producing facilities and distribution lines were targeted by the bombings. 14

<sup>13</sup> As a reference for heuristic validation of our aggregate results, we can look at the indirect costs reported by Raphaeli (2009) in terms of the real GDP growth rate in 2006, the year of the war. Accordingly, Lebanese real GDP growth, which had achieved a rate of 5-6% in the first half of 2006 ended the year on the negative side with a decline of 5%, representing a loss of output in 2006 in the order of USD 2.2 billion (at 2005 prices). However, no estimate at the regional and sectoral levels was provided.

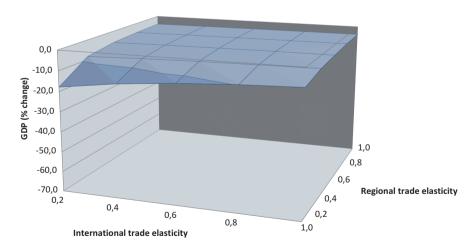
<sup>14</sup> Power plants and fuel tanks have been targeted: the supply of the South was totally disrupted and the rest of the country experienced rationing. Several water reservoirs and pipes were affected, and, in the absence of electricity, water supply in the South was cut. Deficiencies of these two services are the main cause of deterioration of the material situation in the localities in the South (Verdeil, Faour, and Velut 2007).

Table 4: Sectoral effects: activity level (in percentage change).

1. Agriculture and livestock	-17.89
2. Energy and water	-44.15
3. Manufacturing	-30.51
4. Construction	-4.48
5. Transport and communication	-7.81
6. Other services	-2.84
7. Trade	-1.81
8. Administration	-5.14

Manufacturing and agriculture also presented great losses, not only because of direct damages to factories and farms, but also because of disruption in the transportation infrastructure – modeled as increasing trade costs in the country due to damage in the available infrastructure (bridges and roads). As tradable goods, increasing transaction costs in space hampered sectoral competitiveness. Additionally, non-tradable sectors (i. e. services sectors) were also negatively affected due to a reduction in real income caused by the general increase in prices, which also hampered Lebanese competitiveness in foreign markets.

Figure 7 presents the surface of total damage in terms of national GDP, considering different scenarios of resiliency. Similar surfaces are presented for regional (Figure 8) and sectoral (Figure 9) damage surfaces. GDP impacts range



**Figure 7:** Total damage surface under different assumptions of regional resiliency, Lebanon (in percentage change in GDP).

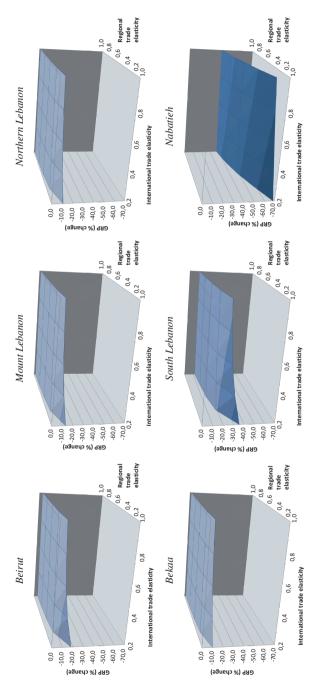


Figure 8: Regional damage surfaces under different assumptions of regional resiliency, by governorate (in percentage change in GRP).

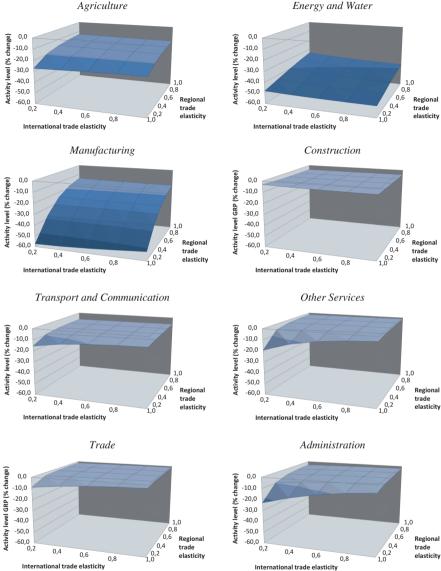


Figure 9: Sectoral damage surfaces under different assumptions of regional resiliency, by governorate (in percentage change in activity level).

