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MEASURING MACROECONOMIC SHOCKS OF THE COVID-19 PANDEMIC: AN
EMPIRICAL ANALYSIS FOR BHUTAN

by

Lekey Dorji

PGDPA, Royal Institute of Management, 2015

A Thesis

Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

School of Analytics, Finance, and Economics
in the Graduate School
Southern Illinois University Carbondale
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THESIS APPROVAL

MEASURING MACROECONOMIC SHOCKS OF THE COVID-19 PANDEMIC: AN
EMPIRICAL ANALYSIS FOR BHUTAN

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Lekey Dorji

A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of
Master of Science
in the field of Economics

Approved by:

Dr. Kevin Sylwester, Chair

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Graduate School
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TITLE: MEASURING MACROECONOMIC SHOCKS OF THE COVID-19 PANDEMIC: AN EMPIRICAL ANALYSIS FOR BHUTAN

MAJOR PROFESSOR: Dr. Kevin Sylwester

Taking GDP growth and CPI inflation as endogenous variables, this paper employs a Structural VAR from Baumeister and Hamilton (2015, 2019) to identify aggregate demand and aggregate supply shocks for Bhutan, focusing on the COVID-19 pandemic. The results suggest that 94 percent of the GDP growth plunge in 2020 is attributable to a fall in aggregate supply. The higher inflation during the COVID-19 pandemic also implies a negative supply shock. Although the magnitudes differ, characterizing the COVID-19 pandemic in Bhutan as a supply shock coincides with preceding episodes that were also primarily driven by supply shocks.

Keywords: SVAR, supply shock, demand shock, Bhutan, COVID-19, pandemic

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PREFACE

Bhutan was in the midst of implementing the 12th Five-Year Plan (FYP 2018-2023) when the COVID-19 pandemic emerged at its peak in 2020. The 12th FYP is apparently Bhutan's last consecutive FYP as a Least Developed Country⁹ (LDC). Hence, a successful accomplishment of the 12th FYP goals is pivotal to Bhutan's seamless graduation.

However, like most countries, Bhutan encountered myriads of economic ramifications from the COVID-19 pandemic. On the supply side, public health curfews such as remote working, physical distancing, business closures, and lockdowns reduced output and employment. Simultaneously, the collapse of consumer confidence, a drastic fall in consumption and investment spending resulted in a demand shock causing further contractions in production and employment. Also, the collapse of tourism, a significant source of revenue, was the final nail in the coffin of the economy, depressing the demand severely. All these repercussions are conspicuous as the GDP fell by more than 10 percent in 2020 which is one of the lowest in Bhutan's recorded history.

Therefore, Bhutan's post-pandemic priority must be an economic revival in pursuit of the LDC graduation. For that, it is crucial to understand whether the COVID-19 pandemic is a supply shock or a demand shock relative to Bhutan's economy. So, at this juncture, economic studies such as this prove handy for framing macroeconomic policy responses to the COVID-19 pandemic.

Pleasant reading, everyone!

⁹ Refer Razzaque, 2020 (page 1-3) for details on LDC graduation criteria. Also, 2015 and 2018 triennial assessments on Bhutan.

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CHAPTER 1

INTRODUCTION

Like most countries, Bhutan suffered a sharp economic downturn in 2020 due to the COVID-19 pandemic. On the supply side, public health curfews such as remote working, physical distancing, business closures, and lockdowns reduced output and employment. Simultaneously, the collapse of consumer confidence, a drastic fall in consumption and investment spending resulted in a demand shock causing further contractions in production and employment. Also, the collapse of tourism, a significant source of revenue, was the final nail in the coffin of the economy, depressing the demand severely. These economic repercussions are conspicuous as the GDP fell by more than 10 percent in 2020 which is one of the lowest in Bhutan's recorded history.

But how might one characterize the COVID-19 pandemic relative to Bhutan's economy? Do decreases in spending caused by a fall in aggregate demand dominate or do business closures and workplace changes (such as remote working) lead to a fall in aggregate supply? To answer these questions, one might want to undertake a deeper study on the impacts of the COVID-19 pandemic on the economy.

