EXPLOITING A NEGATIVE SUPPLY SHOCK TO UNDERSTAND BETTER MACROECONOMIC ADJUSTMENTS IN THE BRAZILIAN ECONOMY

By

Brandon Shane Tracy

Submitted to the

Faculty of the College of Arts and Sciences

of American University

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy

In

Economics

Chair:

Professor Larry Sawers

Professor Robert Feinberg

Professor Xuguang Sheng

Professor Subodh Mathur

Dean of the College of Arts and Sciences

October 18, 2011

Date

2011
American University
Washington, D.C. 20016

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In 2001 the Brazilian government implemented a national electricity rationing program that lasted nine months and mandated the reduction of electricity consumption by 20 percent. The rationing program received much blame when the economy grew only one percent in 2001. This dissertation motivates the questions: What were the effects of the rationing program on the Brazilian economy? Were existing economic relationships altered by the rationing program? And, What role did substitution play in allowing the economy to adjust to the reduced electricity consumption?

Univariate and multivariate forecasting techniques are used with monthly data to estimate the impact of the rationing program. During the intervention period, industrial electricity consumption was 16.4 percent below trend values and commercial electricity consumption was 25.2 below trend values; GDP was 3.1 percent below trend values. Economic relationships, as indicated by Granger causality, do change between the pre-intervention and post-intervention periods. Annual elasticities of substitution, calculated from the parameters of a translog cost function, are quite stable during the intervention. Fuel substitution does not appear to be the primary means of adjusting to the input shock.

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CHAPTER 1

INTRODUCTION

Economic shocks are generally studied to assess their overall impacts and to identify optimal recovery plans. Many studies of economic shocks evaluate the performance of the policy implemented to restore the economy after the shock.[1] The results of such studies can serve as guides to minimizing impacts of similar shocks in the future.

Energy shocks in general, and more specifically electricity shocks, are studied due to their typically disruptive effects on economies. In periods of stability, energy and electricity are studied to identify economically significant relationships within the productive and consumptive sectors; economic models are used to construct forecasts of expected energy and electricity consumption under varied assumptions. The first notable and global energy shock spurred research on the relationships between energy inputs and economic output in the 1970s. The results of such studies were intended to assist policy makers, but inconsistent outcomes fueled debate and the need for additional research (Akarca & Long, 1979, 1980; Kraft & Kraft, 1978). This era also spurred research on the substitution capabilities among factors and fuels (Berndt & Wood, 1975, 1979; Pindyck, 1979a).

[1] See, for example, Baade, Baumann, and Matheson (2007).

The energy economics literature, however, does not provide assessments of the performance of pre-shock models and their predictions during the post-shock period. Without the knowledge of how a shock, exogenous or endogenous, affects the very metrics estimated prior to the shock, economists may produce misleading recommendations. Economic relationships, forecasts, and metrics may be robust to energy shocks, but the literature presently does not provide *ex post* analyses of *ex ante* models, which are needed to assess their robustness.

Based on the results of the analyses conducted in this dissertation, economic relationships between electricity, other inputs, and output do appear tenuous, changing in response to a shock. As a given shock can induce changes among those relationships, forecast models need to incorporate such changes to account for the new relationships. More specifically the results of this dissertation indicate that electricity consumption can be substantially reduced with little or no impact on output.

This dissertation exploits a negative quantity shock created by an electricity rationing program implemented in Brazil from June 2001 through February 2002. In addition to estimating the impact of the rationing program on the Brazilian economy, the dissertation develops and tests hypotheses regarding the stability of economic relationships within the economy. The means by which an economy adjusts to shocks are expected to be case specific; the state of the economy at the time of the shock largely defines the range of possible reactions to the shock. However, as large industrialized economies share many characteristics, generalizations from the findings of this research should not be limited to the case of Brazil.

Chapter 2 provides the related background literature on economic shocks, energy shocks, and electricity shocks. Chapter 3 provides details of the electricity rationing program, presents a descriptive analysis of the effects of its implementation, and develops the hypotheses tested in chapters 4 and 5. Chapter 4 first tests the hypothesis that the rationing program did not affect electricity consumption, output, and other economic series; univariate techniques are used for these tests. Then a multivariate model of the Brazilian economy is developed to test the same hypothesis, and to test the hypothesis that relationships existing before the intervention were not different after the intervention. Chapter 5 employs a translog cost model for factors and fuels to test the hypothesis that elasticities of substitution did not change from the pre-intervention period to the post-intervention period. Price elasticities of demand are then used to estimate expected fuel and factor consumption during the intervention period. Assessing the differences between expected and actual consumption of factors and fuels provides a partial understanding of the paths followed by the industrial sector during the intervention. Chapter 6 concludes with a synthesis of the findings from these analyses.

CHAPTER 2

ECONOMIC, ENERGY, AND ELECTRICITY SHOCKS

2.1 Introduction

The event studied in this dissertation is an electricity rationing program implemented in Brazil in 2001-2002. The immediate cause for this program was a severe drought that reduced Brazil's ability to generate electricity, as the country's primary source of electricity was from hydroelectric sources. It is important to understand that a dramatic reduction in the supply of electricity was imminent when the policy intervention was announced. Even though the reduction was attained by the implementation of a policy, the policy's rapid implementation and the dramatic forced reduction place the event within the literature related to economic shocks.

This chapter presents relevant literature concerning negative energy quantity shocks. The literature highlights important contributions emerging from studies of economic shocks, with a specific focus on and policy responses to electricity supply shocks. While each shock can be considered a unique event, the policy response to the shock determines the optimality of the recovery path. In addition to measuring the impact of the shock and policy response, the study of shocks can reveal changes to economic relationships in the economy and shock-induced changes to aggregate production. Literature related to these areas is also presented and used to motivate the empirical analyses undertaken in this dissertation.

2.2 Economic Shocks

Some economic shocks are wholly exogenous and cannot be avoided, while others are endogenous to the given economic system. Economic shocks are usually remembered according to their severity. While the severity of an economic shock can depend upon the nature of the shock, the policy response to the shock is also an important factor determining the severity of the shock's economic consequences. If an earthquake destroys a power plant, the economic effects of the reduced power supply may be evident until energy supply returns to its original level; by varying the resources allocated to rebuilding the power plant, the policy response to the earthquake can influence the duration of the reduced power supply. If a shock is attributed to the collapse of demand and high unemployment, the economic impact may continue until policies are introduced to stimulate demand. Ultimately, the study of an economic shock should address the nature of the shock and the policy response to it, as both factors affect the severity of the shock.[2]

Economic shocks can be viewed as quantity shocks or price shocks, though the two are not mutually exclusive. Quantity shocks are more commonly related to exogenous events, such as volcano eruptions or earthquakes; price shocks can result from quantity shocks or from changes endogenous to the economic system. This important distinction is relevant to the available set of policy options that can be employed to eliminate or reduce the effects of the shock, with price shocks allowing greater flexibility in the policy response. One example of a price shock not related to a quantity shock is the

[2] With minimal probability the optimal policy response may be selected for implementation, thus revealing the true economic impact of the shock; all other policies contribute to the impact of the shock as they deviate from the optimal response.

ongoing economic crisis in the United States: irresponsible policy changes allowed housing prices to be driven by speculation rather than by market fundamentals and, once the bubble was evident, available policy options were not employed to constrain the bubble’s size (Baker, D'Arista, & Epstein, 2009).

Numerous techniques are available to study the impacts of economic shocks and the choice among them begins with data availability and the question(s) to be asked. In a review of techniques commonly used in the analysis of economic shocks, Rose (2004) presents problems and benefits associated with input-output (I-O) matrix approaches, computable general equilibrium (CGE) models, and econometric techniques. While highlighting the problems and biases of I-O and CGE models, Rose (2004), perhaps unintentionally, creates an argument for econometric techniques if forecasting and changes in substitution behavior are desirable study results. In a review of the application of general equilibrium models for energy studies, Bhattacharyya (1996) highlights their potential use for *ex ante* policy analysis. However, in a general critique of general equilibrium models, Mitra-Kahn (2008) identifies many problems should be explicitly addressed before applying this technique to energy studies.

The study of economic shocks is broad and motivated by a variety of interests. Numerous questions can be raised for a given shock or event, but some general questions of interest are more common than others. One question of interest is, what was the economic impact of the shock? A second question is, how did markets or economic actors react to the shock? A third question is, did the shock affect existing relationships or structures in the economy? The policy response selected from the set of possible policy responses may also be of interest, as this choice contributes to the magnitude and duration of the shock. In a study of economic shocks, Baade, Baumann, and Matheson (2007) estimate the economic impacts of the Rodney King riots in Los Angeles and the impacts of Hurricane Andrew in Miami. Beyond estimating these impacts the authors assess the contrasting nature of the two shocks and the different policies implemented in response to each. Market responses to the shocks and shock responses are contrasted to explain the rapid recovery in Miami and the near-absence of a recovery in Los Angeles. The study results are applied to post-Katrina New Orleans and identify possible means of speeding recovery (Baade et al., 2007).

The impacts of a negative input shock can vary greatly. Input shocks to an isolated sector may result in economic impacts limited to that sector. However, the stronger the linkages with the impacted sector the stronger the effects may be on output and/or consumption of related goods. Given such linkages and their vulnerability to exogenous shocks, shocks to food commodities can have dire social and economic implications. Ivanic and Martin (2008) study the impacts of price shocks to food commodities in nine countries to understand better such effects of shocks on household incomes and poverty levels. Rising food prices particularly affect the poor in net importers of food, such as Pakistan, where one estimate indicates a food price shock increased poverty by 8.2 percentage points and doubled the number of extremely poor (ul Haq, Nazli, & Meilke, 2008, p. 483). Other research highlights the potential role played by commodity dependence on the ability of a government to respond to shocks (Isham, Woolcock, Pritchett, & Busby, 2005). Ferreira and Schady (2008) review research on the effects of numerous price shocks in order to test hypotheses relating their impacts to child health and education outcomes. Quantity input shocks, perhaps from floods and droughts, often result in reductions of input consumption within the household unit. Similar to price shocks, they often disproportionately affect children and the poor and can create a long-term shock to labor quality. One example studies the effects of flooding in Bangladesh on food-related household consumption (del Ninno & Lundberg, 2005); Ferreira and Schady (2008) review the effects of drought in Malawi and Cote d'Ivoire.

The study of resource input shocks, such as the effects of a drought on water use, can result in better policies for the use of the resource. With the right policies, the potentially dramatic effects of droughts and other resource shocks can be mitigated to a point where they are considered merely a factor influencing consumption rather than a shock. Smith and Wang (2008) highlight ongoing issues in the drought literature, such as the potential for neoliberal economic policies to increase the potential for drought; they also highlight how properly designed demand-side water policies can incorporate potential drought effects into normal operations. Another example develops a model to test and identify optimal policies to manage limited water supply in the Rio Grande basin (Booker, Michelsen, & Ward, 2005). Pint (1999) exploits drought conditions in California to estimate more useful price elasticities for water demand, highlighting the effectiveness of price signals. Partially depending on local conditions, property rights, and economic incentives, droughts can lead to increased use of more efficient irrigation technologies and farm innovation (Schuck, Frasier, Webb, Ellingson, & Umberger, 2005).

In some instances exogenous and endogenous shocks occur simultaneously, as was the Indonesia case in the years 1998-2000, when it faced a drought and a financial crisis (Frankenberg, Smith, & Thomas, 2003). Indonesia suffered a tremendous loss of more than 150,000 deaths as a result of the 2004 Indian Ocean tsunami. With much of its productive capacity spared and financial assistance from the international community, the effect of the tsunami on GDP growth was expected to be about 0.4 percentage points (Athukorala & Resosudarmo, 2006, p. 18). Pelling et al. (2002) advocate greater integration of disaster management in national policies, as failure to do so can exacerbate the economic and social effects of disasters.

Studies of energy shocks gained prominence in the literature after the oil shocks of the 1970s, which were predominantly price shocks associated with quantity shocks. For example, Hudson and Jorgenson (1978) use a dynamic CGE model to assess the effects of proposed federal policies on oil price controls in the U.S., and Hubbard (1986) studies the effects of oil supply shocks on spot and contract prices for oil. The past oil shocks have induced research on possible outcomes for similar shocks. Doroodian and Boyd (2003) simulate the effects of an oil price shock on the U.S. economy in 2000 using a dynamic CGE model; their results indicate that the impact of such a shock is highly dependent upon the structure of the economy. Incorporating shocks into economic studies allows for more complete testing of theories, for example, in monetary policy (Bernanke, Gertler, & Watson, 1997) and in labor market dynamics (Keane & Prasad, 1996). In addition to macroeconomic impacts, oil shocks often exhibit nonlinear effects (Rahman & Serletis, 2010).

Shocks to electricity supply, acting through price changes or supply reductions, can be studied to understand economic behavior in the same manner as energy shocks. However, electricity's widespread use, unique role in energy delivery, and difficulty in being stored, result in special concerns related to possible disruptions in its supply.

Shocks to electricity prices, perhaps stemming from price changes in underlying fuel sources, can be studied in much the same fashion as other energy price shocks; quantity shocks to electricity supply can be more complex than price shocks. An electricity outage of short duration in an industrial facility can ruin products and equipment; production may not resume for hours after even a brief interruption. An ICF estimate of the costs resulting from the 2003 blackout in the northeast of the U.S. is US$8.55 billion (ICF, 2003, p. 2). One estimate of the cost of electrical power interruptions in the U.S. is US$80 billion per year (LaCommare & Eto, 2004). As a testament to the importance and potentially-dramatic effects of an electricity supply shock, the U.S. government funds studies to estimate the economic impacts of such shocks, for example, for different scenarios of a hypothetical attack on the power grid in New Jersey (Greenberg, Mantell, Lahr, Felder, & Zimmerman, 2007). Maurer et al. (2005) review the electricity rationing programs of six countries, including California and Brazil.

While the Californian electricity supply shortage in 2001 was created by a number of factors, one of the means to address the shortage included rate increases. As these rate increases were not enough to reduce the quantity demanded to an equilibrium state, the system operator was forced to address the shortage through rolling blackouts. One early estimate of the economic impact of the California electricity shock is $21.8 billion (AUS Consultants, 2001, p. 17). One study of the California electricity crisis focused on the San Diego electricity market reveals that residential consumers did respond quickly to rapidly increasing prices, contrary to the beliefs of many policy makers (Reiss & White, 2008). The data presented by Reiss and White indicate that in the three months of high electricity prices, residential electricity consumption fell 13 percent as prices increased from 10 to 23 cents per kWh. For two years following the price spike, prices were capped around 14 cents per kWh, and electricity consumption remained about 7 percent lower than before the spike in prices (2008, pp. 640, 657).[3] Perhaps the most important result from the study, and one that could have been applicable to the Brazilian rationing program, is that "The evidence indicates that when policymakers cap energy prices following market shocks, they preclude substantial—and quite rapid—reductions in energy use" (Reiss & White, 2008, p. 636).

2.3 Policy Responses to Electricity Shocks

The discussion of policy responses to shocks can be focused on policies related to limiting supply, as the Brazilian electricity rationing program was a supply-limiting response to a negative quantity shock to electricity. A basic tenet of economic theory is that price signals allow competitive markets to establish equilibrium. If electricity markets were comparable to competitive markets, no intervention would be necessary when facing a shock since the market would adjust to market-clearing prices—at least in theory. However, the supply of electricity is typically a heavily-regulated market, as is common with energy supply markets in general. This regulation stems from the tendency for natural monopolies to emerge in the generation, transmission, and distribution of electricity.

The discussion of policy options available to address a negative supply shock to an electricity market can be approached as a discussion of how to limit a negative

[3] The authors indicate appeals for conservation and other rebate programs also influenced electricity consumption during this period.

externality. The negative externality arises if over-consumption results in blackouts;[4] the externality can be viewed as a probability of blackouts, which increases with the consumption of electricity. The policymaker seeks the best policy to reduce electricity consumption to a point where the probability of enduring blackouts is kept sufficiently low. Long-run policy options that could be implemented to avoid future electricity shortages are not considered here.

A review of the externality literature indicates a lack of consensus regarding the best policy option to limit consumption. Weitzman (1974) departs from the assumed equivalency between prices and quantity mechanisms to reduce undesirable externalities and his results highlight that quantity mechanisms are more desirable when the slope of marginal social cost is greater than the slope of marginal social benefits. Kaplow and Shavell (1997) critique Weitzman's argument, indicating that his conclusion is based on the use of linear taxes to address the nonlinear harm function. They conclude that the use of nonlinear tax schedules are generally more efficient than quantity measures.[5] Glaeser and Shleifer (2001) highlight that both arguments ignore the costs of enforcement related to the price or quantity mechanism; their model indicates that costs associated with the chosen policy option determine the efficiency of that option. They also note that price mechanisms, unlike quantity mechanisms, are more likely to create adverse behavior incentives.

[4] Due to their associated economic and social impacts, blackouts are considered the worst means of addressing an electricity shortage.

[5] See Spulber (1992) for an exposition of models incorporating nonlinear pricing schemes that face quantity rationing.

The question of equity is also important when addressing the impacts of an economic shock, as the impacts may fall unevenly across the affected population. For some shocks this may be of little concern; for shocks affecting necessities, access to minimum quantities may be a matter of survival. Weitzman (1977) proposes a model that incorporates needs while controlling for income when a previously market-traded good faces a negative quantity shock. His results indicate that quantity rationing becomes more equitable as income inequality increases. Bennett (1998) extends Weitzman's (1974) findings to include possible inefficient distribution of the under-supplied good; his findings highlight that when distribution is sufficiently inefficient, Weitzman's findings can be overturned.

Self-rationing of electricity is a preemptive means of avoiding wide-spread blackouts, and it entails agreements among private electricity consumers to be rationed in the future under certain conditions. In return, the consumer receives lower electricity rates. While these agreements are common among large industrial consumers, the intention of such contracts are not to avoid prolonged outages when demand surpasses supply, but rather to address interruptions of short duration.[6]

This brief review indicates that policy makers facing an electricity shortage have numerous options available, but economic theory does not indicate one as being better than the others. Political limitations may complicate further the implementation of a policy response to an electricity shortage. To contribute to the literature on energy shocks, this dissertation identifies and tests hypotheses related to the outcomes of the

[6] See Schwarz and Taylor (1987) for comments on early self-rationing models, Doucet and Roland (1993) for extensions to self-rationing models, and Albadi and El-Saadany (2008) for a review of the demand response literature typically associated with large electricity consumers.

electricity rationing program in Brazil. The design of the rationing program is taken as given, but future research could question the optimality of the program's design. The details of the Brazilian electricity rationing program are presented in the next chapter, highlighting the characteristics of the program along the dimensions presented in this section. Even if the policy response to an energy shock is taken as given, determining the economic impacts of the shock and expected shifts in the related economic relationships may not be a simple task.

2.4 Economic Responses to Energy Shocks

Once a policy to address a given shock is designed and implemented, a study of subsequent economic performance can be used to assess the design of the policy. Furthermore, different aspects of the economy can be studied to understand if and how they were affected by the shock and corresponding policy. Two important questions related to electricity shocks are as follows. How did the shock affect relationships existing in the economy before the shock? Given that the shock affected a widely-used intermediate good, did the economy adapt to the shock through substitution?

The energy economics literature contains numerous studies of the relationships among energy consumption, factors of production, and output. A review of the literature addressing relationships between energy and economics also indicates that little consensus can be found among the results of these studies, or even how a given study should be specified. Very few studies directly consider whether an energy shock changes existing relationships.

The analysis of relationships considered in this literature typically utilize Granger causality tests. While Granger (1969) defines what was to become known as “Granger causality” in mathematical terms, he does not assert that any policy implications follow from findings of Granger causality. Granger’s work does, however, mention that causal relationships may exist between variables that are not found in a specified model due to the frequency of the data used: “a simple causal mechanism can appear to be a feedback mechanism if the sampling period for the data is so long that details of causality cannot be picked out” (1969, p. 427). Also, Granger (1969, p. 429) cautions that a causal relationship found at some time *t* may not continue to exist at a different time. These statements highlight the importance of using high-frequency data, as low-frequency data (for example, annual data) may indicate different relationships; they also highlight potential problems related to conclusions drawn from such causal mechanisms.

Many authors in the literature studying relationships among energy and output repeat a standard set of policy implications asserted by the results of Granger causality tests, even though these implications ignore Granger’s advice. The four possible policy implications from a bivariate analysis on energy and output are as follows: (1) a unidirectional causal relationship from energy to output implies that energy conservation programs would reduce growth, (2) a unidirectional causal relationship from output to energy implies that energy conservation would not affect growth, (3) a bidirectional causal relationship between energy and output implies an ambiguous outcome if one of the two variables is changed, and (4) no causal relationship between energy and output implies that either variable can change without affecting the other.

In an early attempt to contribute to the argument about whether or not energy conservation programs might have adverse effects on GNP, Kraft and Kraft (1978) model energy inputs and GNP from 1950 until 1970 and find unidirectional causality from GNP to energy consumption. Shortly thereafter Akarca and Long (1980) perform the same study while excluding the last two observations—possible outliers affected by the oil embargo—finding no causality in either direction between GNP and gross energy consumption. Glasure and Lee (1997) highlight past discrepancies of energy-output studies and find results that are quite different from previous studies of South Korea and Singapore. Guttormsen (2004) reviews a number of energy-output studies and highlights cases where changes to the sample period or changes to the sampling frequency result in different outcomes for the study. Such mixed results can lead to the hypothesis that energy-output relationships vary from economy to economy and over time. Mozumder and Marathe (2007) present a summary of 27 energy-output studies found in the literature and highlight the lack of consistent results from different economies. Zachariadis (2006) highlights inconsistencies in multiple studies, the dubious policy implications following empirical studies, and potential methodological problems associated with energy-output causal analyses.