from -17.8% to -4.2%, with increasing levels of resiliency generating lower GDP losses. What is noteworthy is that given its high external dependency and its low internal complexity, the Lebanese economy is more sensitive to lower

levels of substitutability with foreign products. In the scenarios with better access to international suppliers, the post-bombing adjustment process was favored, suggesting smaller losses with greater international responses to the production shortages in the country. The shape of the surface also suggests a non-linearity as the scenarios approach a "Leontief world", in which less flexible substitutability alternatives prevail. At the regional level, Nabatieh, the governorate that was more severely damaged by the bombing attacks, seems to be also pretty much sensitive to regional trade elasticities scenarios (Figure 8) given its relatively high dependence on the core regions of the country. In sectoral terms, access to regional markets of final manufactured goods produced in Lebanon is responsible for a greater sensitivity of the manufacturing sector to lower degrees of resiliency also at the regional level (Figure 9).

Finally, Figure 10 presents the total impact, in USD terms, and Figure 11 presents the total impact-damage ratio, both under different assumptions of regional resiliency. Given the different sets of regional and international trade elasticities, total impact of bombing was in the range of USD 1,138 to 5,521 million. With the estimated direct damage equivalent to USD 1.105 million, total impact-damage ratio ranges from 1.03 to 5.00.

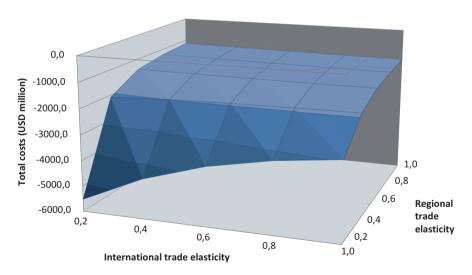


Figure 10: Total impact under different assumptions of regional resiliency (in USD million).

The main shock absorbers are related to access to alternative suppliers and markets. The impact of different scenarios of resiliency can also be perceived in Figure 12, which illustrates the impacts of both interregional and

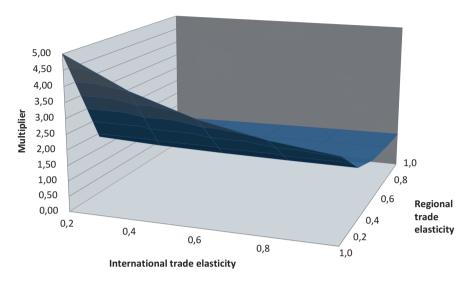


Figure 11: Total impact-damage ratio under different assumptions of regional resiliency.

international trade flows in the post-bombing equilibrium. The information is presented in arrows that indicate (i) the direction of flows, for each pair of origin-destination; (ii) the direction of changes – blue relates to increases in the flows while red indicates decreases; and (iii) the intensity of the changes in the flows, given by the thickness of the arrows. In the two resiliency cases that were considered, it is clear the role played by the interactions with the international markets in the higher degree of resiliency case, acting as a mechanism to minimize the negative impacts associated with regional production disruptions in the bombed areas. As the possibilities of substitution diminish, the Lebanese regional economies become less prone to mitigate the economic losses through trade deviation.

# 5 Concluding Remarks

The economic infrastructure in Lebanon has a low capacity to easily absorb an exogenous shock that destroys linkages in the production chain, creating an environment of uncertainty for those dependent on local suppliers and local markets. Moreover, because it can be considered as a developing economy due to the lack of redundancy in its economic infrastructure, i. e. the inability to have alternatives to solve the given problem of logistics, communications or

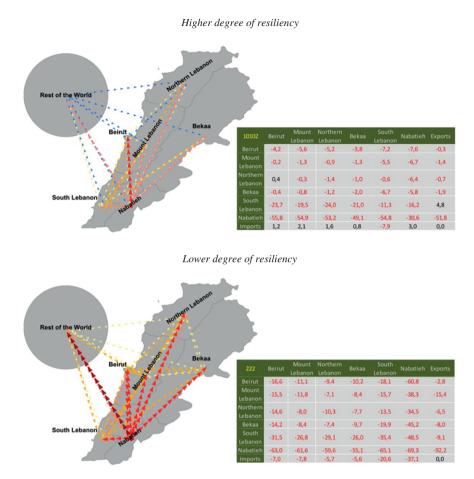


Figure 12: Impacts on international and interregional trade flows.