In general, downturns are triggered either by a demand shock or a supply shock (Blanchard & Quah, 1989). This is evident in the works of literature which had categorized the causes of almost all the preceding global downturns into either of the two. In the same vein, studies pertaining to advanced economies such as the US reported the COVID-19 pandemic as a large aggregate supply shock to the economy (Bekaert, Engstrom, & Ermolov, 2020). Similarly, the literature for developing economies such as India also revealed the COVID-19 pandemic as a large aggregate supply shock (Patnaik, 2022).

The reason to identify these shocks is to better design policy responses. The macroeconomic remedies that are effective in reversing a downturn triggered by a supply shock are not necessarily effective in tackling a downturn triggered by a demand shock. For instance, if the economic shock comes from the inability of the businesses to operate under the new circumstances of the economic downturn, executing fiscal measures to boost the household income and enhance consumption spending will not be of great help. Whereas, in a demand-driven downturn, where consumption spending has collapsed owing to fear of future insecurities, enhancing the capabilities of businesses to produce more is not so wise. Instead, expansionary fiscal measures such as government spending and monetary measures such as adjusting interest rates would yield better chances of economic recovery.

However, no empirical studies estimating the shocks of the COVID-19 pandemic on Bhutan's economy exist. A priori, how the COVID-19 pandemic affected Bhutan is not clear. Besides being an import-driven economy, Bhutan has a small manufacturing sector and therefore, the industrial structure varies largely from the countries researchers have examined.

For these reasons, my paper attempts to measure the size of the aggregate supply and aggregate demand shocks of the COVID-19 pandemic by estimating a Bayesian Structural Vector Autoregression (BSVAR) from Baumeister and Hamilton (2015, 2019) and using annual output growth and inflation as data.

The study not only characterizes the 2020 shock as an aggregate supply or demand shock but also explores the pre-COVID period from 1989 to 2019 and identifies shocks from that window. One can then better determine to what extent the COVID-19 shock conforms to other recent economic shocks in Bhutan.

CHAPTER 2

LITERATURE REVIEW

2.1 The COVID-19 pandemic; a supply or a demand shock?

A long line of studies has decomposed economic movements into supply and demand shocks. For instance, Vernengo and Nabar-Bhaduri (2020) reported that economic downturns such as Reagan's recession of 1981-82 and the Great Recession of 2007-09 were triggered by demand shocks whereas the Energy Crisis in the 1970s stemmed from a supply shock. The demand shock contributing significantly to the Great Recession has also been reported by Mian and Sufi (2014) and later corroborated by Bekaert, Engstrom, and Ermolov (2020).

Researchers continued this line of study with the COVID-19 pandemic, assessing whether demand or supply shocks drove the downturn. Some find evidence of a supply shock (Bekaert, Engstrom, and Ermolov, 2020; del Rio-Chanona, Mealy, Pichler, Lafond, and Farmer, 2020; Fornaro and Wolf, 2020; Guerrieri, Lorenzoni, Straub, and Werning, 2020; Brinca, Duarte, and Faria-e-Castro, 2021; Baqaee and Farhi, 2020; Patnaik, 2022). However, not all agree finding more evidence of a demand shock (Vernengo and Nabar-Bhaduri, 2020).

2.2 VAR as an approach to estimate the shocks in the economy

One way to identify shocks is through a Vector Autoregressive (VAR) Model. Some of the early prominent attempts at using VAR estimation in this way include, but are not limited to, Beveridge and Charles, (1981); Watson (1986); and Clark (1987). These papers identify disturbances by imposing a priori restrictions on the response of output to each of the disturbances; permanent and transitory component. Further VAR estimation was used in Evans (1987); Campbell and Mankiw (1987b); Clark (1988); Shapiro and Watson (1988); and Blanchard and Quah (1989); Blanchard and Diamond (1990), Faust (1998); Davis and

Haltiwanger (1999); Canova and De Nicoló (2002); Uhlig (2005) and etc. to propose structural inferences. Since then, hundreds of papers followed suit and today it is one of the highly used econometric models to obtain structural conclusions.

