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Economic consequences of aviation system disruptions: A reduced-form computable general equilibrium analysis

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A B S T R A C T

The state of the art approach to economic consequence analysis (ECA) is computable general equilibrium (CGE) modeling. However, such models contain thousands of equations and cannot readily be incorporated into computerized systems to yield rapid estimates of economic impacts of various types of transportation system failures due to natural hazards, terrorist attacks or technological accidents. This paper presents a reduced-form approach to simplify the analytical content of CGE models and make them more transparent and enhance their utilization potential. The reduced-form CGE analysis is conducted by first running simulations one hundred times, varying key parameters, such as the magnitude of the initial shock, duration, location, behavioral responses, and resilience, according to a Latin Hypercube sampling procedure. Statistical analysis is then applied to the "synthetic data" results in the form of both ordinary least-squares and quantile regression. The analysis yields linear equations that are incorporated into a computerized system and utilized along with Monte Carlo simulation methods for propagating uncertainties in economic consequences. Although our demonstration and discussion focuses on aviation system disruptions caused by terrorist attacks, the approach can be applied to a broad range of threat scenarios.

1. Introduction

Aviation systems worldwide are facing ongoing challenges due to increasing uncertainties of various threats such as terrorist attacks, hurricanes, blizzards, volcanic eruptions and air control system shut-downs. For instance, after the 9/11 World Trade Center terrorist attack, the entire civil aviation system of the U.S. was completely closed for two days. Many incoming international flights were diverted to Canada and Mexico, and the backlog of delayed air services took several days to clear. During the 2010 volcano eruptions of Eyjafjallajökull in Iceland, commercial aviation services in 20 countries were closed and affected about 10 million travelers due to the spread of ash clouds, causing the largest aviation system disruption since World War II (Hawkins, 2012). During the blizzard that occurred in the U.S. northeast states in January 2015, more than 4700 flights were delayed, including nearly 3900 flights being cancelled on a single day. The most recent aviation system disruption was the Atatürk Airport terrorist attack occurred in June 2016 in Istanbul, Turkey. The attack caused severe

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consequences, including a partial shutdown of the Turkish aviation system and a tightening of security at major international airports around the world, in addition to the direct impacts such as death, injuries and property damages. Protecting aviation from various threats and minimizing the negative economic consequences caused by a system disruption requires not only knowledge of system design, operation and management, but, more importantly, it requires policy makers to have an efficient decision-making capability in terms of resource allocation and emergency response based on a valid understanding of the economy-wide consequences of the disrupted aviation system.

The state of the art approach to Economic Consequence Analysis (ECA) of disasters is computable general equilibrium (CGE) modeling (Rose, 2015). However, ECA imposes major requirements on both public and private sector analysts and their computation environments for several reasons. First, CGE is a complex applied microeconomic/macroeconomic model that contains thousands of equations and variables representing the entirety of economic activities. ECA is implemented with a simulation approach, using unique programming software to change the values of key variables and/or parameters. This requires an analyst to have advanced training in microeconomics. Second, CGE analysis requires working knowledge of specialized programming platforms, such as GAMS (Lofgren et al., 2002), GEMPACK (Codsi and Pearson, 1988), or Matlab (Bröcker and Korzhenevych, 2013). Third, the analysis is also time-consuming given the needed data construction, simulation execution and interpretation of results. It is clear that, although CGE is a powerful quantitative approach, it is costly and technically burdensome to use readily for aviation security analysis when rapid simulations are needed by a broad range of non-technical users.

A way of making ECA more manageable is reduced-form analysis, which simplifies the process of complex simulation models while maintaining their intellectual merits. In the field of economics, "reduced-form" refers to an empirical analysis that derives a subset of parameters that reflect statistical relationships between dependent and independent variables, and usually focuses on identification concerns (in other words, the identification of the best estimated parameters in a regression) through econometric estimations (Ichimura and Taber, 2002; Chetty, 2008). It contrasts with structural approaches, such as CGE, which tend to identify functional relationships through simulations of complete models of economic behavior and welfare (Chetty, 2008). More generally, a "reduced-form" approach refers to a simplified version of a more complex model that can readily be operated by users with a limited amount of knowledge of economics and with a rapid turnaround. For instance, Heatwole and Rose (2013) developed a reduced-form model for rapid loss estimation of earthquakes in the United States. Rose et al. (2011) developed a different approach to reduced form analysis in the context of a macroeconometric model. The impacts of the Pennsylvania Climate Action Plan on the state's economy were assessed through a reduced-form, multivariate regression analysis of the macroeconometric model results. Likewise, Muller and Mendelsohn (2006) also developed a reduced-form tool called Air Pollution Emission Experiments and Policy Analysis Model (APEEP), which is essentially an integrated assessment model primarily used for environmental analysis. In addition, Dixon et al. (2014) developed a reduced-form computation tool for an ECA of radiological/nuclear attacks with time-related considerations. The economic damage estimated from a dynamic CGE model was measured as a deterministic function of the consequence durations, time-paths, and other variables. The results were converted to elasticity values measuring the response to various sets of threat characteristics.

Our study introduces an innovative reduced-form approach to ECA of aviation system disruptions that enables analysts and policymakers to conduct rapid estimates of the economic impact in terms of changes in gross domestic product and employment within a general equilibrium framework. Essentially, the CGE model is run multiple times using Monte Carlo simulation methods for propagating uncertainties in economic consequences for variations in key variables and parameters. This provides the "synthetic" data that are used in regression analysis to generate reduced-form equations. The dependent variable is a major consequence indicator (e.g., GDP loss or employment loss), while the independent variables (typically hazardous event characteristics and resilience response related) explain the variability in these losses. The reduced-form approach differs from standard CGE analysis in six ways: (1) it is easier to use and interpret; (2) its application does not require substantial training; (3) it provides greater transparency; (4) it differs from previous reduced-form CGE approaches in that it provides more sophisticated decompositions of CGE results; (5) it is based on a statistical method that incorporates uncertainties; and (6) it is programmed in MS Excel using Visual Basic for Applications (VBA). Hence, the utilization of complex CGE analysis is greatly facilitated. This approach can also be applied to other transport modes, as well as other threat types, such as natural disasters and human related terror attack.

Three factors should be considered in evaluating the performance of our methodology. First is the soundness of the theoretical underpinnings. This is guaranteed to a great extent by the fact that the synthetic data are generated by CGE models, which have been vetted on both a theoretical and empirical plane (Dixon and Rimmer, 2013). CGE models reflect the behavioral responses of businesses and households within an economy to changes in prices, as well as taxes, regulation and other external shocks, within the constraints of labor, capital, and natural resource assets. Such models are based on economic theory relating to producer and consumer choice and the workings of markets. They are able to estimate not only the direct responses, such as property damages, and labor force reductions, but also indirect ones related to behavioral responses leading to total economic impacts, or consequences, referred to as "general equilibrium" effects, which relate to price and quantity interactions in upstream and downstream markets.[1]

[1] One of the reviewers pointed out that no model is likely to express the full range of human reactions to events. In addition, CGE models, like most other modeling approaches, have limitations in capturing the uncertainty existing in both micro- and macro-economic activities, which in turn may constrain the performance of the reduced-form analysis.