To further highlight these issues in the literature, Asafu-Adjaye (2000) considers the trivariate causal relationships between energy consumption, GDP, and a price index for India and three other countries for the period 1973-1995. The results of this study differ from a previous study by Cheng (1999) that considers the causal relationships between energy consumption, economic growth, capital, and labor, covering the period 1952-1995 (Paul & Bhattacharya, 2004). Paul and Bhattacharya indicate that the discrepancies between Asafu-Adjaye's results and Cheng's results could be due to "the choice of the sample period or to the measure of the variables or to the choice of the methodology or to both" (2004, p. 979).

Most of the studies found in the literature employ annual data, with more recent studies tending to use higher-frequency data. One study uses monthly data between 1973 and 1978 to analyze causal relationships between total energy consumption and employment, and finds a negative relationship from energy to employment with an eight-month delay (Akarca & Long, 1979).

Only three studies found in the literature consider the case of Brazil. Cheng (1997) studies the causal relationship between energy consumption and GDP for the period 1963-1993 and finds a negative relationship from energy consumption to GDP. This finding implies that a reduction in energy consumption could increase GDP. In the second study, bi-directional causality between final energy consumption per capita and GDP per capita is found for Brazil using annual data from 1971 to 2000 (Chontanawat, Hunt, & Pierse, 2006). The third study considering Brazil conducts a causal analysis between electricity demand and GDP for the period 1969-1999 using annual data; the residential, commercial, and industrial sectors are modeled separately and only long-run results are reported (Schmidt & Lima, 2004).

The review of the literature cited above is by no means exhaustive, but it serves to highlight some of the issues presently displayed in energy economics. One means of addressing the observed lack of consistent results in causal analyses would be to test the stability of existing relationships given a shock. A comparison of causal relationships found in the economy before the shock to those found after the shock would present the literature with an understanding of how such relationships change in response to the given shock. This study is conducted for the Brazilian case in Chapter 4.

The energy economics literature contains numerous studies highlighting substitution possibilities and studies estimating substitution elasticities between energy inputs and factors of production. A review of this literature indicates that substitution possibilities vary over time and among different economies; estimated elasticities of substitution also vary with model specification. Very few studies consider how an energy shock affects existing substitution possibilities and behavior, which is of great importance given the widespread use of elasticities to prescribe policy in other areas. Disaggregated energy models in this literature often include electricity as an input, which plays a special role in industrialized economies. In industrialized economies, electricity is a vital input to essentially every production process and service; it is also heavily used in the production of other sources of energy.

An important question within energy economics continues to be, to what extent are energy, capital, and labor substitutable inputs? The answer to this question has important implications for energy policy. For example, one study indicates that elasticities of substitution of 0.5 allow for considerable energy reduction with minimal effects on output, whereas elasticities of substitution of 0.2 do not allow for energy reduction without significant losses to output (Koopmans, Bullard, Hogan, & Lave, 1978, p. 129). Results from a cross-country panel estimate of the elasticities of substitution between energy, capital, labor, and materials, for the years 1963-1974, show that “Indeed, it appears that substitution is a most effective means of achieving energy conservation objectives” (Özatalay, Grubaugh, & Long, 1979, p. 370).

The first oil crisis stimulated much research on energy policy with the intention of understanding better input substitution possibilities. In the same year as the first oil crisis, Christensen, Jorgenson, and Lau (1973) introduced what would become the standard approach to estimate elasticities of substitution in energy economics. Their model, the translog cost function,[7] does not impose a theory of production on the data, but rather it allows theoretical questions to be tested empirically. More importantly, their model does not restrict the elasticities of substitution to be constant. Berndt and Wood (1975) are the first authors to apply the translog model to question substitution possibilities between energy and other inputs. Following the energy crisis and extending applications of the translog cost function, Long and Schipper (1978) question the ability of production processes to adjust to rapid shortages of a given input, while noting many technological limitations to uses of certain inputs. More recently, Karanfil and Yeddir-Tamsamani (2009) apply the translog technique to a 12-sector analysis of the French economy. As an attempt to understand the mixed results of the role of energy in production, some authors specify models that consider capital to be quasi-fixed in a dynamic environment (Morrison, 1988; Pindyck & Rotemberg, 1983; Wing, 2008). One of the early applications of the translog cost function to a developing country is Kim and Labys (1988), who question the effects of price regulation on fuel choice, and subsequently, on elasticities of substitution in Korea. A more recent study of Korea is motivated by possible changes in interfuel substitution induced by distinct growth periods before and after 1989 (Cho, Nam, & Pagán, 2004). Ma et al. (2009) consider the case of China and

[7] The translog cost function is the dual to the translog production function, which is less commonly used.

apply the translog cost function to seven regions. No similar studies can be found in the literature for Brazil.

One advantage of estimating a translog cost model is that its parameters can be used to calculate elasticities of substitution. Starting with early papers in the literature (Berndt & Wood, 1975; Pindyck, 1979a), Allen/Uzawa partial elasticities of substitution became a standard means of reporting results. However, Blackorby and Russell (1989) highlight the improper use of the Allen/Uzawa elasticity of substitution (AES) in many studies and show that its usefulness is limited and applies only to the two input, Cobb-Douglas case. They present the Morishima elasticity of substitution (MES) as exhibiting all of the desirable properties of an elasticity of substitution for a multiple input production or cost function. An additional and notable property of the MES is that it does not impose symmetry on production elasticities, whereas the AES does. Interpreting the sign of AES has produced disagreement between studies regarding the substitutability or complementarity between capital and labor. Thompson and Taylor (1995) re-estimate previous studies and use MES, rather than AES, to determine substitutability.[8] They find that the previous disagreement is nearly eliminated when using the MES, as more than 97 percent of their estimated MES show capital and energy to be substitutes (1995, p. 566). Use of the MES is especially important for the case where one energy input is shocked, as asymmetries within the elasticities of substitution may contribute greatly to the observed outcome.

[8] Addressing the question of disagreement through a different technique, Hisnanick and Kyer (1995) utilize an objective function to estimate confidence intervals around the AES of a previous study, and find that capital and energy are complementary, contrary to other results.

No examples of studies questioning the effects of an input shock on elasticities of substitution can be found in the literature. Perhaps elasticities of substitution are stable and do not react substantially to an input shock; or perhaps the economy exhibits substitution possibilities sufficient enough to absorb an input shock. While other possibilities exist to explain how an economy reacts to an input shock, the question of how an input shock affects elasticities of substitution remains unanswered. Chapter 5 addresses this question by estimating elasticities of substitution around the rationing period and by attempting to reconcile observed substitution behavior with substitution behavior predicted from these results.

2.5 The Potential Role for Energy Efficiency Improvements

This dissertation cannot directly test the means by which the Brazilian economy adapted to the rationing program. One possible result of the hypotheses to be tested in this dissertation is that the rationing program did not have an impact on output. For this hypothesis to be plausible, arguments should be provided that indicate an industrialized economy could, if necessary, rapidly reduce its electricity consumption without affecting output.

One argument found in the literature supporting this possible outcome is typically found in the literature regarding environmental regulations of industries. The Porter Hypothesis, as posited by Michael Porter (1991), asserts that properly created regulations can induce innovation that leads to product improvements or process improvements;

these improvements typically begin by reducing or eliminating waste.[9] The hypothesis further asserts that these improvements often provide the firm with cost reductions greater than the cost of regulatory compliance. Porter and van der Linde (1995) cite numerous examples of firms that opted to innovate when faced with an environmental regulation, rather than attempting to comply with the regulation by preventing the regulated substances. Rather than losses, these firms showed direct economic benefits in response to the new regulations. Although the Porter hypothesis primarily considers regulations and/or policies related to the environment, it is not specifically limited to this area. For the case of the Brazilian electricity rationing program, firms that acted according to the Porter Hypothesis would innovate their products and processes to reduce electricity consumption, rather than merely foregoing the consumption of electricity. Such innovation would be expected to result in long-term reductions in electricity consumption; firms not making such improvements would be expected to rebound to pre-intervention period consumption when the intervention is terminated.

A second argument, which also bolsters the Porter Hypothesis, regards the widespread availability of energy efficiency improvements. Schipper (1979) highlights different means of enhancing energy efficiency and discusses the dramatic consumption differences between energy-intensive sectors of the U.S. and Sweden. Hausman (1979) finds that U.S. residential consumers forego extensive future operating cost savings to save a small amount when purchasing air conditioners. Figuratively speaking, these results indicate that energy efficiency improvements are left sitting on the shelf. A study

[9] Similar to the Porter Hypothesis, Leibenstein's (1966) X-efficiency, and X-inefficiency present evidence that tremendous potential gains in production remain unexploited; see Klein and Rothfels (1999) for a combined test of X-inefficiency and the Porter hypothesis.

of electric motors in the industrial sector of Malaysia highlights the need for efficiency-related regulation in order to capture gains from lower energy consumption and reduced operating costs (Mahlia & Yanti, 2010). Another study encompassing global energy use found that “By capturing the potential available from existing technologies . . . we could cut global energy demand growth by half or more over the next 15 years” (Bressand et al., 2007, p. 9).

While additional arguments exist to explain how a country could adapt to a rapid reduction in electricity without affecting output, these two arguments are sufficient to deem this possible outcome plausible.

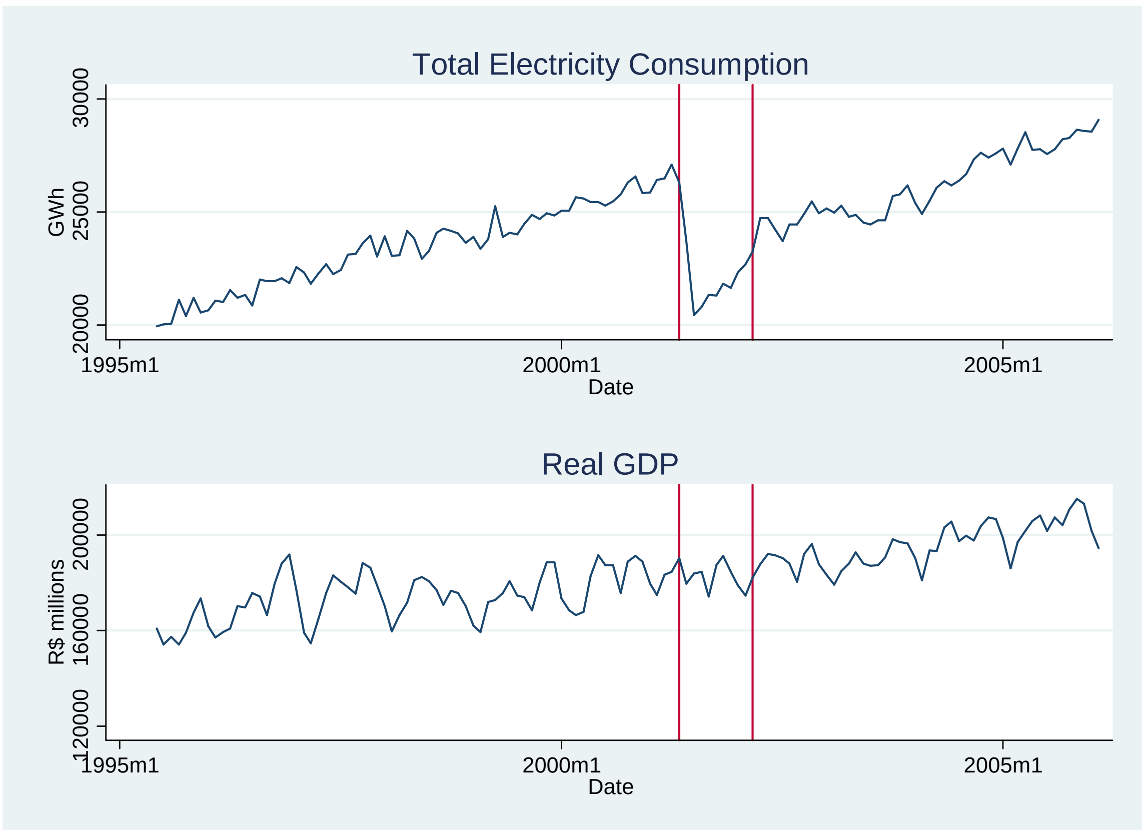
CHAPTER 3

BRAZIL'S ELECTRICITY RATIONING PROGRAM OF 2001-2002

3.1 Introduction

This chapter presents a brief background surrounding the need to create and implement the electricity rationing program in Brazil in 2001-2002. This chapter uses descriptive statistics and graphs to illustrate the impact of the rationing program on electricity consumption and GDP. Available elasticities relating output and electricity consumption are used to identify the expected effects of the rationing program on GDP. Empirical tests of these expectations are performed in later chapters of this dissertation in an effort to understand the impact of the input shock on the Brazilian economy.

Around the start of the new millennium, Brazil was producing roughly 90 percent of its electricity from hydroelectric sources. Confronting a severe drought in 2001, the Brazilian government faced a tough decision when many of its hydroelectric power plants were nearing inability to produce electricity. The government could allow roaming blackouts to equate electricity demand and supply, or it could implement a policy leading to the necessary reductions in electricity consumption. Policy options included quantity rationing and/or electricity rate increases to achieve the goal of stable electricity supply. In May of 2001, the government opted for a policy of quantity rationing, requiring an average 20 percent reduction in electricity consumption for the country (Pêgo Filho, Mota, Carvalho, & Pinheiro, 2001). Within a year, enough rain had fallen to allow repeal of most of the policy. Figure 3.1 highlights the dramatic effects this policy had on total electricity consumption during the intervention, and shows GDP for the same period.[10] While the intervention had a clear impact on electricity consumption, little or no noticeable impact from the electricity rationing program is visible in the GDP series.



Source: Data adapted from SGS 2009, various series.

Figure 3.1. Total Electricity Consumption and GDP.

[10] As no monthly real GDP series is available, the 'real' series presented in this and other chapters is created according to the methodology presented in appendix A.1.

While the actual policy implemented was somewhat complex, the general approach of the electricity rationing program was a requirement for individual consumers of electricity in all regions other than the southern region to reduce electricity consumption by 20 percent.[11] The details of the policy indicate the different goals specified for different consumers (industrial, commercial, and residential), as well as fines to be faced by those not meeting their goals. The policy, or policies, also seemed to change over time, at least in the initial periods of the crisis. Ultimately, the policy was announced in the middle of May 2001, was initiated the beginning of June 2001, and was terminated at the end of February 2002.

3.2 Details of the Electricity Rationing Program

Maurer, Pereira, and Rosenblatt (2005) compile and discuss the major causes to Brazil's crisis, which include:

- a severe and prolonged drought, lowering reservoir levels since 1997
- increasing electricity demand, but not a demand shock
- failure to increase generation capacity as demand grew
- misstated risks of an electricity disequilibrium situation

The latter two reasons can be partially attributed to the government's improper handling of Brazil's power sector reform. It is also interesting to note that, even in the face of low reservoir levels since 1997, the government focused on increasing supply rather than slowing or reducing demand. Only in March 2001 did the government publicly

[11] The southern part of Brazil was not required to participate in the mandated reduction due to continued abundance of electricity there during the crisis. In 2000, the southern region produced 18% of Brazil's GDP (IPEAdata, 2011).

acknowledge that a crisis was imminent; the government did not release its planned rationing program to the public until mid-May (pp. 47–54).

The work produced by Maurer, Pereira, and Rosenblatt (2005) is quite comprehensive and considers many aspects of electricity rationing programs around the world. While the solutions to any rationing situation can vary according to the specifics of each case, the Brazilian electricity rationing program[12] is cited as an "international best practice" for addressing a rationing situation (Maurer et al., 2005, p. 6).

The government developed and implemented a rationing system employing penalties and bonuses. It contained provisions to protect the poor while also encouraging them to conserve: the rationing program exempted the poor from the required reductions while offering bonuses, i.e., discounted rates, if they could attain reductions greater than 20 percent. The rationing program also allowed some commercial and industrial customers to auction their quotas (Maurer et al., 2005, pp. 59–64).[13] Maurer, Pereira, and Rosenblatt succinctly explain the rationing program:

> The quota system consisted of monthly energy consumption targets for almost all consumers and a set of rules for trading quotas, setting bonuses for overachievers and penalties for violators. . . . Quotas were set up as percentages of consumption in a similar period during the previous year. For instance, each residential consumer above 100 kWh per month was assigned a quota corresponding to 80 percent of his or her average consumption during the period of May to July of 2000. Other targets were: 90 percent for rural consumers, 80 percent for commercial consumers, 75 to 90 percent for industrial consumers (depending on the type of industry), and 65 percent for government buildings. (2005, p. 61)

The Brazilian electricity rationing program appears to match policy recommendations found in the literature and discussed in Chapter 2. The policy option

[12] Brazil is one of six case studies included in the work.

[13] An estimate from the data presented in Maurer et al. (2005, p. 69) indicates quota trading amounted to 0.2 percent of total electricity consumption during the rationing program.

implemented in Brazil was somewhat of a hybrid between a quota system and a price mechanism: the consumer was allocated a quota, based on similar consumption from the previous year, but the consumer was fined heavily if the quota was exceeded. The initial penalty for exceeding quotas was around three times the maximum rate (Maurer et al., 2005, p. 58). The purpose of the rationing program was to avoid the extremely high social and economic costs of blackouts, and thus follows Weitzman's (1974) advice to target quantities. The high fines and threat of disconnection for consumption exceeding the quota are similar to Kaplow and Shavell's (1997) nonlinear tax recommendation. As the policy mainly targeted existing consumers, the costs of implementing the quota system and identifying violations were low. The rationing program exempted consumers below a minimum electricity consumption, thus partially mitigating distributional concerns. Also mitigating distributional concerns, a consumer's quota was established from observed behavior at established prices.

3.3 Initial Reactions to the Electricity Rationing Program

Shortly after the government announced the need of and plans for the electricity rationing program, the Brazilian media was replete with commentary predicting severe economic consequences as a result of this policy. One business association, the Confederação Nacional da Indústria (National Industry Confederation, or CNI), surveyed 918 firms during the first month under the energy rationing policy and found numerous unfavorable expectations:

> [F]or 76% of the companies, meeting the goal will only be possible with a reduction in production. . . . These impacts on production should also be reflected

> in the level of industrial employment, with 63% of the companies declaring that they will probably have to dispense workers. (CNIa, 2001, p. 1)

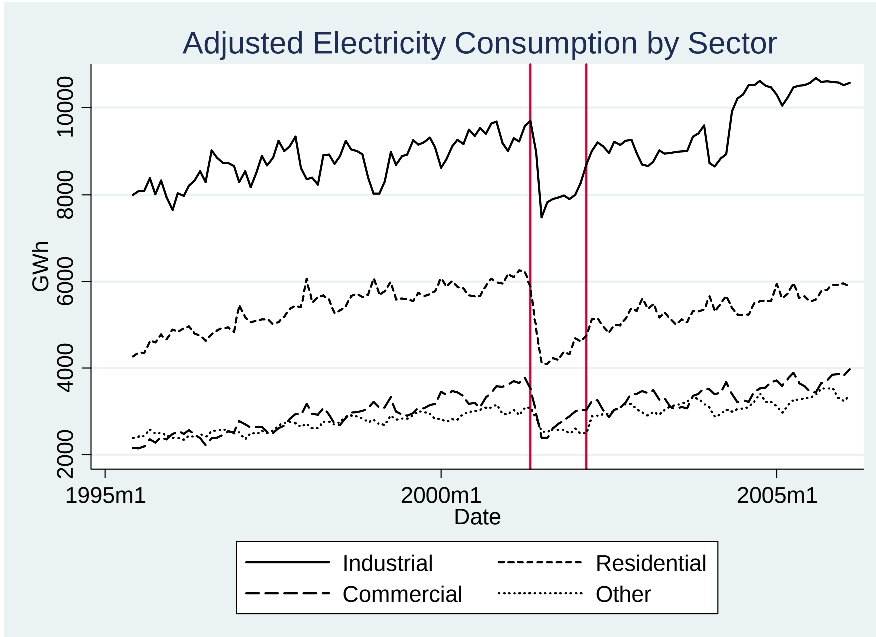
While there was much conjecture regarding the economic impacts the rationing program would have on the Brazilian economy, specific projections and studies were in short supply. The *Jornal do Brasil*, a major Brazilian newspaper, dedicated an entire issue of its news magazine to the crisis with the title “A Questão Energética,” or “The Energy Question,” (*Jornal do Brasil*, 2001a). In its opening editorial, it calls the rationing program a “real nightmare” and an “obstruction to economic growth” (*Jornal do Brasil*, 2001b, p. 5). However, aside from an interview with the Minister of Mines and Energy that focused on the then-nascent rationing program (*Jornal do Brasil*, 2001c), most articles focused on general topics in the energy sector related to increasing electricity supply and transmission in the future. Few government officials, if any, made official statements regarding the expected outcome of the intervention, even though the need for the intervention was apparent.

The Applied Economic Research Institute (IPEA) reported the possibility that the rationing program would cause a one percentage point impact on GDP in April, before the final rationing program was announced, but without any accompanying details or analysis (IPEA, 2001, p. VI). A few months later and while the specifics of the electricity rationing program were still being determined, Pêgo Filho et al. (2001), also from IPEA, presented the results of scenarios considering the impact of the rationing program on public sector accounts. Their status quo scenario without the electricity rationing program included an estimated 4 percent increase in real GDP for 2001; the two additional scenarios considered, which incorporated varied responses to the crisis, projected GDP growth at 3.2 percent and 3.0 percent (Pêgo Filho et al., 2001, p. 11).

The rationing program faced initial disapproval by many political actors and individuals due to fears that: consumers simply would not or could not reduce consumption, that the administration of the quotas would be impossible, and that any reduction would be short lived with blackouts being the only effective solution to the limited ability to supply electricity (Maurer et al., 2005, pp. 54–55). Quoting Maurer, Pereira, and Rosenblatt, “The initial reaction from customers was total perplexity” (2005, p. 55).