In light of the COVID-19 pandemic, several works adopted SVAR models to examine shocks. In particular, Patnaik (2022) uses a Bayesian Structural Vector Autoregressive (BSVAR) model pioneered by Baumeister and Hamilton (2015, 2019) to estimate the COVID-19 pandemic-induced shocks on output and inflation in India, finding a larger aggregate supply shock than demand shock. Similarly, Brinca, Duarte, and Faria-e-Castro, 2021 estimate the shocks of the COVID-19 pandemic on the US labor market using BSVAR conforming to Baumeister and Hamilton (2015). They again find greater evidence for characterizing COVID-19 pandemic as a supply shock, likely stemming from the curfews and lockdowns accompanying it.

Similar to those mentioned above, this paper also uses a BSVAR following Baumeister and Hamilton (2015, 2019) and Patnaik (2020) to study the shocks from the COVID-19 pandemic but applies it to the case of Bhutan.

CHAPTER 3

METHODOLOGY

3.1 Data

I use annual data for real GDP growth and CPI inflation for Bhutan from 1981 to 2021 since GDP data is only available annually. Data comes from National Statistics Bureau of Bhutan and World Bank.

Figure 1: Annual GDP growth rates: 1981-2021

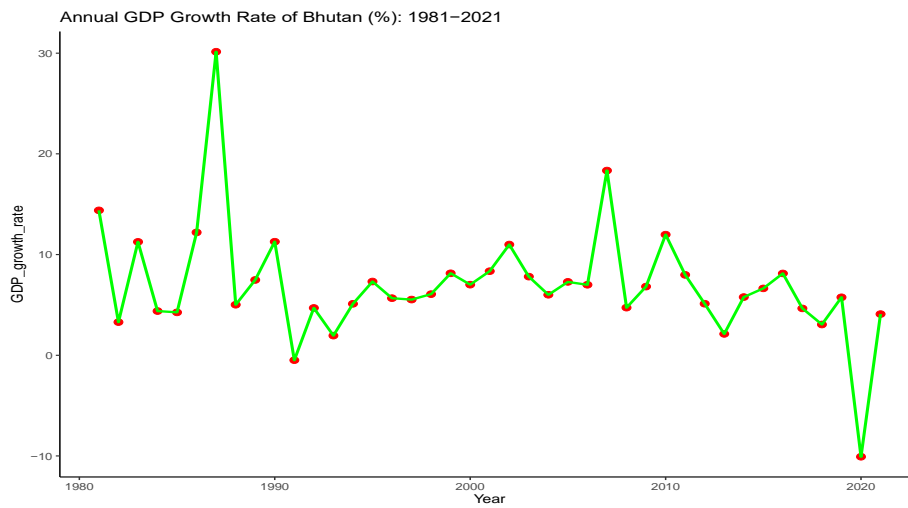
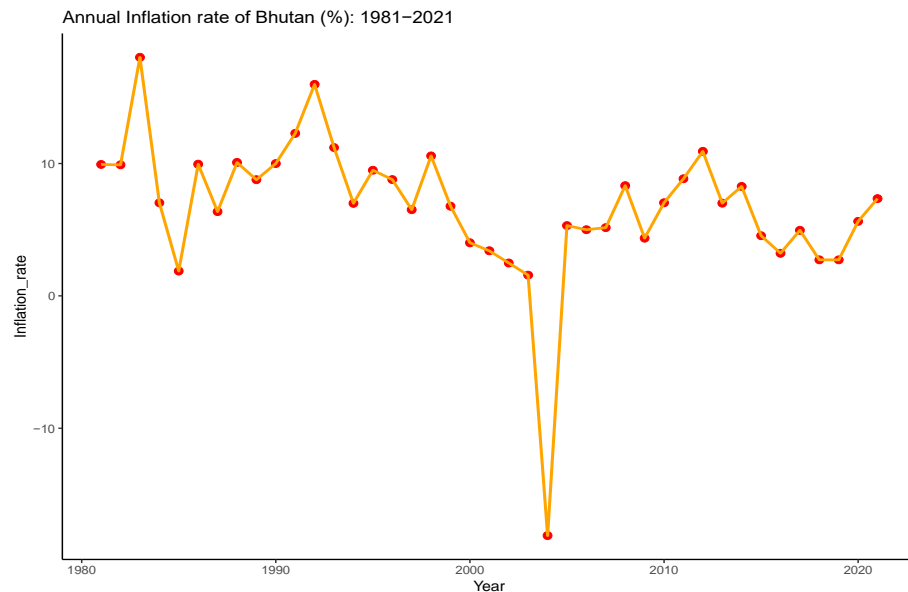