energy, Lebanon tended to suffer more severely the impacts of the war. In our modeling exercise, given the conditions of limited information that prevail in Lebanon, the lack of behavioral parameters to properly calibrate the model brings further uncertainty for the simulation results. The default value used for the Armington elasticities in the ARZ model – identified as the analytically most important parameters in generating the model outcomes – was in accordance with the estimates in the prevailing literature. Nonetheless, it denotes stronger substitution possibilities than a small, specialized economy such as Lebanon would potentially face. Resiliency, in the form of substitution possibilities, is

intrinsically related to the complexity and diversity of an economy's production structure. It seems to us that the "right" magnitude of such set of parameters for Lebanon would be much lower than that used in the benchmark, leading to an approximate value of the economic costs of the July War closer to the upper bound of our estimates.

As discussed in Section 2, the economic impacts from man-made hazards, such as the 2006 bombing events in Lebanon, may appear similar to natural hazards; thus, similar methodologies and analytical frameworks can be employed, since wars and natural hazards share some common features, such as physical destructions, uneven damages over space, human casualties, among others. What differentiates bombing events from natural hazard events are: 1) the occurrence of a man-made hazard can be avoided via diplomatic and/or international efforts; 2) location of damages can be determined strategically, rather than unexpectedly by natural hazards; and 3) the consequences of a hazard, thus the disaster, can be premeditatedly determined. Subsequently, the use of the results from such research may well be different from the analysis of economic impact of disasters by a natural hazard which has been used to evaluate the countermeasures for mitigating such economic impacts. On the other hand, studies of economic impacts of a war, like in this paper, that investigate the costs of such war, can derive the opportunity cost (benefit) to avoid such an event (Caruso et al. 2016).

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# Appendix. The Equation System of the ARZ Model (cf. Haddad 2014a)

The functional forms of the main groups of equations of the spatial CGE core are presented in this Appendix together with the definition of the main groups of variables, parameters and coefficients.

The notational convention uses uppercase letters to represent the levels of the variables and lowercase for their percentage-change representation. Superscripts (u), u = 0, 1j, 2j, 3, 4, 5, refer, respectively, to output (0) and to the five different regional-specific users of the products identified in the model: producers in sector j(1j), investors in sector j(2j), households (3), purchasers of exports (4), and government (5); the second superscript identifies the domestic region where the user is located. Inputs are identified by two subscripts: the first takes the values 1, ..., g, for commodities, g + 1, for primary factors, and g + 2, for "other costs" (basically, taxes and subsidies on production); the second subscript identifies the source of the input, being it from domestic region b (1b) or imported (2), or coming from labor (1) or capital (2). The symbol (•) is employed to indicate a sum over an index.

## **Equations**

[A1] Substitution between products from different regional domestic sources

$$x_{(i(1b))}^{(u)r} = x_{(i(1\bullet))}^{(u)r} - \sigma_{(i)}^{(u)r}(p_{(i(1b))}^{(u)r} - \sum_{l \in \mathcal{S}^*} \left(V(i,1l,(u),r)/V(i,1\bullet,(u),r)(p_{(i(1l))}^{(u)r})\right)$$

$$i = 1, ..., g; b = 1, ..., q; (u) = 3$$
 and  $(kj)$  for  $k = 1$  and  $2$  and  $j = 1, ..., h; r = 1, ..., R$ 

[A2] Substitution between domestic and imported products

$$x_{(is)}^{(u)r} = x_{(i\bullet)}^{(u)r} - \sigma_{(i)}^{(u)r}(p_{(is)}^{(u)r} - \sum_{l=1\bullet,2} \left(V(i,l,(u),r)/V(i,\bullet,(u),r)(p_{(il)}^{(u)r})\right)$$

$$i = 1, ..., g; s = 1 \bullet \text{ and } 2; (u) = 3 \text{ and } (kj) \text{ for } k = 1e2 \text{ and } j = 1, ..., h; r = 1, ..., R$$