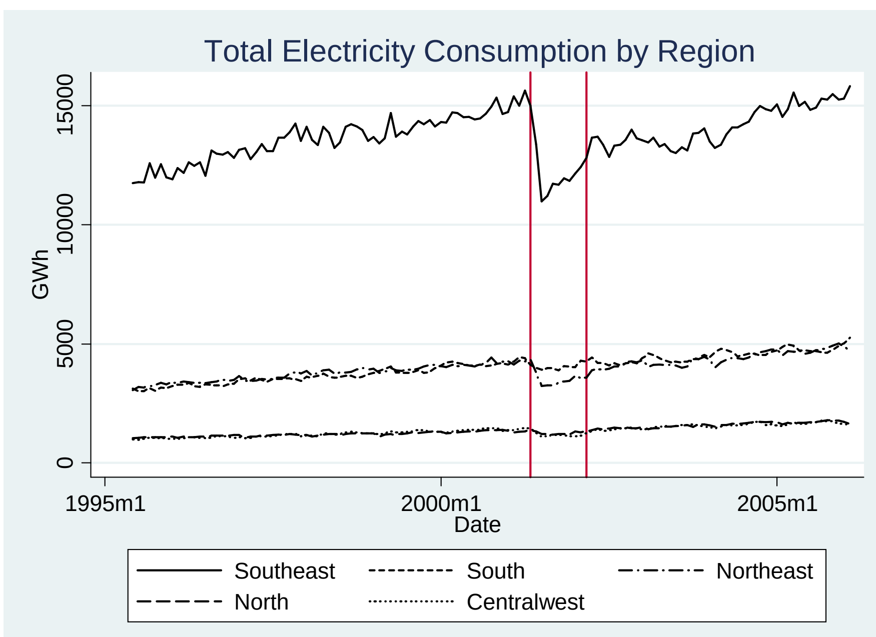
3.4 Observed Effects of the Electricity Rationing Program

Figure 3.2 shows adjusted electricity consumption for each of the four economic sectors: industrial, residential, commercial, and other. The “adjustment” to each series removes the contribution of the southern region, which was not subject to the rationing program. Figure 3.3 shows total electricity consumption for each of the five geographic regions: Southeast, South, Northeast, North, and Centralwest. The overall effect of the policy is evident in the different economic sectors; the regional effects outside of the Southeast are relatively small. The concentration of the effects of the rationing program on the southeast region should not be surprising given that the production and population megacities of São Paulo and Rio de Janeiro are located in this region.



Source: Data adapted from SGS 2009, various series.

Figure 3.2. Electricity Consumption by Sector.



Source: Data adapted from SGS 2009, various series.

Figure 3.3. Total Electricity Consumption by Region.

As stated previously, the intervention required an average reduction of 20 percent, with some slightly higher or lower goals for special consumers; the rationing program also exempted the southern region. By the definition of the policy, “reduction” is the percentage decrease of any month during the rationing program from the consumer’s average consumption in the previous year during the three months of May, June, and July. The average consumption of electricity by the consumer during these three months in 2000 was commonly called the target or goal. Assessing this goal, table 3.1 presents the average monthly percent reduction of electricity consumption by sector. All percents shown are for the adjusted series, except for the “Total” column, which includes the southern region. Table 3.1 shows that the total affected regions of Brazil only met the stated goal of reducing total electricity consumption by 20 percent during July and August; however, each month of the rationing program exhibits a significant reduction in electricity consumption. The residential sector consistently met its goal after the first month of the program until the last two months of the program. Performance in the industrial and commercial sectors appears mixed, perhaps due to the diverse rules applied to these sectors.

Table 3.1. Percent Reduction in Consumption (Adjusted), by Sector

Date	Total	Total (adj)	Industrial	Residential	Commercial	Other
2001m6	6.6	7.4	3.8	14.2	8.3	4.3
2001m7	19.5	22.4	20.0	28.1	26.1	14.6
2001m8	18.1	20.9	16.3	28.5	26.2	15.2
2001m9	16.0	18.5	15.4	26.1	19.4	12.2
2001m10	16.1	18.1	15.0	26.7	16.3	13.4
2001m11	14.1	16.6	14.5	23.7	13.3	13.4
2001m12	14.8	17.3	15.4	24.5	10.9	16.4
2002m1	12.1	14.1	14.3	18.1	7.5	12.7
2002m2	10.6	13.5	11.5	19.5	6.0	16.6

Source: Data adapted from SGS 2009, various series.

For each geographic region, table 3.2 presents the monthly percent reduction in electricity consumption from the average consumption of May, June, and July of the previous year. Table 3.2 shows that the Southeast (SE), which contains São Paulo and Rio de Janeiro, reduced its consumption by more than 20 percent for two of the nine months of the rationing program. The Northeast (NE) attained its goal during three months and the Centralwest (CO) attained its goal only during one month; the exempt southern region (S) had only small reductions.[14]

Table 3.2. Percent Reduction in Consumption, by Region

Date	Total	Total (adj)	SE	NE	CO	N	S
2001m6	6.6	7.4	7.8	8.0	9.1	-0.5	2.5
2001m7	19.5	22.4	24.2	20.9	21.0	8.3	4.6
2001m8	18.1	20.9	22.6	20.4	16.9	8.9	3.2
2001m9	16.0	18.5	19.1	20.1	15.4	9.9	3.1
2001m10	16.1	18.1	19.4	17.6	16.0	8.7	5.5
2001m11	14.1	16.6	17.5	16.3	15.6	8.4	0.8
2001m12	14.8	17.3	18.3	16.0	18.9	9.3	1.9
2002m1	12.1	14.1	16.1	10.2	18.1	0.2	1.8
2002m2	10.6	13.5	14.3	13.0	17.3	2.6	-4.3

Source: Data adapted from SGS 2009, various series.

Even without consistently attaining the goal, table 3.2 shows that the intervention had a marked impact on electricity consumption in the affected regions. The marked impact resulting from the intervention motivates the question of whether the intervention affected consumption and production, at least in those areas affected by the rationing program. If the affected areas had been relatively small, the total expected impact might also have been small. As the average reduction in total electricity consumption was 14.2 percent (16.5 percent if considering only the affected regions) during the intervention

[14] Apparently the southern region implemented voluntary measures to reduce electricity consumption due to media pressures and possible future implications (Maurer et al., 2005, p. 72). The results in Table 3.2 indicate these measures had a small, but noticeable effect.

period and a total average reduction of 7.89 percent for the year, an interesting question becomes, what were the effects, if any, of the electricity rationing program on GDP?

There are many different techniques and approaches to address the question of how the electricity rationing program affected GDP. This section presents some basic descriptive assessments of the electricity rationing program, which aim to motivate more complete and complex analyses of the effects of the rationing program on the Brazilian economy. Many of the data presented in this section and throughout this dissertation draw upon the adjusted, real monthly GDP series. While the appendix A.1 explains the adjustment in detail, the reader should keep in mind that the adjusted GDP series is the result of deflating the nominal monthly GDP series by a linear interpolation of the annual GDP deflator.

Table 3.3 shows the percent changes in adjusted monthly real GDP, based on the same month in the previous year; the last row of the table lists annual values. Each value is the percent change of the given month with respect to the same month in the previous year. The starting month for each annual period, June, corresponds to the starting month of the rationing program. This allows all nine months of the rationing program to be captured within one twelve-month period. The electricity rationing program months are shaded. As can be seen from both the monthly values and the annual rates, Brazil’s economy has demonstrated much volatility over the six years shown. It is important to note that the annual rate of GDP growth for the 2000-2001 period, the period immediately preceding the rationing program, is considerably higher than the preceding three periods. Focusing on the intervention period, the first month of the program experienced the largest drop in GDP during the nine-month intervention, even though total electricity consumption fell by only 6.6 percent. The other eight declines in monthly GDP are not historically large.

Table 3.3. GDP Year-on-year Percent Increases (June-May)

Month	**1996-7**	**1997-8**	**1998-9**	**1999-0**	**2000-1**	**2001-2**
June	5.5	8.0	-0.4	-1.0	6.1	-6.3
July	13.9	2.7	0.2	-3.5	7.4	-1.9
August	10.8	2.2	-0.7	-1.6	7.7	-1.7
September	8.0	5.4	-2.6	-1.3	4.3	-0.9
October	12.9	4.8	-6.2	2.0	5.0	-0.8
November	12.1	-1.0	-5.6	7.3	1.4	0.0
December	10.6	-6.6	-4.9	10.9	0.2	-2.4
January	9.3	-3.8	-4.7	6.9	3.5	-0.2
February	1.1	0.4	-0.1	5.6	3.9	-0.2
March	-3.0	7.6	3.4	-3.2	10.0	-0.6
April	2.5	4.1	0.7	-2.9	9.8	1.7
May	3.2	3.0	-2.9	4.0	4.2	0.9
Annual Increase:	7.2	2.2	-2.0	1.9	5.3	-1.0

Source: Data adapted from SGS 2009, various series.

Table 3.4 presents the same data (year-on-year monthly percent changes) in the more common January-to-December arrangement. This presentation allows for a more direct comparison with reported GDP growth rates. The comparison between the adjusted and unadjusted growth rates also allows the reader to assess the accuracy of the transformations required to create the monthly real GDP series. Table 3.5 displays the monthly and annual growth of GDP for the years 2003 through 2006. The post-intervention values help to create a more complete understanding of the growth Brazil experienced around the time of the intervention and in subsequent years. A basic assessment of the data in these two tables indicates that the growth rates during the intervention years were not outside what could have been expected based on data from

Table 3.4. GDP Year-on-year Percent Increases (January-December)

Month	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
January	9.3	-3.8	-4.7	6.9	3.5	-0.2
February	1.1	0.4	-0.1	5.6	3.9	-0.2
March	-3.0	7.6	3.4	-3.2	10.0	-0.6
April	2.5	4.1	0.7	-2.9	9.8	1.7
May	3.2	3.0	-2.9	4.0	4.2	0.9
June	8.0	-0.4	-1.0	6.1	-6.3	6.7
July	2.7	0.2	-3.5	7.4	-1.9	3.6
August	2.2	-0.7	-1.6	7.7	-1.7	2.0
September	5.4	-2.6	-1.3	4.3	-0.9	3.5
October	4.8	-6.2	2.0	5.0	-0.8	2.5
November	-1.0	-5.6	7.3	1.4	0.0	2.5
December	-6.6	-4.9	10.9	0.2	-2.4	1.8
Annual Increase:	2.3	-0.9	0.7	3.5	1.2	2.0
Real Growth Rate:	3.4	0.0	0.3	4.3	1.3	2.7

Source: Data adapted from SGS 2009, various series.

Note: This direct comparison between the adjusted real GDP series and the unadjusted real GDP series allows the reader to assess the accuracy of the adjusted series. See the Data Appendix for more information.

Table 3.5. GDP Year-on-year Percent Increases (January-December)

Month	**2003**	**2004**	**2005**	**2006**
January	2.3	4.0	4.3	1.6
February	2.7	1.0	2.8	4.5
March	1.5	4.8	1.7	3.4
April	0.2	2.9	4.3	-1.5
May	0.3	5.5	1.3	3.7
June	-1.8	9.2	1.4	3.4
July	-1.7	5.4	2.3	6.2
August	-0.3	6.5	3.8	5.7
September	5.8	3.7	3.2	3.3
October	3.1	2.9	3.2	5.1
November	0.5	5.2	3.7	6.2
December	4.7	5.1	3.2	5.0
Annual Increase:	1.4	4.7	2.9	3.9
Real Growth Rate:	1.1	5.7	3.2	4.0

Source: Data adapted from SGS 2009, various series.

Note: This direct comparison between the adjusted real GDP series and the unadjusted real GDP series allows the reader to assess the accuracy of the adjusted series. See the Data Appendix for more information.

previous years. If any value appears to change abruptly, it is the growth rate of 4.3 percent in 2000. The most important result from these data is that Brazil's economy grew 1.3 percent in 2001, while the country consumed an average of 15.0 percent less electricity during seven months that year.

Table 3.6 indicates the monthly percent change in the GDP series. The monthly percent changes in GDP provide another descriptive analysis of the economy prior to and during the intervention. Similar to table 3.4, table 3.6 suggests that the only large, abnormal change occurred in June 2001. This drop in GDP corresponds to the smallest reduction in electricity consumption during the rationing program. Perhaps related to the large negative change in GDP in June 2001 is the positive change in July 2001. In all other years, the month of July exhibits a negative change in GDP; following the abnormal decrease in June 2001, the July percent change may indicate a possible rebound in GDP.

Table 3.6. GDP Month-to-month Percent Increases (January-December)

Month	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
January	-7.7	-4.9	-4.7	-8.2	-5.1	-2.9
February	-10.1	-6.2	-1.7	-2.8	-2.5	-2.5
March	-2.7	4.2	7.9	-1.1	4.8	4.4
April	6.7	3.2	0.6	0.9	0.7	3.0
May	6.5	5.4	1.6	8.8	3.2	2.4
June	4.3	0.8	2.8	4.8	-5.8	-0.3
July	-1.5	-0.9	-3.4	-2.2	2.4	-0.5
August	-1.3	-2.2	-0.3	0.1	0.3	-1.3
September	-1.5	-3.4	-3.2	-6.2	-5.5	-4.1
October	7.4	3.3	6.8	7.4	7.6	6.5
November	-1.1	-0.5	4.7	1.2	2.1	2.1
December	-3.9	-3.2	0.1	-1.2	-3.6	-4.3
Annual Increase:	2.3	-0.9	0.7	3.5	1.2	2.0
Real Growth Rate:	3.4	0.0	0.3	4.3	1.3	2.7

Source: Data adapted from SGS 2009, various series.

Note: This direct comparison between the adjusted real GDP series and the unadjusted real GDP series allows the reader to assess the accuracy of the adjusted series. See the Data Appendix for more information.

While less likely to be related to the rationing program, the negative GDP growth for January 2002 is much smaller than in previous years. The remaining ten months of 2002 do not indicate any systematic change that might be attributed to the end of the rationing program.

3.5 Expected Effects of the Electricity Rationing Program

The two previous sections present the electricity rationing program and the observed changes in electricity consumption and GDP. One of the many questions that can be asked of the policy intervention is, before the policy was implemented, what were the expected effects of a 20 percent reduction in electricity consumption on GDP? A second question is, to what extent can the adjustment paths followed by the Brazilian economy in response to the rationing program be identified?

Two examples of answers to these questions include estimations from economic models and simple energy-output elasticities. One study, based on a CGE model, estimates that the rationing program should have reduced GDP by approximately 3 percent (Scaramucci et al., 2006, p. 990). It is interesting to note that the CGE model employs an endogenous tax to reduce electricity consumption, rather than an explicit and exogenous quantity restriction. No details are provided to understand how the expected reduction would be realized in the economy. As an answer to the first question, it does not reflect the policy that was actually implemented and it does not provide an explanation of why the predicted performance of the economy does not agree with the observed economic performance. The potentially devastating effects of an electricity rationing program warrant a better understanding of how to approach a similar crisis in the future. A better approach to learning from the Brazilian example would be to model the expected effects of the shock using the most appropriate techniques, and then to evaluate the performance of those techniques to highlight discrepancies. Such an analysis would contribute specifically to the literature on the Brazilian intervention and to the energy shock literature in general.

The second question regards the path or paths followed by the economy in response to the shock. One obvious explanation would be that the economy substituted other energy sources for the reduced consumption of electricity. The Balanço Energético Nacional, or National Energy Balance, provides data that can be used to create a GDP/electricity elasticity of .765 for the period 1993-1997 (BEN, 2004, p. 24). Combining this elasticity with the 7.89 percent decline in total electricity consumption in 2001 leads to the estimation that GDP should have fallen by 6.03 percent in 2001. If the 20 percent reduction were to be attained through blackouts, this estimated decrease would not include expected indirect effects,[15] as indirect losses associated with blackouts can be much larger than the primary effects (AUS Consultants, 2001). Such a discrepancy between an estimate and an observed value motivates a more-complete analysis of the substitution possibilities within the Brazilian economy at the time of the intervention. An analysis of the substitution possibilities should also provide explanations of the actual paths followed, as they would help to reconcile the discrepancy. Such an explanation would be valuable to understand better the specific case of Brazil versus other

[15] Indirect losses include, among others, multiplier impacts related to lost revenues attributed to the power interruption, for businesses and employees.

industrialized economies; it would also be valuable to other countries facing similar shocks in the future.

Both of these estimated effects of the rationing program on GDP overstate the observed effects on GDP, which grew 1.3 percent in real terms in 2001. These discrepancies lead to the hypotheses tested in this dissertation: Would the dramatic reduction in electricity consumption be expected to decrease Brazil's GDP in 2001? And, is substitution the primary means by which the Brazilian economy adapted to the electricity rationing program? While numerous reasons exist to lead to a conclusion that GDP should fall with a reduction in electricity consumption, many other examples highlight means of reducing electricity consumption that could actually stimulate an economy. Two available means that could allow adjustment to the required lower electricity consumption include substituting other energy sources for electricity and eliminating wasteful consumption of electricity. In addition to these hypotheses, this study of the Brazilian electricity rationing program also provides insight into the effects of model specification on possible conclusions drawn from the results through the exploitation of an intervention framework, which allows model predictions to be assessed against observed values.

CHAPTER 4

QUANTIFYING THE EFFECTS OF THE RATIONING PROGRAM THROUGH TIME SERIES ANALYSIS

4.1 Introduction

The purpose of this chapter is to answer the question, what should the expected effects of a 20 percent reduction in electricity consumption be on GDP? One of the purposes of answering this question is that it serves as a test of the hypothesis, did the reduction in electricity consumption affect GDP? The answers to these questions are important to understand more fully the electricity rationing program in Brazil. However, to understand better the possible changes induced by the rationing program, a further question is addressed: did the rationing program change identifiable relationships in the Brazilian economy? The answers to and the implications of this question can be applicable to energy shocks in general, providing guidance beyond the Brazilian case.

The assessments of the rationing program in chapter 3 are descriptive and do not provide a complete representation of the effects of the electricity rationing program. This chapter begins with an assessment of the rationing program on electricity consumption, GDP, and other series that may have been affected by the rationing program. In addition to the understanding of the effects of the rationing program, this assessment provides benchmark estimates for the effects of the program. The assessments are conducted using univariate techniques. To answer the question of expected effects of the rationing program on GDP requires a model capable of incorporating causality, but not structurally developed to include causality. This question is approached through the use of multivariate VAR/VEC models. The use of multivariate techniques allows the final question to be addressed. By providing an assessment of the changes to statistical causality induced by the rationing program, policy recommendations based on energy shock studies can be stated more accurately.

Motivated by the brevity of the electricity rationing program, the analyses in this chapter use monthly data. While monthly forecasts and analyses for developed countries are becoming common place, monthly data for developing countries are still uncommon. This chapter exploits available data for Brazil to create a real monthly GDP series; appendix A.1 provides more detail on the construction and performance of this series. The use of higher-frequency data allows the analysis to capture short-run effects that may not be evident in lower-frequency data.

4.2 The Univariate Assessment and Results

This section conducts a univariate intervention analysis on economic series that may have been affected by Brazil’s electricity rationing program, in order to assess the effects of the intervention. The analysis begins with an estimation of the reduction in electricity consumption, followed by an estimate of the reduction in output, as measured by GDP. The analysis is also conducted on other, plausibly-related series to assess the effects of the rationing program beyond electricity consumption or output.

The literature addressing Brazil's electricity rationing program presents few estimates of the effects of the rationing program on output; one was created before the rationing program began (Pêgo Filho et al., 2001). Other sources cite estimates whose sources are not available or provide estimates without details on the methodology used (IPEA, 2001). This analysis contributes to the energy shock literature by providing a documented example of the estimation of the effects of the rationing program in Brazil.

The methodology used to estimate the effects of the rationing program employs three basic models: OLS, ARIMA, and exponential smoothing. These techniques are well-documented in the forecasting and intervention analysis literature. By presenting the results from three distinct models, this analysis highlights the impact of model choice on the obtained results. These techniques are used to create counterfactual series that can be used to estimate and quantify the effects of the intervention on the given series. Enders (2004, Ch. 5) outlines the generic steps of an intervention analysis, while Box, Jenkins, and Reinsel (1994, pp. 462–480) present common techniques of intervention analysis in greater detail; Shadish, Cook, and Campbell (2002, Ch. 6) present a similar methodology.

The basic structure of intervention analysis is to create a comparison between a pre-intervention estimate for the post-intervention period and the observed post-intervention values. The three techniques are used to model each series in the pre-intervention period; the pre-intervention models are used to forecast the series into the post-intervention period. The three forecasts for each series are then used to quantify and assess the impact of the rationing program.

The OLS model creates a non-dynamic baseline model against which the other techniques can be compared. Each variable's specification can include terms for a deterministic trend, a change in the deterministic trend, and a change in the constant; the final specification for each series depends on that series' characteristics. Each model includes 11 centered monthly dummy variables to account for possible seasonality. The model specification including all possible terms is:

$$y_t = \alpha_o + \alpha_1 t + \alpha_2 p + \alpha_3 d + \alpha_4 (dt) + \sum_{5}^{16} \alpha_i m_i + \varepsilon_t \tag{4.1}$$

where y_t is the series to be modeled, *t* is a trend variable, *p* is a unit pulse dummy variable, *d* is a unit step dummy variable, (*dt*) is change-in-trend variable associated with a change to trend *t* occurring at time *d*; the m_i are centered monthly dummy variables, the α_i are estimated parameters, and ε_t is a well-behaved error term.

The ARIMA model estimates series through the identification of autoregressive and moving average processes in the series; the integration process controls for stochastic trends in the series. Specification of an ARIMA model entails the selection of the number of lags for the autoregressive and moving average processes. The general notation of an ARIMA model, written in lag-operator notation is:

$$\phi\left(L^p\right)\phi_s\left(L^P\right)\Delta^d \Delta_s^D y_t = \theta\left(L^q\right)\theta_s\left(L^Q\right) \tag{4.2}$$

where □ is the first-order autocorrelation parameter, *θ* is the first-order moving-average parameter, Δ^d, $\Delta^D{}_s$ are the difference and seasonal difference operators, *L* is the lag operator, and y_t is the series under consideration. Centered seasonal dummy variables are also included in each model.