Figure 2: Annual Inflation rates (CPI): 1981-2021



3.2 Empirical Methodology

This paper follows the Baumeister and Hamilton (2015, 2019) methodology to estimate the aggregate demand shock and aggregate supply shock of the COVID-19 pandemic on real GDP growth and inflation.

3.2.1 Model Setup

Consider a dynamic Structural Vector Autoregressive (SVAR) model of the form:

$$Ax_t = Bz_{t-1} + U_t \text{-----} (1)$$

where x_t is an $(n \times 1)$ vector of endogenous variables, A is an $(n \times n)$ matrix denoting the contemporaneous structural relationships between the variables, z_{t-1} is a $(k \times 1)$ vector (where $k = mn + 1$) containing a constant and m lags of x_t ($x'_{t-1}, x'_{t-2}, \dots, x'_{t-m}, 1$), B is an $(n \times k)$ matrix of lagged structural coefficients, and U_t is an $(n \times 1)$ vector of structural innovations assumed to be independent and identically distributed. Transforming (1) to its reduced VAR form:

$$x_t = \Phi z_{t-1} + \varepsilon_t \text{-----}(2)$$

where, $\Phi = A^{-1}B$ and $\varepsilon_t = A^{-1}U_t$

3.2.2 Priors for the VAR

Baumeister and Hamilton (2019) incorporate prior information to identify the structural parameters, including elements of matrix A (structural parameters), elements of matrix B (lagged structural coefficients), and elements of the variance covariance matrix D . Generally, these informative priors are obtained from previous studies. For instance, Patnaik (2022) uses prior information of slope parameters for the aggregate supply curves and aggregate demand curves of India reported in Goyal and Kumar (2018) and Salunkhe and Patnaik (2019) in order to measure demand and supply shocks from the COVID-19 pandemic for the Indian economy. Whereas,

Brinca, Duarte, & Faria-e-Castro (2021) use informative priors on labor demand elasticity and labor supply elasticity from Baumeister and Hamilton (2015, 2018) to measure labor demand and supply shocks at the sectoral level around the COVID-19 pandemic, focusing on the US labor market.

I am aware of no similar informative priors for Bhutan. Instead, I also use the informative priors¹⁰ for the Indian economy due to the economic connections between the two. For instance, in 2020 trade with India accounted for 82 percent of Bhutan's total external trade. The imports from India accounted for 87 percent of Bhutan's total imports whereas 90 percent of exports went to India (Bhutan Trade Statistics, 2020). Many assume that the inflation in Bhutan is borrowed inflation. Kharka (2018) states that 66 percent of inflation in Bhutan is determined by Indian inflation. Since the launch of the Bhutanese currency – the Ngultrum (Nu.) in 1974 – its value has been pegged to the Indian Rupee. In fact, the Rupee is recognized as a legal tender in Bhutan and similarly, the Nu. is a legal tender in several Indian border towns with strong commercial ties to Bhutan.

Also, India contributed largely to Bhutan's development projects since 1961, fully financing the first two five-year development plans (1961-66 and 1966-71). For the 12th five-year plan (2018-2023), India granted Rs. 45 billion of the total Nu. 320 billion budget outlay, a little more than 14 percent of the total budget outlay.