[A3] Substitution between labor and capital

$$\begin{aligned} x_{(g+1,s)}^{(1j)r} - a_{(g+1,s)}^{(1j)r} &= \alpha_{(g+1,s)}^{(1j)r} x_{(g+1\bullet)}^{(1j)r} - \sigma_{(g+1)}^{(1j)r} \{ p_{(g+1,s)}^{(1j)r} + a_{(g+1,s)}^{(1j)r} + a_{(g+1,s)}^{(1j)r} \\ &- \sum_{l=1,2} \left( V(g+1,l,(1j),r) / V(g+1,\bullet,(1j),r) \right) (p_{(g+1,l)}^{(1j)r} + a_{(g+1,l)}^{(1j)r}) \} \\ j &= 1, ..., h; s = 1 \text{ and } 2; r = 1, ..., R \end{aligned}$$

[A4] Intermediate and investment demands for composites commodities and primary factors

$$x_{(i\bullet)}^{(u)r} = z^{(u)r} + a_{(i)}^{(u)r}$$
  $u = (kj)$  for  $k = 1, 2$  and  $j = 1, ..., h$  if  $u = (1j)$  then  $i = 1, ..., g + 2$  if  $u = (2j)$  then  $i = 1, ..., g$ ;  $r = 1, ..., R$ 

[A5] Household demands for composite commodities

$$\begin{split} V(i,\bullet,(3),r) \big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big) &= \\ \gamma_{(i)}^r P_{(i\bullet)}^{(3)r} Q^r \big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big) + \beta_{(i)}^r \big(C^r - \sum_{j \in G} \gamma_{(j)}^r P_{(i\bullet)}^{(3)r} Q^r \big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big)\big) \end{split}$$

$$i = 1, \ldots, g; r = 1, \ldots, R$$

[A6] Purchasers' prices related to basic prices and margins (trade costs)

$$V(i, s, (u), r)p_{(is)}^{(u)r} = (B(i, s, (u), r) + \sum_{m \in G} M(m, i, s, (u), r)p_{(m1)}^{(0)r},$$

$$i = 1, ..., g; (u) = (3), (4), (5)$$
and  $(kj)$  for  $k = 1, 2$  and
$$j = 1, ..., h; s = 1b, 2 \text{ for } b = 1, ..., q$$

$$r = 1, ..., R$$

[A7] Foreign demands (exports) for domestic goods

$$(x_{(is)}^{(4)r} - fq_{(is)}^{(4)r}) = \eta_{(is)}^{r}(p_{(is)}^{(4)r} - e - fp_{(is)}^{(4)r}), i = 1, ..., g; s = 1b, 2 \text{ for } b = 1, ..., q; r = 1, ..., R$$

[A8] Government demands

$$x_{(is)}^{(5)r} = x_{(\bullet \bullet)}^{(3)r} + f_{(is)}^{(5)r} + f^{(5)r} + f^{(5)} i = 1, ..., g; s = 1b, 2 \text{ for } b = 1, ..., q; r = 1, ..., R$$

[A9] Margins demands for domestic goods

$$x_{(m1)}^{(is)(u)r} = x_{(is)}^{(u)r} + a_{(m1)}^{(is)(u)r}$$
  $m, i = 1, ..., g;$   $(u) = (3), (4b) \text{ for } b = 1, ..., r, (5) \text{ and } (kj) \text{ for } k = 1, 2;$   $j = 1, ..., h; s = 1b, 2 \text{ for } b = 1, ..., r;$   $r = 1, ..., R$ 

[A10] Demand equals supply for regional domestic commodities

$$\begin{split} \sum_{j \in H} Y(l,j,r) x_{(l1)}^{(0j)r} &= \sum_{u \in U} B(l,1,(u),r) x_{(l1)}^{(u)r} \\ &+ \sum_{i \in G} \sum_{s \in S} \sum_{u \in U} M(l,i,s,(u),r) x_{(l1)}^{(is)(u)r} \ l = 1,...,g; \ r = 1,...,R \end{split}$$

[A11] Regional industry revenue equals industry costs

$$\sum_{l \in G} Y(l,j,r) \big( p_{(l1)}^{(0)r} + a_{(l1)}^{(0)r} \big) = \sum_{l \in G^{\star}} \sum_{s \in S} V(l,s,(1j),r) \big( p_{(ls)}^{(1j)r} \big), \; j = 1,...,h; \; r = 1,...,R$$