Exponential smoothing models estimate parameters by a process that incorporates a fraction of forecasting error during each step of the forecasting procedure. Seasonality within exponential smoothing models is addressed by use of the Holt-Winters forecasting system.[16] One notation[17] for writing the multiplicative seasonal Holt-Winters exponential smoothing model is:

$$\hat{y}_{t+\tau} = (a_t + b_t\tau)s_{t+\tau-L} \tag{4.3}$$

where a_t, b_t, and s_t are defined as:

$$a_t = \frac{\alpha x_t}{s_{t-L}} + (1-\alpha)(a_{t-1} + b_{t-1})$$

$$b_t = \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1}$$

$$s_t = \frac{\gamma x_t}{a_t} + (1-\gamma)s_{t-L}$$

and $\hat{y}_{t+\tau}$ is the τ-step ahead forecast for series x_t, α, β, and γ are smoothing parameters recursively estimated from the sample, and L is the number of periods comprising the seasonality. a_t represents the level updating equation, b_t represents the trend updating equation, and s_t represents the seasonality updating equation.

To summarize the univariate analysis methodology, each of the three modeling techniques is applied to each series for the pre-intervention period. The best-performing models are used to create forecasts for the post-intervention period; the difference between the forecast and the actual series can then be used to quantify the effect of the rationing program on the series. The percent reduction for each series, for both the nine-

[16] See Gardner (2006) for a history of exponential smoothing, including the development of the Holt-Winters forecasting system.

[17] This presentation is drawn from StataCorp (2005, pp. 271–272) and Gardner (2006, pp. 640-641).

month intervention period and the four-year post-intervention period, is calculated as $\%R = \frac{\sum fore - \sum act}{\sum fore} * 100$, where $\%R$ is the percent reduction,[18] $\sum fore$ is the sum of the forecast values over the specified period, and $\sum act$ is the sum of the actual values over the specified period.[19] This specification of the percent reduction calculation reports deviations from the forecast values as positive percents.

The starting observation for the univariate analysis is June, 1995. The first month of the intervention is June, 2001, and the last date of the intervention is February, 2002. Thus, the pre-intervention period consists of data from June 1995 through May 2001. The length of the post-intervention period is chosen to include four years after the end of the rationing period, starting March, 2002 and ending February, 2006. While the forecast, four-year, post-intervention period can be considered long when created from a six-year, pre-intervention period, the length of the post-intervention period is selected to allow the series ample time to reflect possible changes induced by the intervention. As indicated in chapter 3, the Brazilian economy began to exhibit stronger sustained growth in 2004.

The data used for this analysis are grouped into primary (Group 1) and secondary (Group 2) series. The primary group includes the five electricity series and GDP, as the focus of this dissertation is on the economic effects of the electricity rationing program. Each electricity series is the sum of the four regional series; the southern region is excluded, as the rationing program was not enforced in that region. The secondary group

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[18] Negative values indicate the sum of actual series is greater than the sum of forecast series, during the given period.

[19] The reported percent reductions for the Group 1 variables are calculated on the original series, not on the logged values.

includes eleven additional series that could have been affected directly or indirectly by the rationing program. Table 4.1 presents a summary of the primary and secondary series used in the univariate analysis, with variable names, a brief description, and units. A complete definition for the series is shown in appendix A.1; the appendix also gives a detailed explanation of the creation of the real monthly GDP series.

Table 4.1. Univariate Analysis Variables

Variable Name	Variable Title	Units
Group 1		
elec_tot	Adjusted Total Electricity Consumption	ln(gwh)
elec_ind	Adjusted Industrial Electricity Consumption	ln(gwh)
elec_res	Adjusted Residential Electricity Consumption	ln(gwh)
elec_com	Adjusted Commercial Electricity Consumption	ln(gwh)
elec_oth	Adjusted Other Electricity Consumption	ln(gwh)
gdp	Real GDP	ln(R$, millions)
Group 2		
emplformal	Index of Formal Employment	Index
totsal	Index of Total Industrial Wages	Index
unempsp	Unemployment Rate, Metro. São Paulo	%
caputil	Installed Capacity Utilization	%
indprod	Physical Industrial Production	Index
exchange	Real Effective Exchange Rate Index	Index
exports	Exports	US$ (millions)
imports	Imports	US$ (millions)
capact	Capital Account Balance	US$ (millions)
finact	Financial Account Balance	US$ (millions)
fdirinvt	Foreign Direct Investment	US$ (millions)

The results of the univariate assessment for the primary series are reported in table 4.2, which shows the calculated percent reductions from the forecast values for each model for the nine-month intervention period and the four-year post-intervention period. The forecasts of the intervention period vary little among the forecasts of the three models, with the GDP models showing the greatest variation.[20] The post-intervention period results exhibit greater variation, which is expected given the longer time frame. For the five electricity consumption series, the intervention period measures provide an estimation of the full impact of the rationing program, as opposed to reporting reductions based on the previous year's consumption or target for the rationing program. All five series show the dramatic reduction of electricity consumption during the intervention period compared to forecast consumption. The post-intervention period estimates indicate the sustained intervention-induced reduction in electricity consumption. The results for GDP indicate a reduction between three and six percent during the intervention period, with a sustained reduction from forecast values during the post-intervention period. As mentioned earlier, most of this difference appears related to the large reduction in GDP in June 2001, which corresponds to the smallest reduction of electricity consumption in the intervention period. If the reduced GDP is related to the electricity rationing program, the reduction appears to be a reaction to the announcement and beginning of the rationing program, rather than the actual reduction of electricity consumption. Appendix A.2 presents graphs of the model forecasts.

Table 4.2 Percent Reductions from Forecast Values (Group1)

	Intervention			Post-Intervention		
Variable	OLS	ARIMA	ES	OLS	ARIMA	ES
elec_tot	21.97	22.22	22.27	14.06	14.89	14.63
elec_ind	16.39	18.03	18.92	5.102	8.463	11.35
elec_com	25.24	25.26	25.72	23.37	23.27	25.23
elec_res	30.59	29.28	27.78	24.22	23.02	17.01
elec_oth	18.48	18.37	18.62	10.64	10.21	11.27
gdp	3.112	6.026	6.253	0.367	5.768	8.610

[20] It is important to note that the OLS results are much less sensitive to the month used to initiate the forecasts. Additional tests varying the starting month for the ARIMA and ES models revealed forecasts above and below the observed values in the intervention and post-intervention periods.

Table 4.3 reports the calculated percent reductions for the Group 2 variables. The first three series capture employment and wage effects. Formal employment and industrial wages show small deviations during the intervention, while the unemployment rate indicates a higher rate of unemployment than forecast. This result stems, in part, from the unusually low levels of this indicator during 2000 and the beginning of 2001; these low levels affect the model specifications. A reversal of these low levels just before the intervention period results in forecasts that are much lower than actual values. While the modeling techniques employed in this analysis cannot reveal the underlying factors driving unemployment, one plausible explanation is that unemployment rates were regressing to recent mean values. Explanations attributing unemployment to the rationing program would need to address the delayed effect in labor adjusting to the intervention and that the largest jump in unemployment occurred during the post-intervention period.

Table 4.3. Percent Reduction from Forecast Values (Group 2)

	Intervention			Post-Intervention		
Variable	OLS	ARIMA	ES	OLS	ARIMA	ES
emplformal	0.305	0.262	0.152	-0.243	-1.359	-3.028
totsal	-0.328	1.347	4.382	-1.643	-10.52	-6.586
unempsp	-15.09	-12.55	-13.50	-0.321	-52.84	-34.99
caputil	1.771	1.448	2.472	2.387	-0.817	1.729
indprod	1.247	4.551	5.585	-3.483	1.327	-1.251
exchange	-21.52	-10.10	-0.688	-3.673	-19.18	11.29
exports	-0.579	6.664	10.75	-51.04	-36.96	-31.68
imports	11.82	16.63	23.99	1.670	8.685	28.48
capact	159.1	140.4	147.4	-212.0	-44.58	-81.68
finact	10.17	5.057	24.77	104.9	105.0	102.4
fdirinvt	47.08	15.44	51.51	70.61	36.06	73.13

Continuing with the fourth variable in Table 4.3, the capacity utilization models indicate a small reduction during the intervention period, while the industrial production models reveal considerable differences in the estimated values. The lack of dramatic change in these two series motivates an analysis that attempts to explain how industry maintained its capacity utilization and only slightly reduced its production during the intervention period. Brazil's quasi-fixed exchange rate regime became a floating regime in January 1999. While such a change could stimulate consumption of domestic goods over imported goods, the change could reduce investment due to market uncertainty. Given the regime change, model fit for the exchange rate is poor and should not be considered useful. The export models do not produce consistent estimates for the percent reduction during the intervention; exports increased greatly during the post-intervention period. Imports appear to have decreased during the intervention, which could represent ongoing adjustments to the currency devaluation in 1999. The post-intervention period results for imports are not informative, as the series experienced large changes. The capital account series exhibits a large negative outlier during the intervention period. While nothing suggests this outlier is related to the rationing program, it does render the reported estimates uninformative. The financial account could indicate real or speculative changes related to the rationing program as could the foreign direct investment series. Both the financial account and foreign direct investment series are highly volatile, which detracts from the forecasting ability of the pre-intervention models. While table 4.3 reports large percent reductions for both series, these estimations do not stem from adequate models of the series.

Taken collectively, the results of the univariate analysis indicate that the electricity rationing program resulted in a large and mostly sustained reduction in electricity consumption. The sustained reduction in electricity consumption, rather than a rebound in electricity consumption at the end of the rationing period, is consistent with efficiency-enhancing investments. In addition to efficiency-related investments, behavioral changes to reduce electricity consumption are expected to be lasting. An initial loss of output occurred in the first month of the rationing program, but output does not appear to be affected after that point. Further research is required to identify the relationships between output and electricity consumption. The analysis of the Group 2 series provides a more complete understanding of the Brazilian economy around the time of the intervention, which may have been affected by the ongoing Argentine economic crisis and multiple economic problems affecting the U.S. The electricity rationing program does not appear to have affected the labor market, while capacity utilization and industrial production were slightly below forecast values during the intervention period. The Brazilian currency continued to depreciate during part of the intervention, only to appreciate strongly during the latter half of the intervention period. Exports remained close to forecast values, while imports declined and remained below forecast values for two years after the intervention ended. Thus, based on the results of a univariate analysis, the effects of the rationing program appear limited to the targeted electricity series, with a small, one-month effect on GDP. The design of the analyses conducted this section precluded the identification of relationships between series. Questions regarding possible relationships between output and other factors are addressed in the next section through the application of multivariate analysis techniques.

4.3 Multivariate Analysis

The purpose of the multivariate analysis is to test for impacts of the electricity rationing program on GDP. By using a technique that allows for causality (though without structurally defining causality), a model representing the Brazilian economy in the pre-intervention period can be used to create forecasts of GDP into the intervention period. Comparisons between the forecast series and the observed series provide the basis needed to identify impacts to GDP caused by the rationing program. The model design follows the energy economics literature and includes proxies for output, energy, labor, and capital.

The second goal of this analysis is to identify changes to causal relationships between Brazil's electricity consumption and output. The causal relationships discussed in this section are based on Granger causality (Granger, 1969). This multivariate analysis attempts to identify causal relationships, if any, between the variables included in the model, and it studies possible changes to those relationships. As the electricity rationing program clearly had an impact on electricity consumption, the question remains whether the reduction in electricity consumption had any effect on output or factors of production. The results from this analysis of causal relationships fill a void in the energy economics literature. While the energy economics literature offers many studies employing Granger causality, no study is found that compares the results of an *ex ante* Granger causality analysis to the *ex post* effects of a shock to one or more series. Presently Granger causality test results are used to caution against energy conservation efforts if causality is found from energy consumption to GDP. Building on the literature presented in chapter 2 that highlights explanations of why Granger causality test results may change among different tests, if a shock to one or more series can change the observed relationships, then the present use of Granger causal analysis to recommend energy policy may need to be limited.

4.3.1 Methodology and Data for the Multivariate Analysis

Following the energy economics literature on multivariate models and incorporating the critiques of some models presented in chapter 2, a vector autoregression (VAR) model is the best model specification for the intent of this analysis. The model is estimated for the pre-intervention period and then used to create forecasts for the intervention and post-intervention periods. The forecasts are used to calculate the differences, in percent, between the forecast series and the observed series. The analysis of changes to causal relationships is conducted by testing for Granger causality among the series during the pre-intervention model and comparing these results to tests for Granger causality among the post-intervention period model.

The first step to specify a VAR model is to identify the degree of integration (non-stationarity) of the series to be included in the model.[21] Unless the series is suspected of containing a break, the augmented Dickey-Fuller (ADF) test for a unit root can be performed to check for non-stationarity. The likelihood ratio test is then used to identify the number of lags to include in the VAR model.

The resulting VAR model can be used to create impulse response functions for all series pairs. The impulse response functions are useful to indicate the effects of an innovation in one variable on another. VAR models can create forecasts in the intervention and post-intervention periods. Post-estimation tests on the VAR model can be used to test for Granger causality: unlike a VEC model, a VAR can only exhibit short-

[21] The stationarity tests reveal some series are trend stationary while others follow a unit root process; a VEC model is not appropriate for this combination of series and is not discussed further.

run causality (Engle & Granger, 1987, p. 259). Granger causality tests between two series can indicate the following relationships: no causality, unidirectional causality, or bidirectional causality.

A model of aggregate production that will provide an understanding of the effects of the rationing program can be specified to include electricity, output, employment, and capital utilization. The quadrivariate model can identify possible changes to relationships between electricity and output, and to relationships among other factors of production. The natural logarithm of the real monthly GDP (*gdp*) series is used as a measure of aggregate production. The most complete measure of electricity consumption that was affected by the rationing program can be designated “productive electricity consumption” (*elec_prod*), and is defined as the natural log of the sum of the industrial, commercial, and other series, excluding the southern region:

$$elec\_prod = ln(exp(elec\_ind) + exp(elec\_com) + exp(elec\_oth))$$

The proxy for employed labor in Brazil is the unemployment rate in the greater São Paulo region (*unempsp*). As the greater São Paulo region is Brazil’s largest single labor market, it was affected significantly by the rationing program. *Unempsp* captures both formal and informal labor markets. The index of capacity utilization (*caputil*) is used as a measure of employed capital. As the intention of this study focuses on the related effects of and adjustments to the nine-month rationing program, capital utilization is a better measure of industry’s reaction to the shock than a capital stock variable. Appendix A.1 provides more information and sources for these variables. A VAR model containing the four variables is specified and estimated for the pre-intervention and post-intervention periods.

The pre-intervention model includes the sample period June 1995 until May 2001 and the post-intervention model includes the sample period March 2002 until February 2006.

4.3.2 Multivariate Analysis Results

The unit root test results indicate that *elec_prod* and *gdp* are trend stationary during both periods, and that *caputil* and *unempsp* follow a unit root process during both periods. Table A.5 in appendix A.3 reports the results of the unit root tests. The resulting VAR models include *elec_prod* and *gdp* in levels, and *caputil* and *unempsp* in first differences; exogenous variables included in the model are: a deterministic trend variable, and eleven centered monthly dummy variables. Both the pre-intervention and post-intervention models incorporate three lags of the endogenous series. Post-estimation diagnostic tests indicate that both models are stable, but each model contains autocorrelation at the twelfth lag.

The forecasts from the pre-intervention model are shown in figure 4.1. The observed values for *gdp* are considerably below the forecast series for the first two observations during the intervention period, with the series returning to near-forecast values for the remainder of the intervention. The observed *elec_prod* series is considerably below the forecast series during the intervention period, and its continued performance below forecast values highlight the permanence induced by the rationing program. The *captutil* series, in first differences, performs very close to the forecast values during and after the intervention. Reflecting the poor performance of the model to explain the *unempsp* series, also in first differences, the series performs above forecast values for part of the intervention period, but returns to forecast values around the end of the intervention period; the series oscillates between adequate and poor during the post-intervention period.

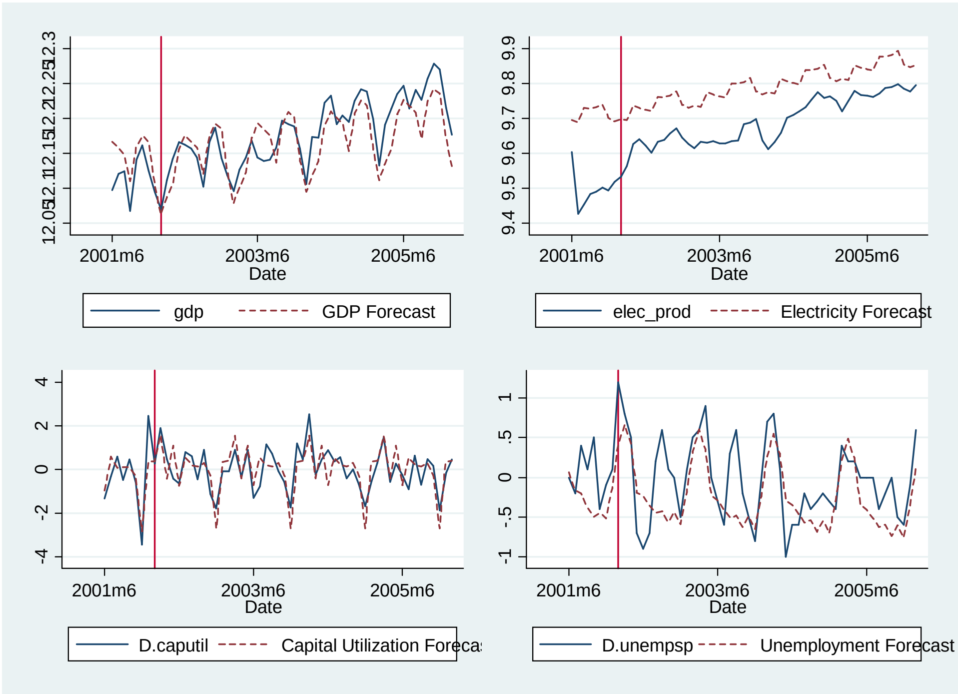

Figure 4.1. Pre-Intervention Multivariate Model Forecasts.

For series that enter the model in levels, the forecasts are used to calculate percent reductions of the observed values. For series that enter the model in first differences, a difference between the forecast and observed series is reported. Table 4.4 reports the percent reductions for the *elec_prod* and *gdp* series, and the differences for the *caputil* and *unempsp* series. The dramatic effects of the intervention on productive electricity consumption are indicated by the large decrease during the intervention period, with the induced effects of the intervention evident in the post-intervention period. GDP performs slightly below forecast values during the intervention period and experiences a slight rebound in the post-intervention period. Changes in capital utilization increase minimally during the intervention period, but fall slightly in the post-intervention period. The model results for changes in unemployment, which are poor for this series, indicate that the series increases more than forecast during the intervention and post-intervention periods.

Table 4.4. Reductions from Forecast Values

	Intervention	Post-Intervention
elec_prod (%)	18.940	9.787
gdp (%)	2.760	-1.395
Δcaputil	-0.047	0.693
Δunempsp	-3.440	-9.295

The pre-intervention model is also used to create impulse response functions, which indicate the expected reaction of the response variable to a shock of the impulse variable. Figure 4.2 shows the impulse response functions for the three variable pairs that include productive electricity consumption. Among these three pairs, the only two relationships that show a response significant at the 95 percent level are for *elec_prod* responding to a shock to *gdp*, and for *elec_prod* responding to a shock to Δ*unempsp*. The lack of a significant response in *gdp* to a shock in *elec_prod* casts doubt on the hypothesis that the electricity rationing program caused the below-forecast performance of GDP during the intervention.

The pre-intervention model results provide useful information that can be used to assess the impact of the intervention, but they do not provide information regarding how the intervention may have changed the existing relationships among the series. A comparison between Granger causality test results for the pre- and post-intervention periods serves as an indication of relationship stability. Table 4.5 presents the results of the Granger causality tests for the pre- and post-intervention periods. The values reported are chi-square values derived from a Wald test on the included parameters. The row series indicates the series whose lags are tested for significance in the column heading's equation.

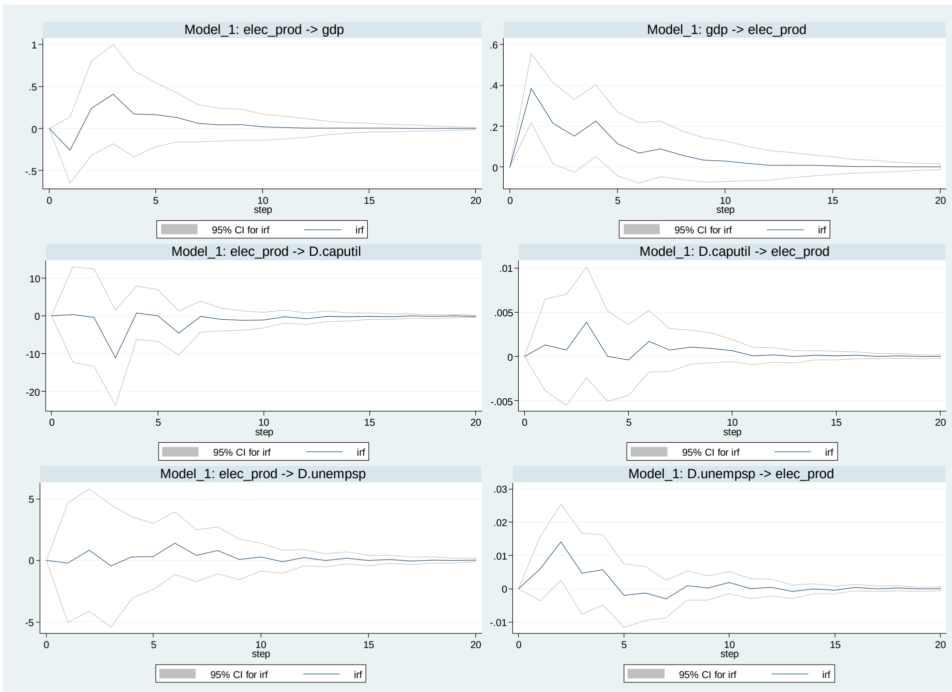

Figure 4.2. Impulse Response Functions for the Pre-Intervention Model.