¹⁰ Of course, differences remain as India is a much bigger country with greater demographic diversity. Nevertheless, given the lack of similar studies on Bhutan, I continue to apply findings from Indian studies to identify the structural parameters.

3.2.3 Priors for the Elements of Matrix A (the structural parameters)

More specifically, consider the following priors for the structural parameters. Both the GDP growth equation and the inflation equation are subject to supply and demand shocks. Let $A = \begin{bmatrix} 1 & -\beta_{12} \\ 1 & \beta_{22} \end{bmatrix}$ where $-\beta_{12}$ and β_{22} ¹¹ are the structural parameters of the GDP equation/inflation equation and therefore referred to as the price elasticity of aggregate supply and price elasticity of aggregate demand of GDP growth/inflation.

The values for the structural parameters and the sign restrictions come from Patnaik (2022). The sign of the price elasticity of aggregate supply (β_{12}) and price elasticity of aggregate demand (β_{22}) of GDP growth/inflation are assumed to be positive and negative, respectively. β_{12} follows a t-distribution with location parameter of 1.5 and scale parameter of 0.6 with three degrees of freedom observing 90 percent probability on $\beta_{12} \in [1.19, 2]$. Similarly, β_{22} follows a t-distribution with location parameter of -23.1 and scale parameter 0.6 with three degrees of freedom observing 90 percent probability on $\beta_{22} \in [-23, -23.5]$.

3.2.4 Elements of matrix B (lagged structural coefficients)

Following Baumeister and Hamilton (2019), prior information on lagged structural coefficients can be derived using the conditional Gaussian distributions, $b_i | A$,

¹¹ The sign of $-\beta_{12}$ and β_{22} changes contingent upon which side of the equation they are on. The BHSBVAR package specifies the matrix A on the left side of the equation, so you must reverse the sign of the parameter you're estimating. Hence, the price elasticity of supply, which we know is positive, will be reflected as negative and the price elasticity of demand, which we know is negative, will be reflected as positive. Appendix B has the details on model setup.

$$P(B | D, A) = \prod_{i=1}^n p(b_i | D, A) \text{-----}(3)$$

3.2.5 The variance covariance matrix D of the structural parameters

For the element of the diagonal matrix D, their reciprocals are assumed to be independent across equations and represented by $\Gamma(\kappa_i, \tau_i)$ distribution¹² for

$$P(D | A) = \prod_{i=1}^n p(d_{ii} | A) \text{-----}(4)$$

The joint distribution of A, D and B (equation 5) is obtained using the prior information such as $p(A, D, B)$. The posterior distribution (equation 6) is derived after applying Bayes' Theorem to the joint prior distribution.

$$p(A, D, B) = p(A) p(D | A) p(B | A, D) \text{-----}(5)$$

$$p(A, D, B | Y_T) = p(A | Y_T) p(D | A, Y_T) p(B | A, D, Y_T) \text{-----}(6)$$

Baumeister and Hamilton (2015, 2019) give the algorithm to generate n numbers of draws from the joint posterior distribution given in equation (6).

3.2.6 Historical Decompositions

The historical decompositions give the behavioral history of the supply and demand shocks. The structural shocks are derived from the residuals (ϵ_t) of the reduced form VAR as follows:

$$u_t = A\epsilon_t$$

The vector moving average representation of the VAR model is provided below:

$$x_t = \sum_{i=0}^{t-1} \Gamma_i u_{t-i} + K_t \text{-----}(7)$$

The historical decompositions are made over the auxiliary variables:

$$\tilde{x}_t = x_t - K_t = \sum_{i=0}^{t-1} \Gamma_i u_{t-i} \text{-----}(8)$$

¹² Γ denotes gamma distribution; κ_i denotes shape parameter; τ_i denotes scale parameter

Such that the historical decomposition of the i^{th} variable to the j^{th} shock is given by:

$$\tilde{x}^{i,j}_t = \sum_{i=0}^{t-1} \Gamma^{i,j}_i u^j_{t-1} \text{-----}(9)$$

The algorithm to estimate the historical decompositions at 95 percent confidence interval is incorporated in the BHSBVAR package of Richardson (2020).