[A12] Basic price of imported commodities

$$p_{(i(2))}^{(0)} = p_{(i(2))}^{(w)} - e + t_{(i(2))}^{(0)}, i = 1, ..., g$$

[A13] Cost of constructing units of capital for regional industries

$$V(\bullet,\bullet,(2j),r)(p_{(k)}^{(1j)r}-a_{(k)}^{(1j)r})=\sum_{i\in G}\sum_{s\in S}V(i,s,(2j),r)(p_{(is)}^{(2j)r}+a_{(is)}^{(2j)r}),\ j=1,...,h;\ r=1,...,R$$

[A14] Investment in period T

$$X_{(g+1,2)}^{(1j)r}(1)X_{(g+1,2)}^{(1j)r}(1) = X_{(g+1,2)}^{(1j)r}(1-\delta_j)X_{(g+1,2)}^{(1j)r} + Z^{(2j)r}Z^{(2j)r} \quad j=1,...,h; \ r=1,...,R$$

[A15] Capital stock in period T+1 – comparative statics

$$x_{(g+1,2)}^{(1j)r}(1) = x_{(g+1,2)}^{(1j)r} j = 1, ..., h; r = 1, ..., R$$

[A16] Definition of rates of return to capital

$$r_{(j)}^{r} = Q_{(j)}^{r} (p_{(g+1,2)}^{(1j)r} - p_{(k)}^{(1j)r}), j = 1, ..., h; r = 1, ..., R$$

[A17] Relation between capital growth and rates of return

$$r_{(j)}^{r} - \omega = \varepsilon_{(j)}^{r} (x_{(g+1,2)}^{(1j)r} - x_{(g+1,2)}^{(\bullet)r}) + f_{(k)}^{(2j)r}, j = 1, ..., h; r = 1, ..., R$$

Other definitions in the CGE core include: import volume of commodities, components of regional/national GDP, regional/national price indices, wage settings, definitions of factor prices, employment aggregates, and accounting identities.

## **Variables**

Variable	Index ranges	Description
$X_{(is)}^{(u)r}$	(u) = (3), (4), (5), (6) and (kj) for $k = 1$ , 2 and $j = 1,,h$ ; if (u) = (1j) then $i = 1,,g + 2$ ; if (u) $\neq$ (1j) then $i = 1,,g$ ; s = 1b, 2 for $b = 1,,q$ ; and $i = 1,,g$ and s = 1, 2, 3 for $i = g+1r = 1,,R$	Demand by user (u) in region r for good or primary factor (is)

(continued)

## (continued)

Variable	Index ranges	Description
$p_{(is)}^{(u)r}$	(u) = (3), (4), (5), (6) and (kj) for k = 1, 2 and j = 1,,h; if (u) = (1j) then i = 1,,g + 2; if (u) $\neq$ (1j) then i = 1,,g; s = 1b, 2 for b = 1,,q; and i = 1,,g and s = 1, 2, 3 for i = g+1 r = 1,,R	Price paid by user (u) in region r for good or primary factor (is)
$X_{(i\bullet)}^{(u)r}$	(u) = (3) and (kj) for k = 1, 2 and j = 1,,h. if (u) = (1j) then i = 1,,g + 1; if (u) $\neq$ (1j) then i = 1,,g r = 1,,R	Demand for composite good or primary factor i by user (u) in region r
$a_{(g+1,s)}^{(1j)r}$ $a_{(i)}^{(u)r}$	j = 1,, h and $s = 1, 2, 3r = 1,, Ri = 1,, g$ , (u) = (3) and (kj) for $k = 1, 2$ and	Primary factor saving technological change in region r
$u_{(i)}$	j = 1,, h r = 1,, R	good i by user (u) in region r
$C^r$ $Q^r$		Total expenditure by regional household in region r Number of households
$Z^{(u)r}$	(u) = (kj) for k = 1, 2 and j = 1,,h r = 1,,R	Activity levels: current production and investment by industry in region r
$fq_{(is)}^{(4)r}$ $fp_{(is)}^{(4)r}$	i = 1,,g; s = 1b, 2 for b = 1,,q r = 1,,R i = 1,,g; s = 1b, 2 for b = 1,,q	Shift (quantity) in foreign demand curves for regional exports Shift (price) in foreign demand curves
е	r = 1,,R	for regional exports Exchange rate
$X_{(m1)}^{(is)(u)r}$	m, $i = 1,,g$ ; $s = 1b$ , 2 for $b = 1,,q$ (u) = (3), (4), (5) and (kj) for $k = 1$ , 2 and $j = 1$ ,,h r = 1,,R	Demand for commodity (m1) to be used as a margin to facilitate the flow of (is) to (u) in region r
$a_{(m1)}^{(is)(u)r}$	m, $i = 1,,g$ ; $s = 1b$ , 2 for $b = 1,,q$ (u) = (3), (4), (5) and (kj) for $k = 1$ , 2 and $j = 1$ ,,h r = 1,,R	Technical change related to the demand for commodity (m1) to be used as a margin to facilitate the flow of (is) to (u) in region r
$X_{(i1)}^{(0j)r}$	i = 1,,g; j = 1,,h r = 1,,R	Output of domestic good i by industry j
$p_{(is)}^{(0)r}$	i = 1,,g; s = 1b, 2 for b = 1,,q r = 1,,R	Basic price of good i in region r from source s
$p_{(i(2))}^{(w)}$	i = 1,,g	USD c.i. f. price of imported commodity i