Table 4.5. Granger Causality Test Results

	gpd	elec_prod	Δcaputil	Δunempsp
Pre-Intervention Period				
gdp		25.45***	0.428	0.552
elec_prod	7.481*		3.531	0.079
Δcaputil	0.69	2.106		3.126
Δunempsp	10.31**	1.973	7.131*	
Post-Intervention Period				
gdp		4.833	1.573	3.445
elec_prod	2.554		22.8***	1.632
Δcaputil	0.233	5.826		6.979*
Δunempsp	0.359	4.822	25.62***	

Significance indicated by: *** p<.01, ** p<.05, * p<.1; all values are χ^2 test statistics.

For the pre-intervention period, the results of the Granger causality tests indicate a bidirectional relationship between GDP and productive electricity. Two additional uni-directional relationships cannot be rejected during the pre-intervention period: changes in unemployment Granger cause GDP, and changes in unemployment Granger cause changes in capacity utilization. For the post-intervention period, the results of the Granger causality tests indicate a bidirectional relationship between changes in unemployment and changes in capacity utilization. An additional, unidirectional causality is found to run from productive electricity to changes in capacity utilization. A comparison between the pre- and post-intervention periods reveals that only the causal relationship of Δ*unempsp* causing Δ*caputil* is found in both periods. Thus, three bi-directional causal relationships found during the pre-intervention period are not found in the post-intervention period, and two bi-directional causal relationships are found in the post-intervention period that are not found in the pre-intervention period.

The results of this comparison illustrate Granger's (1969) concern regarding the use of causality found in one sample to imply the same causality in a different sample. The energy economics literature often ascribes a stable interpretation to the presence of Granger causality, offering policy recommendations based on the identified causal relationships. The results from this assessment of the stability of Granger causality indicate that identified relationships may not be stable over time. While more research is needed to understand what drove the specific changes to the relationships identified in this study, policy recommendations from similar analyses should not be based solely on the outcome of Granger causality tests.

4.3.3 Conclusions from the Multivariate Analysis

The results from the multivariate analyses in this chapter contribute answers to the questions, did the Brazilian electricity rationing program affect GDP?, and did economic relationships existing prior to the intervention change in the post-intervention period? The answers to these question contribute to the better understanding of the specific policy intervention in Brazil; they also contribute to the better understanding of energy shocks in general.

The pre-intervention model, which relates GDP, productive electricity consumption, capacity utilization, and unemployment, identifies a causal relationship from productive electricity consumption to GDP with a two-month lag. However, GDP only performs noticeably below its forecast during the first two months of the rationing program. The pre-intervention model indicates that GDP performed only 2.76 percent below forecast values for the intervention period. These results initially appear to be in conflict: if electricity consumption causally affects GDP with a two-period lag, why does GDP fall the most during the first period of the intervention, in which period electricity consumption falls the least? The additional findings from the comparison of causality results between the pre- and post-intervention models offer a partial explanation. The results of these comparisons indicate that causal relationships can change dramatically between periods, although further research is needed to understand how and why the relationships change. Thus, the finding that causal relationships can change dramatically during a short period can be used as a possible explanation of the contradictory findings: if the causal relationship from electricity consumption to GDP was not stable or if it changed near the beginning of the rationing program, the predictions that GDP should have fallen with a two-period lag would not be expected to hold. The finding that the two models exhibit different relationships is reinforced when the results from this analysis are compared to the study by Schmidt and Lima (2004), who find long-run relationships for their models, whereas this study finds only short-run relationships.

The results from the multivariate analysis extend beyond the specific contributions related to Brazil. The most notable finding from this analysis is that electricity consumption can be greatly reduced with little or no impact on GDP, capacity utilization, or unemployment. While the results of this analysis apply directly to the case of Brazil and should not be viewed as externally valid, the country-specific results are still significant to the energy shocks literature. Economies that employ different factors of production and consume energy differently from the patterns found in Brazil may not be able to adapt to an electricity rationing program modeled after the Brazilian program; however, economies that do appear roughly similar to the Brazil could be expected to have similar success if faced with the need to curtail rapidly electricity consumption.

Studies found in the energy economics literature often ascribe policy implications to the results of Granger causality tests. The finding that Granger causality test results can change dramatically between two samples highlights the need for caution when prescribing policy recommendations based on such analyses. The results from this study show that three out of four causal relationships in the pre-intervention period ceased to exist in the post-intervention period, while two new causal relationships were found in the post-intervention period. While it is possible that these findings are specific to Brazil, more research is needed to understand better how such causal relationships evolve in any given economy.

CHAPTER 5

EFFECTS OF A NEGATIVE INPUT SHOCK ON INTERFACTOR AND INTERFUEL SUBSTITUTION

5.1 Introduction

This chapter investigates how substitution among factors of production and fuel inputs may have facilitated industrial production during the dramatic reduction of electricity consumption by the Brazilian economy in 2001. More specifically, this chapter first estimates fuel and factor elasticities of substitution for the industrial sector before the rationing program was implemented, and then it uses these elasticities to predict expected consumption quantities for the fuel and factor inputs. Defining these two outcomes in more detail, the first part of this analysis estimates factor and fuel elasticities of substitution for the Brazilian economy for the pre-intervention period. Two extensions to these base estimations include the construction of time series of elasticities and the estimation of the elasticities for the overall period. These extensions provide an understanding of historical volatility of the elasticities and highlight any abrupt changes to the elasticities plausibly related to the intervention. The second part of this analysis employs the estimated price elasticities to predict changes to input quantities for the year of the intervention period. A comparison between the observed and predicted quantities consumed characterizes the role of substitution in allowing the Brazilian economy to adjust to the negative input shock.

This chapter contributes to the understanding of the effects of the electricity rationing program on the Brazilian economy by estimating elasticities of substitution between factors and fuels commonly used in the industrial sector, and by creating a plausible explanation of how the economy reacted to the negative input shock. This analysis also contributes to the energy economics literature, as the current literature does not contain estimations of elasticities of substitution for the Brazilian economy, nor does it contain quantitative analyses of changes to elasticities of substitution for an observed input shock.

5.2 Methodology and Data

This section presents the methodology to estimate the Morishima elasticities of substitution (MES)[22] for the factor and fuel inputs; the analysis can be described as consisting of four parts. The first analysis estimates the MES for the base model, which covers the pre-intervention period of 1981-2000. This analysis is also applied to the truncated series 1991-2000, to eliminate the period of substantial state intervention in the industrial sector. The comparison of the truncated results with the results from the longer sample provides an understanding of how model parameters vary based on the sample, and how such parameter variations affect elasticities of substitution. The next step in the analysis is to extend these results to produce time series of elasticities. The time series of elasticities are based on the estimated model's parameters and data for each year of the given model. The time series provide an indication of the historical volatility of the elasticities, which is useful when using elasticities to understand adjustments to an input

[22] See Blackorby and Russell (1989) for a comparison of the MES to other elasticities of substitution. By construction, the MES are not symmetric to price or quantity changes in its inputs, which is an important characteristic for the analysis of an input shock.

shock. The third analysis creates a further extension of the base model by calculating the MES for the overall period 1981-2007, which includes the pre- and post-intervention periods. The purpose of the overall analysis is to highlight any abrupt changes to the elasticities around the intervention. The fourth analysis uses price elasticities of demand from the pre-intervention model to predict the factor and fuel input quantities based on observed price changes. A comparison between the observed and expected quantities consumed provides an assessment of the role of substitution in allowing the economy to adjust to the reduced electricity consumption.

The starting point for the estimation of elasticities of substitution is the translog cost function.[23] The translog cost function approach stems from Christensen, Jorgensen, and Lau (1973) and Berndt and Wood (1975). The translog approach uses an aggregate production function that combines multiple homothetic inputs to generate the aggregate output for the given economy. The input prices and output level are assumed to be exogenously determined; the production function is assumed to be twice differentiable. Defining a production function that has capital, labor, and energy as factor inputs and assuming that the function is weakly separable in the energy input, the energy input can be written as a function of its homothetic subcomponents. Defining the energy input's subcomponents to be electricity, petroleum, coal, and natural gas, the resulting production function can be written as:

$$Q = f(K, L, E(elec, petr, coal, ngas))$$

[23] While the translog cost model is still widely used, it is not without problems; recent studies compare the translog to other approaches and highlight its comparative strengths and weaknesses (Feng & Serletis, 2008; Serletis, Timilsina, & Vasetsky, 2009).

where Q is aggregate output, K is capital, L is labor, E is energy, $elec$ is electricity, $petr$ is petroleum, $coal$ is coal, and $ngas$ is natural gas. The assumption of cost-minimizing behavior for this production function allows its dual to be written as a twice-differentiable cost function:

$$C = c(P_K, P_L, P_E(P_{elec}, P_{petr}, P_{coal}, P_{ngas}))$$

where C is the total cost of output and the P_i are the prices of the three factor inputs and four fuel inputs. The transcendental logarithmic cost function, or translog cost function, is a local, second-order approximation to such a cost function (Christensen et al., 1973). For the three factors of production, the non-homothetic translog total cost function can be written as:[24]

$$\begin{aligned} LnC = {} & \beta_0 + \sum_{i=1}^{m} \beta_i LnP_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} \beta_{ij} LnP_i LnP_j + \beta_t t + \frac{1}{2}\beta_{tt} t^2 \\ & + \beta_Y LnY + \frac{1}{2}\beta_{YY}(LnY)^2 + \sum_{i=1}^{m} \beta_{iY} LnP_i LnY + \sum_{i=1}^{m} \beta_{it} t LnP_i + \beta_{Y} t LnY \end{aligned} \tag{5.1}$$

where C is total costs, P_{ij} is the price of the *ij*-th input of capital, labor, or energy, t represents technology through a time trend, and Y is output; *Ln* indicates the natural logarithm operator and β_i is the *i*-th parameter to be estimated. Symmetry of this specification requires that all $\beta_{ij} = \beta_{ji}$ for $i \neq j$. The assumption of homogeneity of degree one in prices, given output, implies:

$$\sum_{i=1}^{m} \beta_i = 1 \qquad \sum_{i=1}^{m} \beta_{it} = 0 \qquad \sum_{i=1}^{m} \beta_{ij} = \sum_{j=1}^{m} \beta_{ij} = \sum_{i=1}^{m} \beta_{iY} = 0.$$

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[24] The explication of the translog cost function and associated constraints follow Berndt's concise presentation (1991, pp. 469-470).

Applying Shephard's lemma produces a system of cost-minimizing demand functions, which can be written as factor share equations:

$$S_i = \beta_i + \beta_{iK} LnP_K + \beta_{iL} LnP_L + \beta_{iE} LnP_E + \beta_{iY} LnY + \beta_{it} t \tag{5.2}$$

where *i* is an index over the three factor inputs, $S_i \equiv \frac{P_i X_i}{C}$, with P_i being the *i*-th input price, X_i is the quantity of the *i*-th input, and *C* is the total cost. The sum of the factor cost shares equals one by construction.

Having specified a cost function that is assumed separable in energy prices, a homothetic aggregate energy price index function can be specified as a translog cost function:

$$LnP_E = \gamma_E + \sum_{i=1}^{n} \gamma_i LnP_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} LnP_i LnP_j + \sum_{i=1}^{n} \gamma_{it} tLnP_i \tag{5.3}$$

where i spans the four fuel inputs. Assuming homogeneity of degree one and applying Shephard's lemma to the energy price index function lead to the system of fuel share equations:

$$S_i = \gamma_i + \gamma_{ie} LnP_e + \gamma_{ip} LnP_p + \gamma_{ic} LnP_c + \gamma_{ig} LnP_g + \gamma_{it} t \tag{5.4}$$

where *i* is an index over the four fuel inputs and subscripts *e*, *p*, *c*, and *g* refer to electricity, petroleum, coal, and natural gas; *t* refers to fuel technology captured through a linear trend. The assumption of homogeneity of degree one in prices implies

$\sum_{i=1}^{m} \gamma_i = 1, \gamma_{ij} = \gamma_{ji}$ for $i \neq j$, and $\sum_{i=1}^{m} \gamma_{ij} = \sum_{j=1}^{m} \gamma_{ij} = 0$.

The first step in the estimation procedure is to apply the stated constraints to the fuel share equations and then, in order to maintain linear independence, estimate three of the four equations simultaneously. Following Christensen, Jorgenson, and Lau (1973), the endogenous variables on the right hand side of the *n-1* share equations are divided by the endogenous variable associated with the dropped equation. The natural gas equation is dropped from the fuel model and the capital equation is dropped from the factor model.[25] Each equation includes a random disturbance term and the disturbance terms can be correlated with the other equations in the given model. Given the system of equations and the imposed constraints, Zellner's iterated, three-stage, least squares estimation procedure is an appropriate technique for this estimation.[26] The parameter estimates from the fuel share equations are placed into the aggregate energy price index function, allowing $Ln\hat{P}_E$ to be calculated.[27] $Ln\hat{P}_E$ is then included in the factor share equation for energy and the same estimation procedure is used to determine the parameters for the factor share model.

The MES can be calculated as $M_{ij} = \varepsilon_{ji} - \varepsilon_{ii}$, where $\varepsilon_{ij} = \sigma_{ij} S_j$, $\varepsilon_{ii} = \sigma_{ii} S_i$, and where $\sigma_{ij} = 1 + \frac{\beta_{ij}}{S_i S_j}$ and $\sigma_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2}$; the β_{ij} are the corresponding parameters from the factor or fuel share equation and the $S_{i,j}$ are the factor or fuel shares calculated

[25] Subsequently, the electricity, petroleum, and coal variables are divided by the natural gas variable in the fuel model, and the labor and energy variables are divided by the capital variable in the factor model.

[26] See Berndt (1991, pp. 449-487) for a detailed motivation and discussion of Zellner's technique applied to the estimation of factor and fuel share parameters.

[27] The constant γ_E is chosen so that $\hat{P}_E$ equals 1 in 1985.

at the series' mean.[28] Significance estimations and confidence interval can be created from the variance and covariance matrices for the included parameter and related sample data. Following Anderson and Thursby (1986), actual share values are used for calculations requiring significance parameters, as the authors show that actual values are more likely to meet normality assumptions than predicted shares. Time series for the various MES are created by replacing the average share variable, S_i, with the observed share value for a given year.

This methodology uses a cost-minimizing function, which requires the assumption that input prices are exogenous. The electricity rationing program did not directly affect the price of electricity, but rather it imposed penalties if the consumer consumed above its target. A similar analysis could be performed through the use of a production function, which requires the assumption that input quantities are exogenous. This assumption would be harder to maintain, given that changes in electricity consumption might be expected to affect the quantities consumed of other inputs. A comparison between the two approaches may not prove useful, as the elasticities of substitution from the two methods can be expected to differ dramatically.[29]

The fourth part of this analysis utilizes the estimated price elasticities to calculate predicted input quantities for 2001, namely those that would be expected to be consumed given the observed price changes between 2000 and 2001. As indicated above, the own- and cross-price elasticities of demand are calculated as an intermediate step in the MES

[28] This standard approach used to calculate the MES utilizes the intermediate calculations of the Allen/Uzawa partial elasticity of substitution (sigma) and price elasticities of demand (epsilon).

[29] That a production function and corresponding cost function are not self-dual is discussed in Pindyck (1979a, 1979b) and shown by Burgess (1975).

calculation. By definition, the price elasticity ε_{ij} is the relative percent change in quantity *i*, for a given percent change in price *j*.[30] Utilizing the estimated ε_{ij}, this definition can be solved for the quantity of interest based on either the own-price elasticity or the cross-price elasticity:

$$Q_{2001,i} = \frac{\varepsilon_{ii} Q_{2000,i} \left(P_{2001,i} - P_{2000,i}\right)}{P_{2000,i}} + Q_{2000,i} \tag{5.5}$$

$$Q_{2001,i} = \frac{\varepsilon_{ij} Q_{2000,i} \left(P_{2001,j} - P_{2000,j}\right)}{P_{2000,j}} + Q_{2000,i} \tag{5.6}$$

where Q is a fuel or factor input quantity and P is a fuel or factor input price. The predicted $Q_{2001,i}$ can then be presented in percentage terms of the actual input quantity consumed in 2001.

The data used for this study include series for output, capital, labor, and four types of energy. All series include annual observations between 1981 and 2007. The Price of Investment for Brazil, from the Penn World Tables, is used as a proxy for the price of capital (Heston, Summers, & Aten, 2009). Net fixed capital stock, for machines and equipment, in billions of R$ 2000 (Capital fixo - estoque líquido - máquinas e equipamentos - R$ de 2000 (bilhões)), index of average weekly hours worked (Horas pagas - indústria geral - índice), average hourly wage, in R$ 2002 (Salário hora - media R$ Jan2002), percent of the population working in industry (População ocupada - indústria transformação - RMs), and population employed (População ocupada) are obtained from IPEAdata (2011). GDP, in R$ 2008, is obtained from the Brazilian Central

[30] See Thompson (1997) for a concise summary of MES, ε_{ij}, and other related definitions.

Bank (SGS, 2009). The quantities for electricity (ELETRICIDADE), petroleum (ÓLEO COMBUSTÍVEL), coal (CARVÃO MINERAL + COQUE DE CARVÃO MINERAL), natural gas (GÁS NATURAL), in 10^3 tons of oil equivalent, and the prices for industrial electricity (ELETRICIDADE INDUSTRIAL), petroleum (ÓLEO COMBUSTÍVEL BPF), steam coal (CARVÃO VAPOR), and natural gas (GÁS NATURAL), in current US$ per barrel of oil equivalent, are obtained from the National Energy Balance ("Balanço Energético Nacional," 2010). The product of the price of capital and net fixed capital stock equals the total cost of capital. The product of hours worked, hourly wage, an assumed 48 weeks worked per year, the percent of workers in industry, and the average population employed equals the total cost of labor. The total cost of energy is the sum of the price of each fuel source multiplied by its price. All monetary values are deflated and/or converted into constant Brazilian *reais*, with a base year of 2000. The sum of the total costs of capital, labor, and energy defines total cost.

5.3 Results

This section presents the results for the four analyses detailed in section 5.2. Section 5.3.1 presents the results from the estimation of the base and truncated models, along with the calculated MES. Section 5.3.2 presents the time series of MES stemming from the base model. Section 5.3.3 presents the results from the overall model, including graphs of the MES time series. Section 5.3.4 presents the percent deviations from the expected input quantities, as calculated from the price elasticities.

5.3.1 Pre-Intervention Period Model Results

This section reports the estimated Morishima factor and fuel elasticities of substitution for the Brazilian economy for the pre-intervention period, 1981-2000. In order to highlight the effects of a changing economy on these elasticities, the results from an analysis on a sub-period, 1991-2000, are also reported. The first step to calculate the MES is to estimate the fuel share model, also called the energy price index function.[31] The estimated parameter results for the fuel share model are presented in table 5.1, and the results for the factor share model are presented in table 5.2. The *i_j* notation used for the coefficients in the table indicates the *j*-th coefficient in the *i*-th share equation.

Table 5.1. Fuel Share Equation Estimation Results

	1981-2000		1991-2000	
Est. Gamma	Coefficient	Std. Errors	Coefficient	Std. Errors
elec_elec	0.18143***	(0.0343)	0.14028***	(0.0183)
elec_petr	-0.1051***	(0.0398)	-0.0408**	(0.0162)
elec_coal	-0.0581***	(0.0070)	-0.0611***	(0.0041)
elec_ngas	-0.0181***	(0.0040)	-0.0382***	(0.0062)
elec_t	0.00274*	(0.0014)	-0.0024***	(0.0007)
elec_con	0.42687***	(0.0311)	0.55056***	(0.0303)
petr_petr	0.09910**	(0.0475)	0.01953	(0.0198)
petr_coal	0.00124	(0.0087)	0.00123	(0.0043)
petr_ngas	0.00475	(0.0079)	0.02009	(0.0140)
petr_t	-0.0058***	(0.0017)	-0.0002	(0.0007)
petr_con	0.36595***	(0.0363)	0.20598***	(0.0268)
coal_coal	0.06852***	(0.0040)	0.07111***	(0.0024)
coal_ngas	-0.0115***	(0.0032)	-0.0111***	(0.0035)
coal_t	0.00006	(0.0003)	-0.0002	(0.0001)
coal_con	0.19723***	(0.0088)	0.20671***	(0.0071)
ngas_ngas	0.02498***	(0.0062)	0.02932*	(0.0153)
ngas_t	0.00301***	(0.0002)	0.00295***	(0.0002)
ngas_con	0.00992	(0.0079)	0.03672***	(0.0106)
Observations	20		10	

Significance indicated by: *** p<.01, ** p<.05, * p<.1

[31] While the fuel model is separate from the factor cost function, it is estimated, in part, to create the energy price index; it is often called the energy price index function.

Table 5.2. Factor Share Equation Estimation Results

	1981-2000		1991-2000	
Est. Beta	Coefficient	Std. Errors	Coefficient	Std. Errors
KK	0.00700	(0.0146)	0.03363	(0.0374)
KL	-0.0179	(0.0144)	-0.0419	(0.0314)
KE	0.01091***	(0.0039)	0.00830	(0.0206)
KY	-0.5460***	(0.0864)	-0.6809***	(0.1473)
Kt	0.01206***	(0.0022)	0.01838***	(0.0042)
K_con	15.5245***	(2.3301)	19.0505***	(3.8768)
LL	0.02740*	(0.0148)	0.05722	(0.0389)
LE	-0.0094***	(0.0035)	-0.0152	(0.0213)
LY	0.53094***	(0.0877)	0.57499***	(0.1320)
Lt	-0.0119***	(0.0022)	-0.0155***	(0.0039)
L_con	-14.111***	(2.3645)	-15.219***	(3.4945)
EE	-0.0014	(0.0040)	0.00698	(0.0185)
EY	0.01510	(0.0191)	0.10592	(0.0951)
Et	-0.0000	(0.0005)	-0.0027	(0.0026)
E_con	-0.4134	(0.5154)	-2.8315	(2.5126)
Observations	20		10	

Significance indicated by: *** p<.01, ** p<.05, * p<.1

While these parameters are estimated for the purpose of calculating the MES, they also explain the behavior of a given share equation, in the simultaneous system of the remaining share equations. For example, the coefficient of -0.1051 on the *elec_petr* parameter in table 5.1 indicates that when the price of petroleum increases by 1 percent, the share of electricity consumed decreases by 0.1051. Fourteen of the eighteen parameter estimates are significant at the 10% level for the fuel share model for the 20-year estimation; thirteen parameters are significant for the 10-year estimation. For the factor share model, nine of the fifteen parameters are significant at the 10% level in the 20-year estimation and six parameters are significant in the 10-year estimation. The lack of significance of some parameters could stem from numerous reasons. For example, reasons might include poor data, regulated fuel markets, and path dependence within a given fuel market.[32]

Table 5.3 reports the fuel and factor Morishima elasticities of substitution for the two estimation periods. Interpretation of the results is aided by the definition of the MES, which is that an MES_{ij} "measures the percentage change in the ratio of input *j* to input *i* when the price of input *i* alters" (P. Thompson & Taylor, 1995, p. 566). This definition also indicates that, for an $MES_{ij} > 0$, *i* and *j* are substitutes, where if $MES_{ij} < 0$, *i* and *j* are complements. A comparison between the two sample periods reveals that more fuel MES are significant in the period 1991-2000, which probably reflects the lower state intervention in the industrial sector during that period; more factor MES are significant during the 1981-2000 period, which may reflect the higher number of observations of these slowly-changing shares. The majority of the fuel MES are substitutes in the shorter period, and all the factor MES are substitutes in the longer period. The results also reveal asymmetry between some inputs. For example, the *coal_ngas* MES indicates that these fuels are complements when the price of coal changes, but the *ngas_coal* MES indicates an effect not different from zero when the price of natural gas changes. These MES provide an understanding of the existing ability to substitute fuels and factors in the Brazilian economy before the rationing period in 2001.

[32] An example of such path dependence could include the decision to use coal for process heating in a given industrial facility. Such decisions are usually made under long-term considerations and typically include long-term fuel supply contracts and the purchase of coal-specific equipment; short-term price fluctuations may not have significant effects on coal's usage.

Table 5.3. Fuel and Factor Morishima Elasticities of Substitution

	1981-2000		1991-2000	
Morishima	Coefficient	Std. Errors	Coefficient	Std. Errors
elec_petr	0.16868	(0.2668)	0.53380***	(0.1325)
petr_elec	0.30801	(0.3163)	0.81247***	(0.1506)
elec_coal	-0.1134	(0.0759)	-0.0389	(0.0695)
coal_elec	-0.0947	(0.0605)	-0.0701*	(0.0378)
petr_coal	0.47281	(0.3723)	0.88474***	(0.1447)
coal_petr	-0.0068	(0.0901)	0.02082	(0.0465)
elec_ngas	0.19420	(0.1342)	-0.1524	(0.1690)
ngas_elec	0.21343	(0.1876)	0.20992	(0.3891)
petr_ngas	0.59924	(0.3906)	1.37364***	(0.4479)
ngas_petr	0.26488	(0.2291)	0.39764	(0.4777)
coal_ngas	-0.3667***	(0.1181)	-0.2688***	(0.0950)
ngas_coal	0.06731	(0.2053)	0.10643	(0.4059)
EL	1.02848***	(0.2501)	0.55189	(1.0076)
LE	0.28177	(0.2457)	-0.1261	(1.2374)
LK	0.81733***	(0.1045)	0.59737**	(0.2723)
KL	0.88635***	(0.1021)	0.70140***	(0.2329)
EK	1.09751***	(0.2425)	0.65592	(0.9498)
KE	1.63306***	(0.2357)	1.37948	(1.0703)
Observations	20		10	

Significance indicated by: *** p<.01, ** p<.05, * p<.1

5.3.2 Pre-Intervention Model Time Series

Morishima elasticities of substitution are calculated for each annual observation by replacing the average share variable with share values for a specific observation. In addition to providing a point estimate of the MES for each year, creating time series of elasticities highlights the variable nature of these measures. Table 5.4 displays the time series for the fuel Morishima elasticities of substitution.

Table 5.4. Fuel Morishima Elasticities of Substitution

Year	elec_petr	petr_elec	elec_coal	coal_elec	elec_ngas	ngas_elec
1981	0.3917	0.5409	-0.6417	-0.6638	-0.1559	-0.1894
1982	0.3566	0.5033	-0.1348	-0.0773	-0.1257	-0.1634
1983	0.3355	0.4814	-0.0647	0.0004	0.0310	0.0451
1984	0.2887	0.4304	-0.0497	0.0021	0.1088	0.1284
1985	0.2358	0.3749	-0.0855	-0.0533	0.1110	0.1116
1986	0.1038	0.2433	-0.1281	-0.1204	0.0803	0.0443
1987	0.0326	0.1730	-0.3115	-0.3438	0.1187	0.0859
1988	0.0373	0.1792	-0.0476	-0.0289	0.0059	-0.0631
1989	0.1135	0.2511	-0.2605	-0.2796	-0.0554	-0.1474
1990	0.0203	0.1605	-0.4568	-0.5172	0.1416	0.1142
1991	0.0634	0.2038	-0.1846	-0.1902	0.1316	0.1098
1992	0.0130	0.1552	-0.1521	-0.1545	0.1211	0.0916
1993	0.0867	0.2285	-0.0504	-0.0259	0.2155	0.2347
1994	-0.0214	0.1262	0.1251	0.1801	0.2120	0.2289
1995	0.0524	0.1979	0.1208	0.1800	0.2238	0.2525
1996	0.0741	0.2182	0.0429	0.0879	0.2826	0.3328
1997	0.0358	0.1799	-0.0400	-0.0150	0.2999	0.3490
1998	0.0055	0.1488	-0.1918	-0.1996	0.2854	0.3204
1999	0.0338	0.1776	-0.2365	-0.2473	0.4062	0.4940
2000	0.0685	0.2142	-0.1871	-0.1800	0.4840	0.6146

Table 5.4. Continued

Year	petr_coal	coal_petr	petr_ngas	ngas_petr	coal_ngas	ngas_coal
1981	0.7515	-0.5594	0.9435	-0.1446	-1.0999	-0.4222
1982	0.6963	0.0238	0.8941	-0.1177	-0.5057	-0.2988
1983	0.6697	0.1000	0.8293	0.0914	-0.3335	-0.0782
1984	0.6080	0.0964	0.7521	0.1758	-0.3000	0.0025
1985	0.5446	0.0369	0.6911	0.1606	-0.3688	-0.0259
1986	0.4030	-0.0347	0.5613	0.0981	-0.4744	-0.1077
1987	0.3317	-0.2601	0.4781	0.1425	-0.6818	-0.1052
1988	0.3350	0.0564	0.5154	-0.0064	-0.4341	-0.2002
1989	0.4115	-0.1952	0.6034	-0.0942	-0.7238	-0.3268
1990	0.3209	-0.4341	0.4588	0.1712	-0.8430	-0.1066
1991	0.3625	-0.1053	0.5071	0.1652	-0.5153	-0.0546
1992	0.3115	-0.0699	0.4603	0.1492	-0.4890	-0.0671
1993	0.3884	0.0610	0.5121	0.2895	-0.2904	0.0992
1994	0.2820	0.2681	0.4106	0.2885	-0.0873	0.1281
1995	0.3569	0.2689	0.4809	0.3091	-0.0744	0.1526
1996	0.3787	0.1763	0.4857	0.3884	-0.1294	0.2173
1997	0.3387	0.0721	0.4409	0.4060	-0.2270	0.2152
1998	0.3071	-0.1143	0.4115	0.3784	-0.4273	0.1543
1999	0.3401	-0.1605	0.4105	0.5510	-0.3925	0.3207
2000	0.3815	-0.0904	0.4301	0.6707	-0.2653	0.4543

Table 5.5 displays the time series for the factor Morishima elasticities of substitution. Both sets of results are for the 20-year estimation model. Inspection of these results indicates that it is not uncommon for a given pair of inputs to switch between being complements and substitutes.[33] Some pairs do not change during the estimation period, as in the case of *petr_elec*, while others change multiple times across the sample, as in the case of *coal_petr*. A comparison between table 5.4 and table 5.5 reveals that the factor elasticities are much more stable than the fuel elasticities, with only the *L_E* pair switching to complements for a five-year period during the twenty years of the sample.

Table 5.5. Factor Morishima Elasticities of Substitution

Year	K_L	L_K	K_E	E_K	L_E	E_L
1981	0.8823	0.8112	1.6046	1.0937	0.3003	1.0226
1982	0.8779	0.8046	1.6887	1.1046	0.2204	1.0312
1983	0.8609	0.7788	1.9592	1.1396	-0.0408	1.0575
1984	0.8635	0.7827	1.9235	1.1349	-0.0058	1.0542
1985	0.8881	0.8200	2.0149	1.1475	-0.0474	1.0794
1986	0.9200	0.8678	2.0515	1.1539	-0.0299	1.1017
1987	0.8971	0.8335	1.7485	1.1130	0.1980	1.0494
1988	0.8916	0.8253	1.6744	1.1031	0.2540	1.0367
1989	0.9012	0.8397	1.6160	1.0958	0.3195	1.0343
1990	0.8960	0.8319	1.6105	1.0949	0.3163	1.0308
1991	0.8840	0.8138	1.7497	1.1127	0.1768	1.0425
1992	0.8676	0.7889	1.6489	1.0991	0.2391	1.0205
1993	0.8659	0.7864	1.5622	1.0878	0.3119	1.0082
1994	0.8781	0.8047	1.3411	1.0593	0.5229	0.9859
1995	0.8890	0.8212	1.5183	1.0826	0.3855	1.0149
1996	0.8926	0.8267	1.5034	1.0808	0.4041	1.0149
1997	0.8897	0.8223	1.5096	1.0815	0.3942	1.0141
1998	0.8805	0.8084	1.5417	1.0854	0.3521	1.0134
1999	0.8766	0.8026	1.7118	1.1075	0.1983	1.0335
2000	0.8835	0.8130	1.6014	1.0933	0.3049	1.0228

[33] The signs of the MES are taken as given; standard errors are not calculated for these values.

5.3.3 Overall Model

This section reports the results of the overall model, which consists of the period 1981-2007. The purpose of this extension is to highlight any abrupt changes to the MES during or following the electricity rationing program. These results constitute a qualitative test of the hypothesis that the industrial sector was capable of absorbing the reduction in electricity consumption through existing channels of input substitution. If the MES do not exhibit significant changes at the time of the intervention, the explanation is accepted that the economy was able to reduce electricity consumption by existing means of substitution, waste reduction, installation of more efficient capital in industrial processes, or other means. Abrupt changes to the MES would be evidence that the rationing program was quite onerous on industry, requiring dramatic changes to its substitution behavior.

Table 5.6 reports the estimation results for the overall model. Thirteen of the fifteen factor model parameters are statistically significant at the 10 percent level and fourteen of the eighteen fuel model parameters are statistically significant at the same level. A comparison between these model estimates and the estimates reported for the 20-year period reveals similar parameter estimates. Table 5.7 shows the calculated factor and fuel MES for the 27-year period. Five of the six factor elasticities are significant and correspond to the significant elasticities for the 20-year model. Five of the twelve fuel elasticities are significant, four more than found for the 20-year model.

Table 5.6. Factor and Fuel Share Equation Estimation Results

	1981-2007			1981-2007	
Est. Beta	Coefficient	Std. Errors	Est. Gamma	Coefficient	Std. Errors
KK	0.00550	(0.0128)	elec_elec	0.17940***	(0.0223)
KL	-0.0245**	(0.0114)	elec_petr	-0.0878***	(0.0266)
KE	0.01907***	(0.0047)	elec_coal	-0.0570***	(0.0048)
KY	-0.5728***	(0.0764)	elec_ngas	-0.0345***	(0.0056)
Kt	0.01149***	(0.0019)	elec_t	0.00226***	(0.0006)
K_con	16.2733***	(2.0571)	elec_con	0.43660***	(0.0242)
LL	0.03437***	(0.0111)	petr_petr	0.07676**	(0.0344)
LE	-0.0097***	(0.0036)	petr_coal	0.00226	(0.0064)
LY	0.52738***	(0.0723)	petr_ngas	0.00885	(0.0111)
Lt	-0.0112***	(0.0018)	petr_t	-0.0066***	(0.0008)
L_con	-14.010***	(1.9472)	petr_con	0.35375***	(0.0295)
EE	-0.0092**	(0.0045)	coal_coal	0.06821***	(0.0029)
EY	0.04542*	(0.0236)	coal_ngas	-0.0134***	(0.0034)
Et	-0.0002	(0.0006)	coal_t	-0.0000	(0.0001)
E_con	-1.2630**	(0.6326)	coal_con	0.19664***	(0.0067)
			ngas_ngas	0.03913***	(0.0084)
			ngas_t	0.00438***	(0.0002)
			ngas_con	0.01299	(0.0088)
Observations	27			27	

Significance indicated by: *** p<.01, ** p<.05, * p<.1

Table 5.7. Factor and Fuel Morishima Elasticities of Substitution

	1981-2007			1981-2007	
Morishima	Coefficient	Std. Errors	Morishima	Coefficient	Std. Errors
EL	1.43362***	(0.2450)	elec_petr	0.19987	(0.1981)
LE	0.29008	(0.2085)	petr_elec	0.39545	(0.2519)
LK	0.77491***	(0.0766)	elec_coal	-0.1466**	(0.0624)
KL	0.85404***	(0.0798)	coal_elec	-0.1560***	(0.0483)
EK	1.51275***	(0.2409)	petr_coal	0.55176*	(0.2951)
KE	1.99758***	(0.2557)	coal_petr	-0.0635	(0.0710)
			elec_ngas	0.04435	(0.1174)
			ngas_elec	0.14785	(0.1720)
			petr_ngas	0.69799*	(0.3844)
			ngas_petr	0.25098	(0.2373)
			coal_ngas	-0.3550***	(0.0803)
			ngas_coal	-0.0178	(0.1773)
Observations	27			27	

Significance indicated by: *** p<.01, ** p<.05, * p<.1

Time series of the fuel elasticities are created for the overall model; graphs of the time series are shown in figure 5.1. The vertical lines in the graphs are drawn for the years 2000 and 2003 in order to surround the start of the intervention in 2001 and the end of the intervention in 2002. Thus, any abrupt change to the elasticities as a result of the intervention is expected to be inside the vertical lines. None of the graphs of the fuel elasticities in figure 5.1 indicates an abrupt change during the intervention period. What is more noticeable is the marked change in some of the series around 2004, when Brazil began to experience higher rates of economic growth.

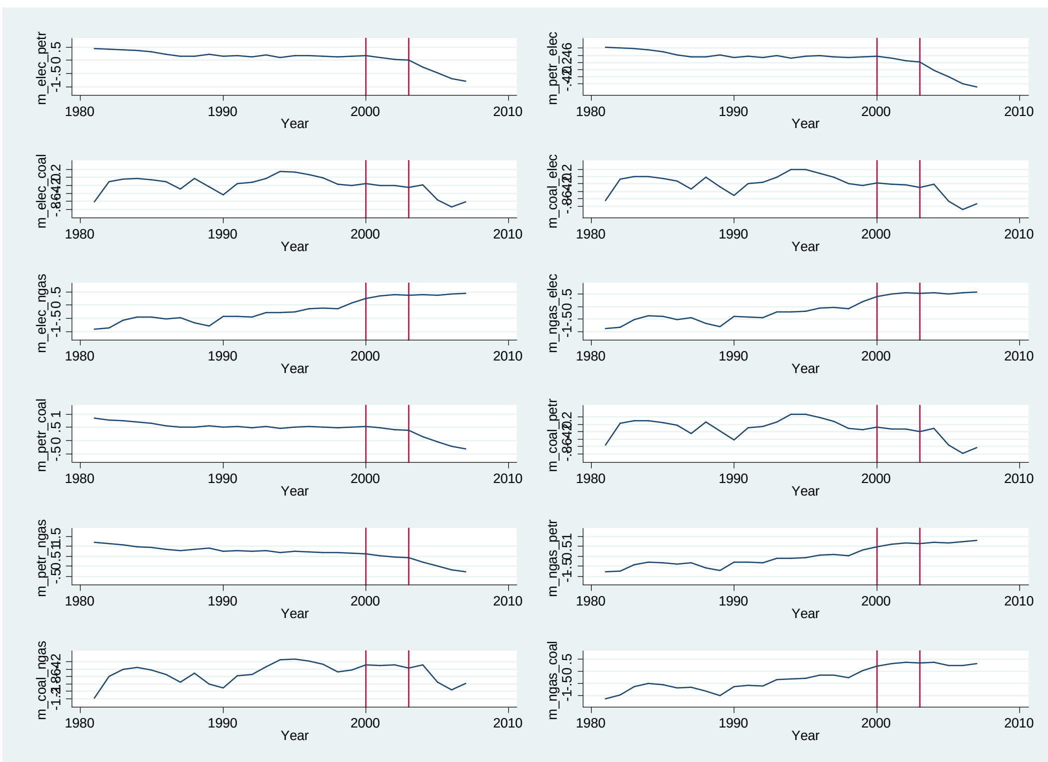


Figure 5.1. Overall Fuel Morishima Elasticities of Substitution.

The stability of the fuel MES around the time of the intervention undermines the notion that the composition of fuel consumption in the industrial sector changed dramatically in response to the negative input shock. These findings support the view that the rationing program was not overly onerous to the industrial sector's consumption of fuel inputs: the conditions of the rationing program appear to have been met by means that did not alter traditional substitution behavior between these fuels.

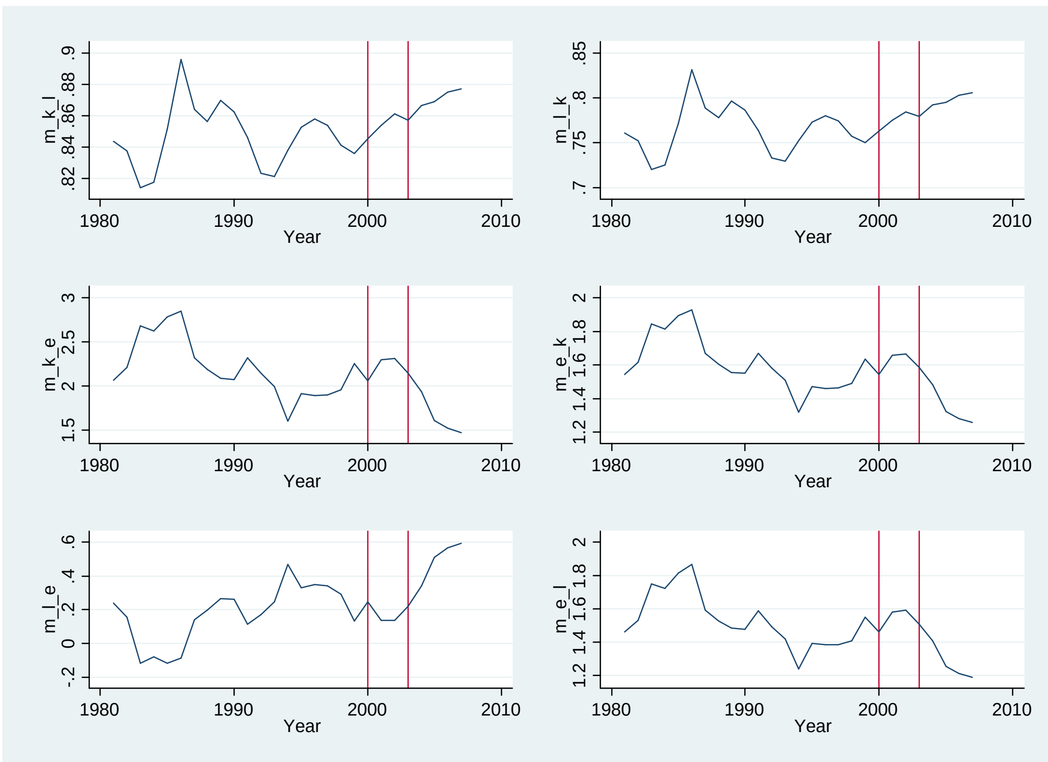


Figure 5.2. Overall Factor Morishima Elasticities of Substitution.

Figure 5.2 displays the graphs of the factor MES. The vertical lines in the graphs are also drawn for the years 2000 and 2003. None of the graphs in figure 5.2 indicates an abrupt change during the intervention period. Similar to the fuel MES, the series show what could be considered marked changes around 2004, corresponding to the increased economic activity. The stability of the factor MES around the time of the intervention casts doubt on the view that the industrial sector changed its factor composition dramatically in response to the negative input shock. This is evidence for the view that the rationing program was not overly onerous to the industrial sector's consumption of factor inputs: the conditions of the rationing program appear to have been met by means that did not alter traditional substitution behavior between these factors.

5.3.4 Predicted Effects from Elasticities

This section reports the predicted quantities of factor and fuel inputs that would have been expected to be consumed in 2001, based on the estimated own- and cross-price elasticities of demand for 2000 and observed quantities and prices.[34] These predicted quantities are presented and discussed in percentage terms. Two different values for each elasticity are used for each input quantity prediction: one prediction is calculated for the pre-intervention model and the other prediction is calculated from the elasticity for the year 2000. The results of this analysis are shown in table 5.8. For the estimates based on the cross-price elasticities, the first fuel or factor listed indicates the quantity whose value is being predicted in response to the price change of the second fuel or factor listed. The predicted differences, in percents, are constructed such that a positive (negative) value indicates that the actual quantity consumed was below (above) the predicted quantity.

[34] The own- and cross-price elasticities of demand are calculated as an interim step for the MES calculation; they are not reported separately. The fuel elasticities are used from the 1991-2000 model estimates and the factor elasticities are used from the 1981-2000 model estimates; these choices reflect higher model parameter significance.