## (continued)

Variable	Index ranges	Description
$f_{(k)}^{(2j)r}$	j = 1,,h	Regional-industry-specific capital shift
	r = 1,,R	terms
$X_{(a+1,2)}^{(1j)r}(1)$	r = 1,,R j = 1,, h	Capital stock in industry j in region r at
(3 : -, -)	r = 1,,R	the end of the year, i. e., capital stock available for use in the next year
$p_{(k)}^{(1j)r}$	j = 1,, h	Cost of constructing a unit of capital for
	r = 1,,R	industry j in region r
$f_{(is)}^{(5)r}$	i = 1,,g; $s = 1b$ , 2 for $b = 1,,q$	Commodity and source-specific shift
()	r = 1,,R	term for government expenditures in region r
$f^{(5)r}$	r = 1,,R	Shift term for government expenditures in region r
$f^{(5)}$		Shift term for government expenditures
ω		Overall rate of return on capital (short-run)
$r_{(j)}^r$	j = 1,,h	Regional-industry-specific rate of return
0)	r = 1,,R	

## Parameters, Coefficients and Sets

Symbol	Description
$\sigma_{(i)}^{(u)r}$	Parameter: elasticity of substitution between alternative sources of commodity or factor i for user (u) in region r
$\sigma^{(0j)r}$	Parameter: elasticity of transformation between outputs of different commodities in industry j in region r
$\alpha_{(g+1,s)}^{(1j)r}$	Parameter: returns to scale to individual primary factors in industry j in region r
$oldsymbol{eta}_{(i)}^r$	Parameter: marginal budget shares in linear expenditure system for commodity i in region r
$\gamma_{(i)}^r$	Parameter: subsistence parameter in linear expenditure system for commodity i in region r
$oldsymbol{arepsilon}^r_{(j)}$	Parameter: sensitivity of capital growth to rates of return of industry j in region $\boldsymbol{r}$
$\begin{split} & \eta^r_{(is)} \\ & B(i,s,(u),r) \\ & M(m,i,s,(u),r) \end{split}$	Parameter: foreign elasticity of demand for commodity i from region $r$ Input-output flow: basic value of (is) used by (u) in region $r$ Input-output flow: basic value of domestic good $m$ ( $m$ =trade) used as a margin to facilitate the flow of (is) to (u) in region $r$

(continued)

#### (continued)

Symbol	Description
V(i,s,(u),r)	Input-output flow: purchasers' value of good or factor i from source s used by user (u) in region r
Y(i,j,r)	Input-output flow: basic value of output of domestic good i by industry j from region r
$Q_{(j)}^r$	Coefficient: ratio, gross to net rate of return

Symbol	Description
G	Set: {1,2,, g}, g is the number of composite goods
G*	Set: {1,2,, g+1}, g+1 is the number of composite goods and primary factors
Н	Set: {1,2,, h}, h is the number of industries
U	Set: $\{(3), (4), (5), (6), (k j) \text{ for } k = 1, 2 \text{ and } j = 1,, h\}$
U*	Set: $\{(3), (k j) \text{ for } k = 1, 2 \text{ and } j = 1,, h\}$
S	Set: {1, 2,, r+1}, r+1 is the number of regions (including foreign)
S*	Set: {1, 2,,r}, r is the number of domestic regions



Figure 13: Governorates in Lebanon.

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