Table 5.8. Predicted Input Quantity Differences (%)

	Own-Price Elasticity		Input	Cross-price Elasticity	
Input	Model	2000	Pair	Model	2000
elec	5.7	5.3	elec_petr	3.8	4.9
petr	22.4	17.1	petr_elec	10.0	14.4
coal	1.8	0.0	elec_coal	5.2	5.3
ngas	-14.7	-9.6	coal_elec	4.0	5.2
			petr_coal	13.6	13.7
			coal_petr	0.6	0.4
			elec_ngas	5.1	4.4
			ngas_elec	-15.2	-24.5
			petr_ngas	12.7	13.6
			ngas_petr	-29.7	-21.8
			coal_ngas	4.3	4.3
			ngas_coal	-14.0	-16.0
E	16.2	16.1	EL	7.8	7.8
L	-8.3	-8.3	LE	-6.8	-6.8
K	-17.3	-17.3	LK	-20.7	-20.7
			KL	-20.3	-20.3
			EK	-18.9	-18.2
			KE	-20.9	-20.9

The percent differences listed in table 5.8 for the four fuel inputs based on the own-price elasticities indicate decreases from expected consumption of electricity, petroleum, and coal, and an increase in the expected consumption of natural gas. These values are similar to the annual changes for these fuel inputs. From 2000 to 2001, the annual reduction in industrial electricity consumption was 5.0 percent; the annual reduction of petroleum consumption was 14.8 percent; the annual reduction of coal consumption was 2.8; and the annual increase of natural gas consumption was 18.1 percent ("Balanço Energético Nacional," 2010; SGS, 2009). The most notable difference in the table is for natural gas, which is easily used to produce electricity, on or off the grid. Based on its own-price elasticity for 2000, natural gas consumption was about 10 percent above its predicted value. Based on the *ngas_elec* cross-price elasticity for 2000, natural gas consumption was about 25 percent above its predicted value. The difference between these two predicted values may indicate that natural gas was substituted for electricity beyond what price changes would have indicated. However, considering the sum of predicted differences from the fuel own-price elasticities, the increased consumption of natural gas is not as great as the decrease in the combined consumption of electricity, petroleum, and coal. These results indicate that the above-predicted consumption of natural gas was not enough to offset the below-expected consumption of the other three fuels. The results for energy, based on its own-price elasticities, from the factor model affirm this generalized conclusion.

The changes at the factor level are harder to interpret, given the large reduction in the consumption of petroleum in 2001. This large reduction and the reduction in the consumption of electricity likely drive the 16 percent lower-than-expected consumption of energy, based on its own-price elasticity for 2000. More interesting are the higher than expected levels of consumption for labor and capital. The higher capital values may reflect rapid investments in equipment upgrades to meet the lower electricity consumption requirements of the rationing program, and the higher labor consumption may reflect increased utilization of labor related to these efficiency-enhancing capital investments. Interestingly, the cross-price elasticity predictions between capital and labor both indicate that the levels of consumption in 2001 were above the otherwise expected levels by 20 percent. Again, these unexpectedly high values could be the result of rapid equipment investments and increased use of labor to meet the demands of the rationing program. More research is needed to discern what actually drove changes at the factor level.

5.4 Conclusion

This chapter investigates the hypothesis that substitution among factors and fuels may have facilitated industrial production during the electricity rationing program. This chapter estimates Morishima elasticities of substitution from a four-input fuel model and from a three-input factor model. By estimating these elasticities of substitution over different periods related to the rationing program, the results presented in this chapter reveal no apparent changes to the elasticities relating to the rationing program; rapid changes to these elasticities are apparent two years after the completion of the rationing program. Price elasticities of demand are use to calculate deviations from expected levels of consumption to highlight consumption that does not appear to follow price signals at the time of the intervention.

The results from the studies in this chapter provide the literature with estimates of elasticities of substitution for Brazil. Estimating these elasticities for two periods before the rationing program and for an overall period highlights how changes to the Brazilian economy may affect substitution behavior. Brazil's substitution behavior over the past 30 years appears to have changed more in relation to the reduction of state intervention in industry than in relation to the electricity rationing program. Rapid changes in substitution elasticities are also evident during Brazil's recent burst of economic activity, starting around 2004.

The analysis of predicted fuel and factor consumption, based on price elasticities, reveals higher-than-expected consumption of natural gas in 2001. However, this increased consumption does not entirely offset lower-than-expected energy consumption during that year. More capital and labor were consumed in 2001 than would have been expected, which can further explain the role of substitution in response to the rationing program. Further analyses are required to understand more fully the observed fuel and factor consumption during 2001, especially regarding the dramatic reduction in petroleum consumption.

The results of these analyses also contribute to the energy shock literature as they reveal the specific responses of an industrialized economy to an energy input shock. While the external validity of these results may be limited, they reveal that a 20 percent reduction in electricity consumption for a seven-month period may not significantly alter substitution elasticities, if the elasticities are similar to those found in this analyses and the economy is similar to that of Brazil. These results also establish a foundation on which further studies can be built to identify the paths followed by an economy experiencing an electricity shortage. For example, the findings that capital and labor were consumed in quantities above what would otherwise be expected in 2001 may indicate a rapid and strong response to the rationing program via investments in and installation of more efficient industrial devices. Also, these results cannot fully isolate the role of natural gas: while its consumption was above expected levels in 2001, it is unclear whether these levels would be enough to completely offset the reduction in electricity consumption.

CHAPTER 6

CONCLUSION

This dissertation contributes to the literature by estimating the impact of a negative input shock on the Brazilian economy and by testing hypotheses related to possible impacts of the shock on the economy. The general results suggest that, given a negative electricity shock:

- An industrialized country can greatly reduce its electricity consumption while experiencing minor losses in output.
- Economic relationships between inputs and outputs are statistically tenuous.
- Elasticities of substitution are stable for factor and fuel inputs.
- Substitution plays an important, but inconclusive, role in the adjustment path followed by the economy.

More specifically, the results from the univariate analysis indicate that, during the intervention, industrial electricity consumption and commercial electricity consumption were reduced from trend values by 16.4 and 25.2 percent, and GDP was reduced by 3.1 percent. Furthermore, the greatest decrease in monthly GDP occurred in the month with the smallest decline in electricity consumption. These two extremes occurred in the first month of the rationing program, which could be interpreted as an initial negative economic adjustment to the uncertainty of the implementation of the rationing program.

Economic activity and growth during the remaining eight months of the program was consistent with activity and growth during the previous four years.

The forecasts from a VAR model estimated with monthly data using electricity, GDP, unemployment, and capacity utilization, indicate that while electricity consumption fell 18.9 percent, GDP fell only 2.8 percent. For this same model, Granger causality tests cannot reject the existence of the following three causal relationships for the pre-intervention period: a bi-directional relationship between GDP and electricity consumption, a uni-directional relationship from changes in unemployment to GDP, and a uni-directional relationship from changes in unemployment to changes in capacity utilization. In the post-intervention period, Granger causality tests cannot reject only two causal relationships: a uni-directional relationship from electricity consumption to changes in capacity utilization, and a bi-directional relationship between changes in capacity utilization and changes in unemployment. This evidence of rapid changes among economic relationships should place into question the policy recommendations found in many studies found in the energy economics literature.

A translog cost model is developed to calculate elasticities of substitution among fuels and factors for the pre-intervention, post-intervention, and overall periods; these elasticities are not presently found in the literature. Time series of these elasticities indicate stability during the intervention. Forecasts of consumption for the fuels and factors during the intervention period are based on price elasticities of demand. Comparisons between observed consumption and these forecasts indicate that natural gas consumption was 14.7 percent above its predicted value, consumption of capital was 17.3 percent above predicted values, and consumption of labor 8.3 percent above predicted values. Combined energy consumption was 16.2 percent lower than predicted, with reduced consumption of petroleum driving this value.

Individually, each result makes an important contribution; collectively, these results cast doubt on arguments that firms reduced electricity consumption by reducing output. Further research is needed to understand the specific adjustment process during the first month of the rationing program; two plausible explanations are as follows. The first explanation is based on an initial reduction in consumption due to uncertainty surrounding the rationing program. An initial drop in consumption could result in lower production during June, with production resuming normal levels in later months as consumers adapted to the rationing program. A second explanation assumes that producers needed to make adjustments to their means of production that would allow them to meet the reduced electricity consumption mandate. While the firms reduced production during June to make their necessary adjustments, production returned to normal levels for the rest of the rationing program. The electricity consumption data show that electricity consumption remained below trend after the end of the rationing program. This shift is consistent with an explanation similar to the second explanation, namely that firms made investments in efficiency and/or altered their production behavior to reduce electricity consumption. The second explanation is also consistent with the above-expected consumption of capital, labor, and natural gas, as reported in chapter 5.

Output in Brazil jumped in 2000 and in the first months of 2001; the year-on-year monthly percent decreases experienced during the rationing program are not large when compared to historical values. Month-to-month growth is also consistent with historical values, after the first month of the rationing program. Further research is needed to understand the drivers of growth during the months prior to the rationing program as the economy recovered from the global financial crisis of 1998-1999. If the growth occurred in sectors highly dependent on electricity, the rationing program may have had an effect greater than what is shown by the results in the present studies. Or, the increases from near-zero growth in the months prior to the rationing program may have been anomalous or transitory. Due to data limitations and scope, the analyses conducted in this dissertation do not discern these differences. Similarly, the importance of a large decrease in the consumption of petroleum in 2001 should be investigated further to understand the economic changes driving this decrease. Such changes may have contributed more to the decline in GDP than the electricity rationing program.

The data and techniques selected for this dissertation are not without problems, subsequently limiting the impact of this research. One contribution made by this dissertation is the use of a monthly real GDP series. Before considering the potential problems associates with the construction of this series, events affecting Brazil’s economic activity should be summarized. Brazil faced a period of hyper-inflation in the early 1990s, with inflation returning to reasonable levels in 1994. Throughout the 1990s, Brazil experienced a strong liberalization of its markets and the privatization of many state-owned enterprises. In 1998 the Asian financial crisis became an international economic crisis, with strong effects on Argentina, Brazil, and Russia. These external events, coupled with internal problems, led Brazil to switch from a controlled currency to a floating currency in January 1999; that change was followed by a rapid depreciation. The years 2000 and 2001 included much international economic turmoil, first with the collapse of speculative investments in technology companies, and then with terrorist attacks in the United States. The Brazilian economy experienced essentially no growth during 1998 and 1999, but grew moderately in 2000. While the questions addressed in this dissertation focus on economic changes related to the electricity rationing program of 2001-2002, the results are based on historical economic data. The economic turmoil in Brazil in the late 1990s and early 2000s complicate the resulting statistical analyses.

Various possible problems with the data series used in the statistical analyses in this dissertation may limit the reader's confidence in the results. The results presented in chapters 3 and 4 are based on the constructed, monthly real GDP series. The methodology used to construct the series and a benchmarking exercise are discussed in the appendix. Using a linear interpolation of the annual price deflator was necessary, as a monthly deflator does not exist, but that poses potential problems given the month-to-month instability in rates of inflation. The results from chapters 3 and 4 are also affected by the inability to separate GDP into contributions from regions affected by the rationing program and from the excluded southern region. This is not expected to be a major limitation, as the southern region represented less than 20 percent of Brazil's total economic activity at the time of the intervention. The results presented in chapter 5 are based on an analysis of annual data, which are more reliable than monthly data. However, only seven months of the rationing program occurred during 2001. By excluding two months of the rationing program and by averaging the included seven months with the rest of 2001, the measured impact of the rationing program is reduced. Also, this analysis utilizes total industrial electricity consumption, which includes consumption in the intervention-exempt southern region.

Additional research is needed to understand better statistically-causal economic relationships and how they change. The results of the present research indicate that such relationships are tenuous and can change quickly. Perhaps these changes are due to real adjustments in the economy, with existing relationships ceasing to exist and new ones becoming established. Perhaps these relationships are spurious or statistical artifacts. Further research could provide economists with a better understanding of the limitations of such relationships, and whether policy recommendations should be derived from their results.

APPENDIX A

APPENDICES FOR CHAPTER 4

A.1 Data Description and Sources

The primary group variables consist of five electricity consumption series and the real GDP series. Table A.1 lists the variable name and the original name (the English translation is in parentheses) of the underlying electricity series used to create the series used in chapter 4. As indicated by the calculations below, the resulting series are the natural logarithms of the sum of the four regional series:

$$\text{elec\_tot} = \ln(\text{elec\_t\_n} + \text{elec\_t\_ne} + \text{elec\_t\_co} + \text{elec\_t\_se})$$

$$\text{elec\_ind} = \ln(\text{elec\_i\_n} + \text{elec\_i\_ne} + \text{elec\_i\_co} + \text{elec\_i\_se})$$

$$\text{elec\_res} = \ln(\text{elec\_r\_n} + \text{elec\_r\_ne} + \text{elec\_r\_co} + \text{elec\_r\_se})$$

$$\text{elec\_com} = \ln(\text{elec\_c\_n} + \text{elec\_c\_ne} + \text{elec\_c\_co} + \text{elec\_c\_se})$$

$$\text{elec\_oth} = \ln(\text{elec\_o\_n} + \text{elec\_o\_ne} + \text{elec\_o\_co} + \text{elec\_o\_se})$$

where the right-hand series are defined in table A.1 and elec_tot is the total electricity consumption, excluding the southern region; elec_ind is the industrial electricity consumption, excluding the southern region; elec_res is the residential electricity consumption, excluding the southern region; elec_com is the commercial electricity consumption, excluding the southern region; and elec_oth is the other electricity consumption, excluding the southern region.

Table A.1. Brazilian Electricity Consumption Series

Variable Name	Variable Title [Portuguese (English)]
elec_t	1406 – Consumo de energia elétrica – Brasil – Total (Electrical energy consumption – Brazil – Total)
elec_c_n	1407 – Consumo de energia elétrica – Região Norte – Comercial (Electrical energy consumption – Northern Region – Commercial)
elec_r_n	1408 – Consumo de energia elétrica – Região Norte – Residencial (Electrical energy consumption – Northern Region – Residential)
elec_i_n	1409 – Consumo de energia elétrica – Região Norte – Industrial (Electrical energy consumption – Northern Region – Industrial)
elec_o_n	1410 – Consumo de energia elétrica – Região Norte – Outros (Electrical energy consumption – Northern Region – Other)
elec_t_n	1411 – Consumo de energia elétrica – Região Norte – Total (Electrical energy consumption – Northern Region – Total)
elec_c_ne	1412 – Consumo de energia elétrica – Região Nordeste – Comercial (Electrical energy consumption – Northeast Region – Commercial)
elec_r_ne	1413 – Consumo de energia elétrica – Região Nordeste – Residencial (Electrical energy consumption – Northeast Region – Residential)
elec_i_ne	1414 – Consumo de energia elétrica – Região Nordeste – Industrial (Electrical energy consumption – Northeast Region – Industrial)
elec_o_ne	1415 – Consumo de energia elétrica – Região Nordeste – Outros (Electrical energy consumption – Northeast Region – Other)
elec_t_ne	1416 – Consumo de energia elétrica – Região Nordeste – Total (Electrical energy consumption – Northeast Region – Total)
elec_t_s	1421 – Consumo de energia elétrica – Região Sul – Total (Electrical energy consumption – Southern Region – Total)
elec_c_co	1422 – Consumo de energia elétrica – Região Centro–Oeste – Comercial (Electrical energy consumption – Center–West Region – Commercial)
elec_r_co	1423 – Consumo de energia elétrica – Região Centro–Oeste – Residencial (Electrical energy consumption – Center–West Region – Residential)
elec_i_co	1424 – Consumo de energia elétrica – Região Centro–Oeste – Industrial (Electrical energy consumption – Center–West Region – Industrial)
elec_o_co	1425 – Consumo de energia elétrica – Região Centro–Oeste – Outros (Electrical energy consumption – Center–West Region – Other)
elec_t_co	1426 – Consumo de energia elétrica – Região Centro–Oeste – Total (Electrical energy consumption – Center–West Region – Total)
elec_c_se	1427 – Consumo de energia elétrica – Região Sudeste – Comercial (Electrical energy consumption – Southeast Region – Commercial)
elec_r_se	1428 – Consumo de energia elétrica – Região Sudeste – Residencial (Electrical energy consumption – Southeast Region – Residential)
elec_i_se	1429 – Consumo de energia elétrica – Região Sudeste – Industrial (Electrical energy consumption – Southeast Region – Industrial)
elec_o_se	1430 – Consumo de energia elétrica – Região Sudeste – Outros (Electrical energy consumption – Southeast Region – Other)
elec_t_se	1431 – Consumo de energia elétrica – Região Sudeste – Total (Electrical energy consumption – Southeast Region – Total)

Source: Banco Central do Brasil- Eletrobrás (Central Bank of Brazil) website (SGS, 2009).

One of the contributions of the analyses conducted in chapter 4 stems from the use of monthly GDP data. While no real monthly GDP series is reported for Brazil, a nominal monthly GDP series is. This data is manipulated through a linear interpolation of the annual GDP deflator to create a "real," monthly GDP series. The original series and translations are listed in table A.2. The related annual series are included in the table (with variable names, if applicable), as they are utilized for various checks on the adjustments to the monthly series.

Brazil experienced a period of hyperinflation during the late 1980s and early 1990s, with hyperinflation becoming controlled in 1994. Additionally, Brazil introduced multiple currencies during this period including the *real* in 1994, which remains in circulation today. Following the adjustment procedures presented below, the effects of hyperinflation were too great on the GDP series and the resulting adjusted series cannot be viewed as useful during the hyperinflation period. Therefore, the starting point for these studies cannot fall before hyperinflation returns to acceptably "normal" inflation; this occurred in the middle of 1994.

Table A.2. Brazilian Output Series

Variable Name	Variable Title [Portuguese / (English)]
GDPN	4380 – PIB mensal – Valores correntes (R$ milhões) (Monthly GDP – Current Values (R$ millions)) 1207 – Produto interno bruto em R$ correntes - R$ (Annual GDP in current R$)
GDPR	1208 – Produto interno bruto em R$ de 2008 – R$ (Annual, GDP in 2008 R$)
DEFX	1211 – Deflator implícito – % (Annual, Implicit Deflator – %)

Source: Banco Central do Brasil, Departamento Econômico (SGS, 2009).

The nominal GDP series can be transformed to a real series after linearly interpolating the annual deflator to a monthly deflator.[35] The general formula for constructing the annual deflator index is $DEFX_{T-1} = \frac{100 \cdot DEFX_T}{DEF_T + 100}$, where $DEFX_{T-1}$ is the deflator index in year $T-1$ and DEF_T is the GDP deflator in year T; the index is calculated by first defining a value of 100 in 2008 and then successively calculating values for previous years. With the base year being 2008, all previous values are subsequently inflated to the base year.

In order to highlight possible introduction of error into the transformation of nominal monthly GDP to a real series, a comparison is made between the reported annual real GDP series, the reported- but deflated- nominal GDP series, and the deflated summation of the nominal monthly GDP values. Table A.3 compares these series and indicates that the only noticeable discrepancy in the data occurs in 1995, where an 8.5 percent error exists between the two series.

To create the monthly deflator index, one-twelfth of the corresponding annual deflator value, which is reported in percentage terms, is applied per month. The general formula for constructing the monthly deflator index is $DEFx_{t-1} = \frac{DEFx_t \cdot 1200}{DEF_{T-1}}$, where $DEFx_{t-1}$ is the deflator index in month $t-1$ of year $T-1$ and DEF_{T-1} is the GDP deflator in year $T-1$. The monthly index is calculated by first defining a value of 100 in 2008 and then successively calculating values for previous months. Each resulting year-month can be identified by defining the notation $DEFx_{t,m}$ where t is a year index and m is a month

[35] The GDP deflator is only reported to two decimal places; preliminary checks reveal small differences between the reported annual real GDP series and the deflated annual nominal GDP series.

Table A.3. Real and Deflated GDP Series

Year	Real GDP, 2008 R$ (millions)	Deflated Nominal GDP, R$ (millions)	Deflated Nominal Monthly GDP, R$ (millions)
1994	1895222	1895196	1895196
1995	1975272	1975263	1820226
1996	2017750	2017823	2017824
1997	2085856	2086018	2086018
1998	2086593	2086677	2086677
1999	2091894	2091944	2091944
2000	2181975	2181972	2181972
2001	2210627	2210585	2210585
2002	2269388	2269417	2269417
2003	2295409	2295371	2295370
2004	2426529	2426440	2426440
2005	2503200	2503097	2503097
2006	2602602	2602486	2602486
2007	2750100	2750091	2750091

Source: Data adapted from SGS 2009, Series 1207, 1208, 1211, and 4380.

month index.[36] With the monthly GDP deflator index, nominal monthly GDP values prior to the base year can be inflated to the base year-month by calculating

$GDPR_{t,m} = GDPN_{t,m} \cdot \frac{100}{DEFx_{t,m}}$, where $GDPR_{t,m}$ is the calculated real GDP in year t and month m, $GDPN_{t,m}$ is the nominal GDP value for year t and month m, and $DEFx_{t,m}$ is the GDP deflator index in year t and month m. The base year-month is July 2008. The starting observation for the resulting real GDP variable, *gdp*, is June, 1995 and the last observation used in the analyses is December, 2006.

The secondary group variable names, Portuguese titles (English titles), and sources are listed in table A.4.

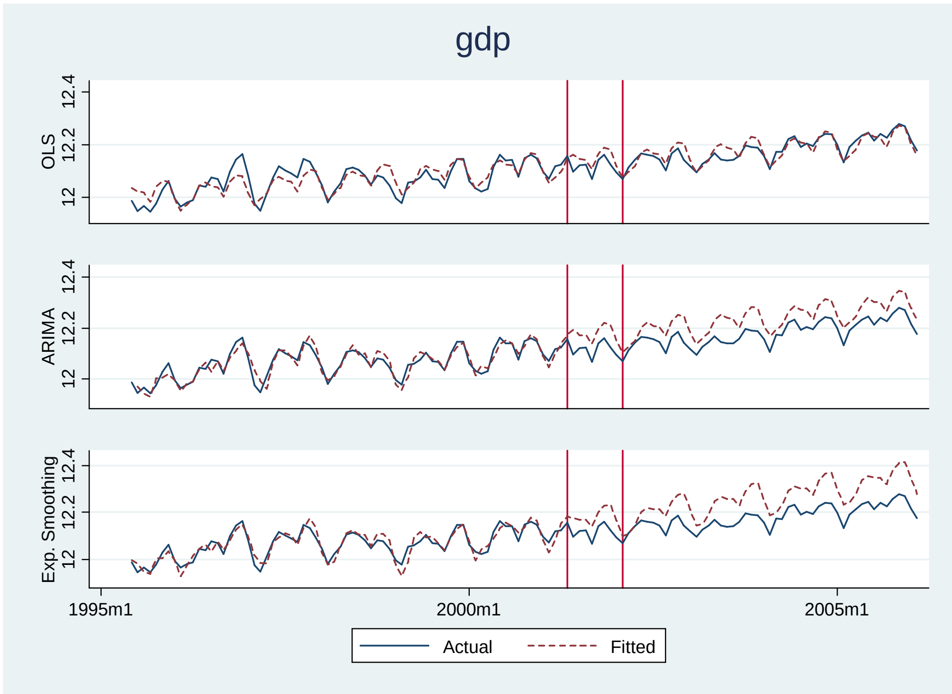
[36] As the choice of starting month for the index is relevant to the resulting series and is unknown, the optimal base month is determined empirically by considering all months. July is selected as the base month, as this base month results in the series that has the minimum squared error when compared to the unadjusted, real annual GDP series from 1996 through 2007.

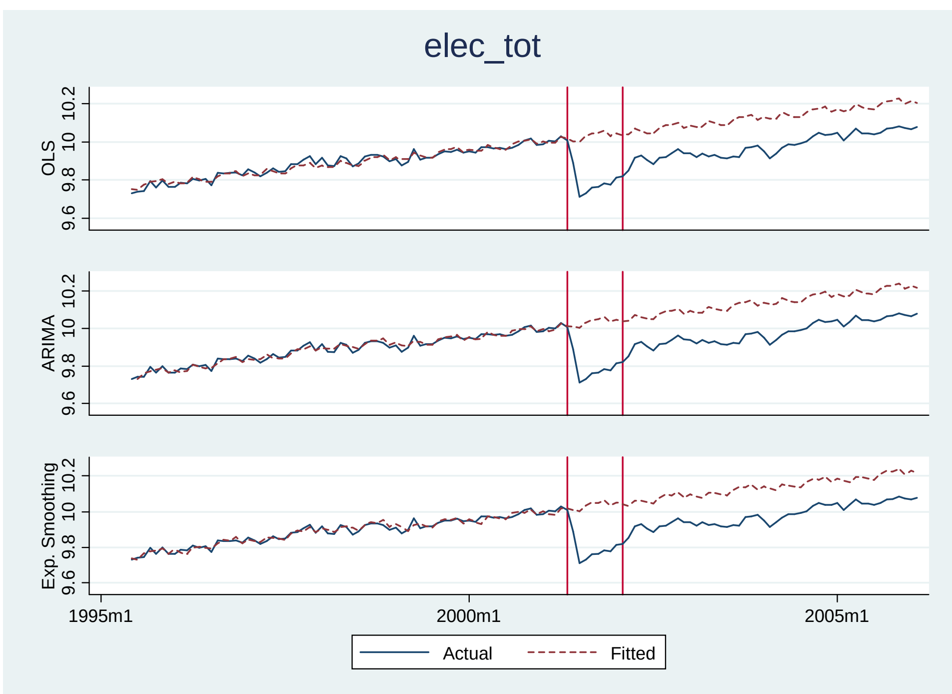
Table A.4. Secondary Data Series and Sources

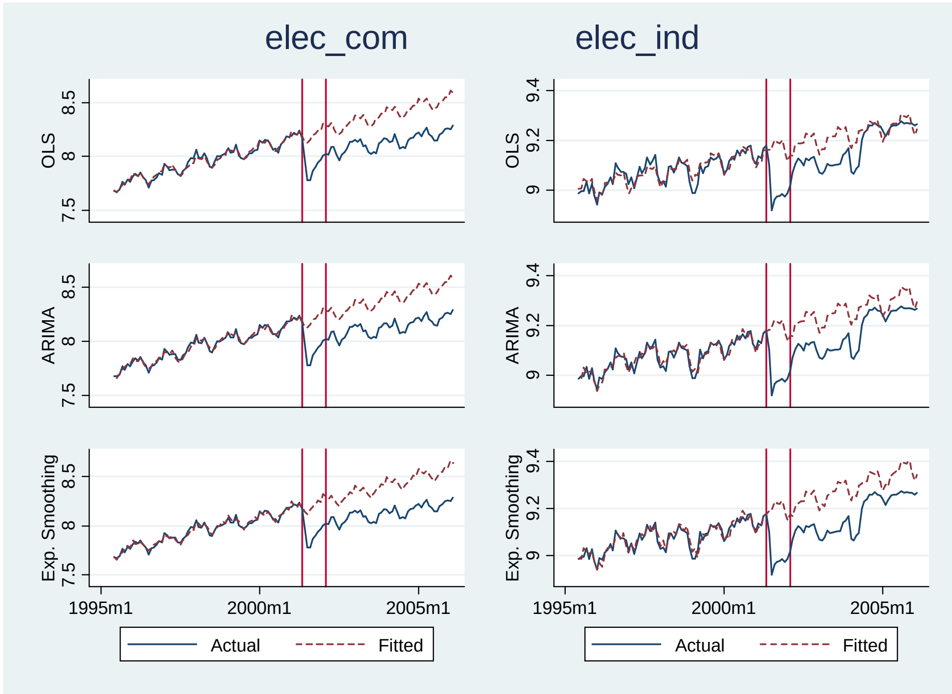
Variable Name	Variable Title [Portuguese / (English)]	Source
emplformal	1586 - Emprego formal - Índice geral (Formal employment)	SGS
totsal	Folha de pagamento - indústria geral - índice - IBGE/Pimes (Index of Total Industrial Wages)	IPEAdata
unempsp	Taxa de desemprego - RMSP - (%) - Seade/PED (Unemployment Rate, Metropolitan Region of São Paulo)	IPEAdata
caputil	1341 - Utilização da capacidade instalada - Geral (CNI) (Installed Capacity Utilization)	SGS
indprod	Produção física industrial (Index of Physical Industrial Production)	SIDRA
exchange	11752 - Índice da taxa de câmbio efetiva real (IPCA) (Real Effective Exchange Rate Index)	SGS
exports	2733 - Exportações de bens (fob) – mensal (Exports)	SGS
imports	2734 - Importações de bens (fob) – mensal (Imports)	SGS
capact	Conta capital e financeira - conta capital - US$ (milhões) (Capital Account)	IPEAdata
finact	Conta capital e financeira - conta financeira - US$ (milhões) (Financial Account)	IPEAdata
fdirinvt	Conta financeira - investimentos diretos - estrang. no país - US$ (milhões) (Foreign Direct Investment)	IPEAdata

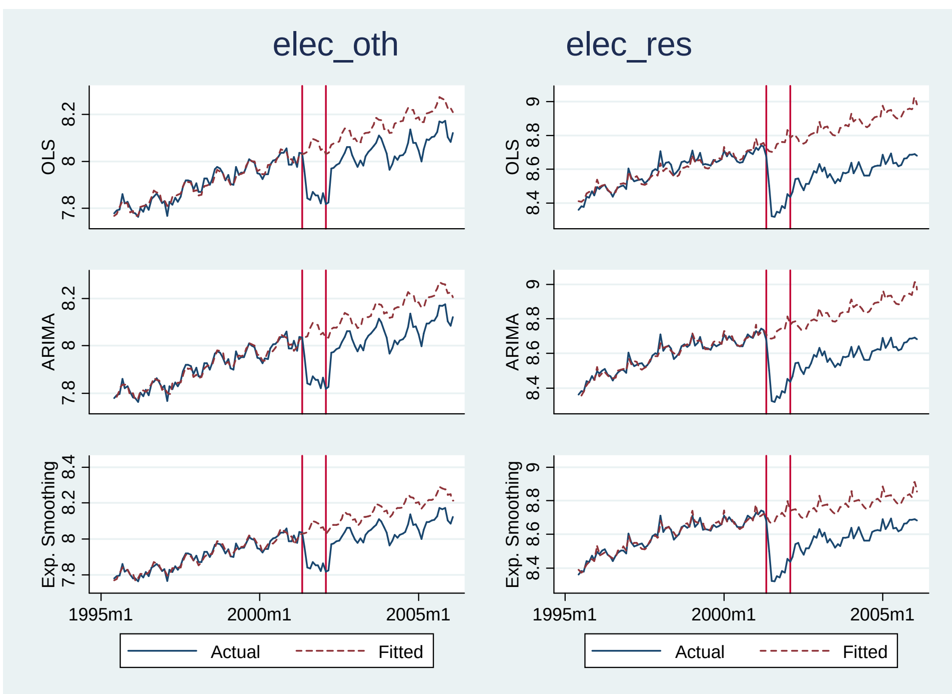
Sources: Banco Central do Brasil, Departamento Econômico (SGS, 2009), Instituto Brasileiro de Geografia e Estatística (SIDRA, 2011), and Instituto de Pesquisa Econômica Aplicada (IPEAdata, 2011).

A.2 Univariate Model Forecasts






elec_com
elec_ind
OLS
ARIMA
Exp. Smoothing
7.5
8
8.5
9
9.2
9.4
1995m1
2000m1
2005m1
Actual
Fitted


elec_oth
elec_res
OLS
ARIMA
Exp. Smoothing
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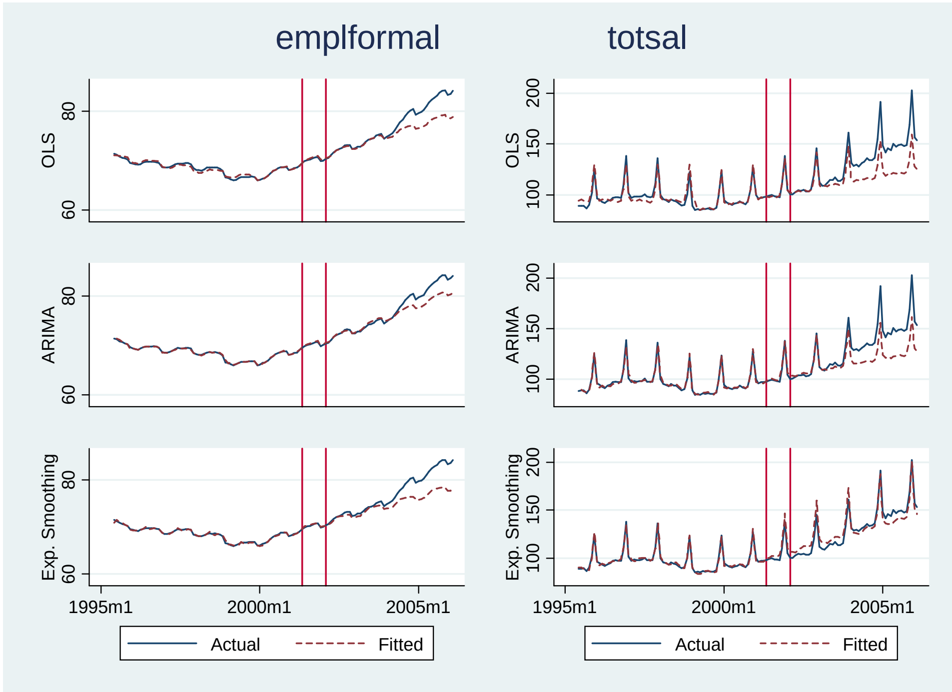
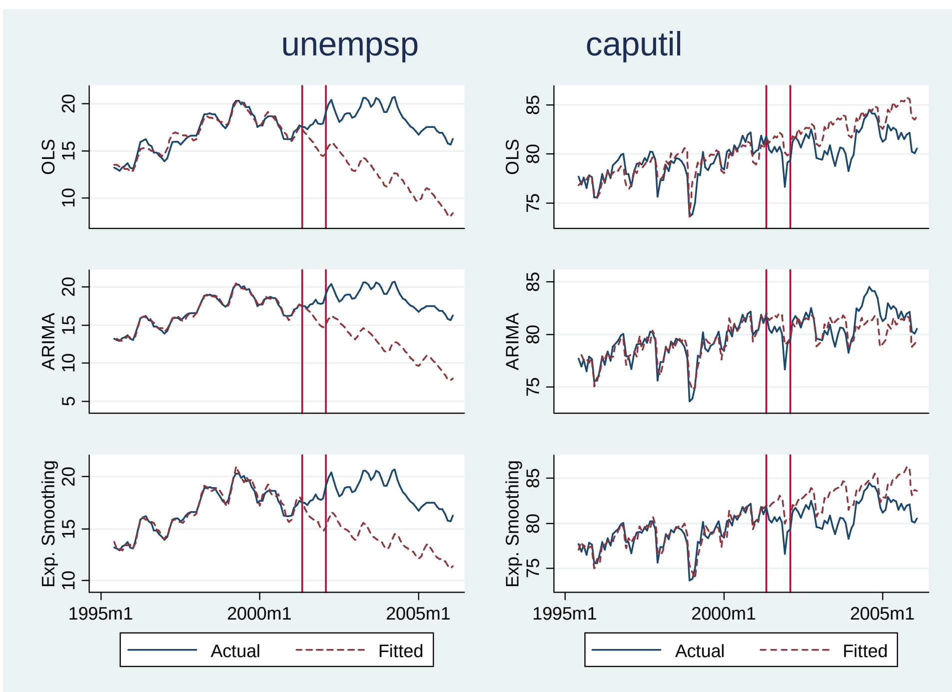
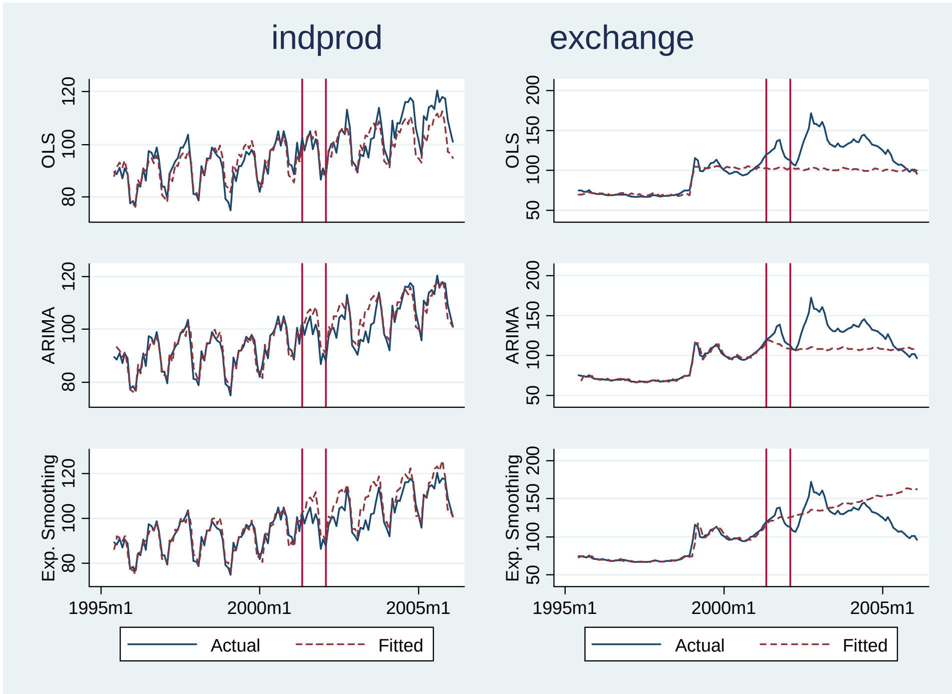
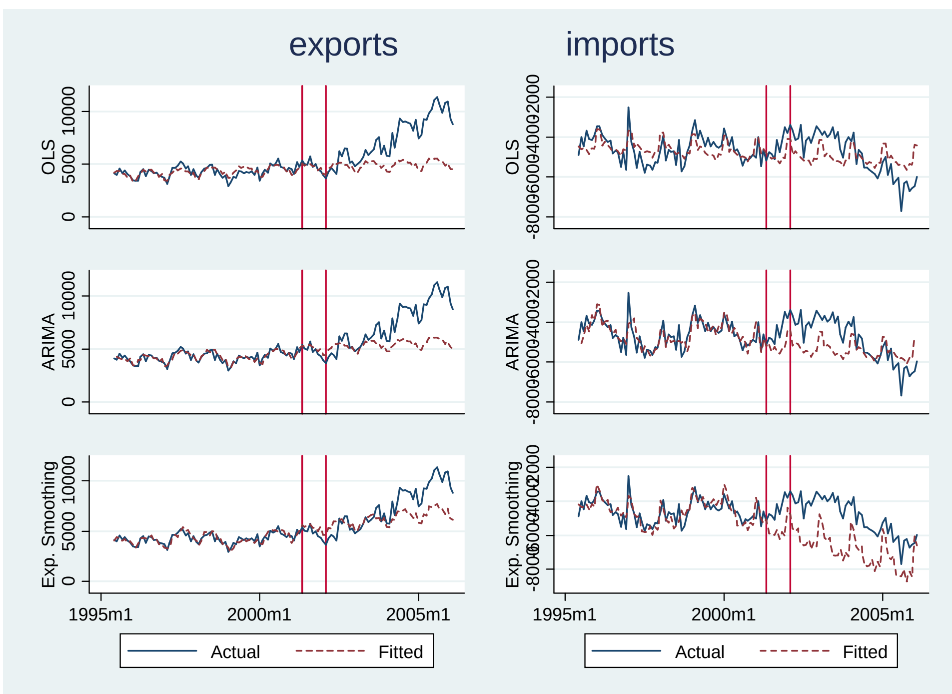
8
8.2
8.4
8.6
8.8
9
1995m1
2000m1
2005m1
Actual
Fitted


emplformal
totsal
OLS
ARIMA
Exp. Smoothing
60
80
100
150
200
1995m1
2000m1
2005m1
Actual
Fitted


unempsp
caputil
OLS
ARIMA
Exp. Smoothing
5
10
15
20
75
80
85
1995m1
2000m1
2005m1
Actual
Fitted


indprod
exchange
OLS
ARIMA
Exp. Smoothing
80
100
120
50
100
150
200
1995m1
2000m1
2005m1
Actual
Fitted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imports
OLS
ARIMA
Exp. Smoothing
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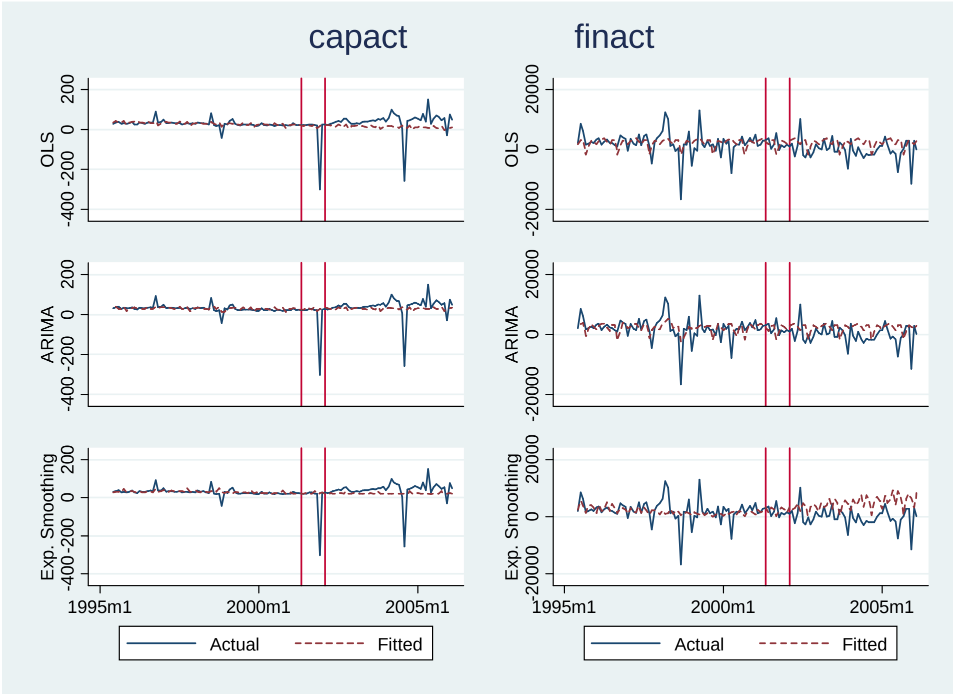
5000
10000
1995m1
2000m1
2005m1
Actual
Fitted


capact
finact
OLS
ARIMA
Exp. Smoothing
200
0
-200
-400
20000
0
-20000
1995m1
2000m1
2005m1
Actual
Fitted


fdirinvt
OLS
ARIMA
Exp. Smoothing
0
2000
4000
6000
5000
10000
1995m1
2000m1
2005m1
Actual
Fitted

A.3 Multivariate Model Unit Root Tests

Table A.5. Augmented Dickey-Fuller Unit Root Test Results

	Pre-Intervention			Post-Intervention		
	Lags	Levels	1st Diff.	Lags	Levels	1st Diff.
elec_prod	1	-3.959***		1	-3.676**	
gdp	1	-5.420***		3	-3.515**	
caputil	1	-3.107*	-3.716***	1	-2.022	-2.604**
unempsp	3	-1.048	-5.006***	2	-1.907	-2.923***

Significance indicated by: *** p<.01, ** p<.05, * p<.1

Note: The post-intervention test results for gdp indicated a minimum SIC at 4 lags; the results at 3 lags are used due to the inability to obtain a stationary series after extensive differencing.

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