CHAPTER 4

EMPIRICAL ANALYSIS

4.1 Preciseness of the Informative Priors

The prior and posterior distribution plots are generated to gauge the preciseness of the informative priors such as the Price Elasticity of Aggregate Demand and Price Elasticity of Aggregate Supply of GDP growth/Inflation. Appendix A shows the plots of the prior and posterior distribution.

For the Price Elasticity of Aggregate Demand, the fine red line (prior distribution) is skewed away from zero with a median of 1.5 while the larger blue region (posterior distribution) was skewed towards the origin with a median closer to zero. This indicates that the Indian prior belief on the Price Elasticity of Aggregate Supply is not so precise for this study.

For the Price Elasticity of Aggregate Supply, the prior and posterior distributions have closely the same median of -23.1. This suggests that the Indian prior belief on the Price Elasticity of Aggregate Demand is significantly applicable to this study.

Additionally, the negative median value corresponding to the Price Elasticity of Aggregate Demand indicates that the aggregate demand curve is downward sloping. While the positive median value of the Price Elasticity of Aggregate Supply implies that the aggregate supply curve is upward sloping.

4.2 Historical Decomposition of GDP Growth and Inflation

Historical Decomposition allows one to examine whether business cycle episodes were caused by supply shocks or demand shocks. I first examine pre-COVID shocks, both to provide a basis of comparison for what happened in 2020 as well as examine to what extent results coincide with important economic events in Bhutan's recent history (see figure 3).

4.2.1 Pre-COVID Episodes

The Southern Uprising (1991-1993) stemmed from low-scale protests in 1990 that exploded the following year (Shaw, 1993). The political turmoil persisted through 1993 (Sinha, 1994). Effects included disruption in trade with India, violence, destruction of land and property, cessation of commercial activities, closure of schools, hospitals, and public offices in the southern part of Bhutan (Shaw, 1993). My results show that the Southern Uprising was mainly characterized as a significant aggregate supply shock. The above effects damaged resources, shut down workplaces, and disrupted labor markets clearly resulting in supply shock.

Southern Bhutan borders Indian towns providing access to Indian markets and therefore plays a key strategic hub for trade and commerce. More than 90 percent of the total trade of Bhutan then was with India. The southern region is also an agricultural nucleus of Bhutan owing to an abundance of fertile lowlands in contrast to the rest of the regions in the country which are mostly mountainous. As the uprising had occurred in such a key strategic zone, a large chunk of economic and trade activities was forcefully frozen and agricultural practices were affected to a large extent.

It is evident that the supply side of the economy took a huge blow. Owing to all these consequences, output plummeted to -0.49, 4.70, and 1.95 percent, and inflation shot up to 12.28, 15.98, and 11.21 percent for the years 1991, 92, and 93 respectively. Whereas, in 1990, the GDP growth rate had been recorded at 11.28 percent with inflation of 10 percent. Therefore, my results largely conform to how one would think of this event.

As for the Economic Boom (2007), Bhutan began full operation of its Tala Hydropower

Project¹³ in March 2007, one of the biggest at the time, and the revenue generated from the hydropower sector doubled from Nu. 4312 million in 2006 to Nu. 8061 million in 2007 (National Statistics Bureau, 2009). So, the huge spike in GDP growth rate of 18.34 percent in 2007 was largely attributable to the upsurge in contribution from Tala Hydropower Project (Ura, 2015) which is clearly a positive supply shock. The Historical Decomposition for the year 2007 also shows a dominant positive aggregate supply shock behind the huge spike in GDP growth.

In 2008, Bhutan transitioned to a Democratic Constitutional Monarchy. The first and second quarters of 2008 have been essentially consumed by formation of democratic institutions and electoral activities. The GDP growth rate plummeted to 4.73 percent in 2008 from 18.34 percent in 2007. Historical Decomposition shows another dominant aggregate supply shock, presumably caused by the economic disruptions amidst the historic political activities.

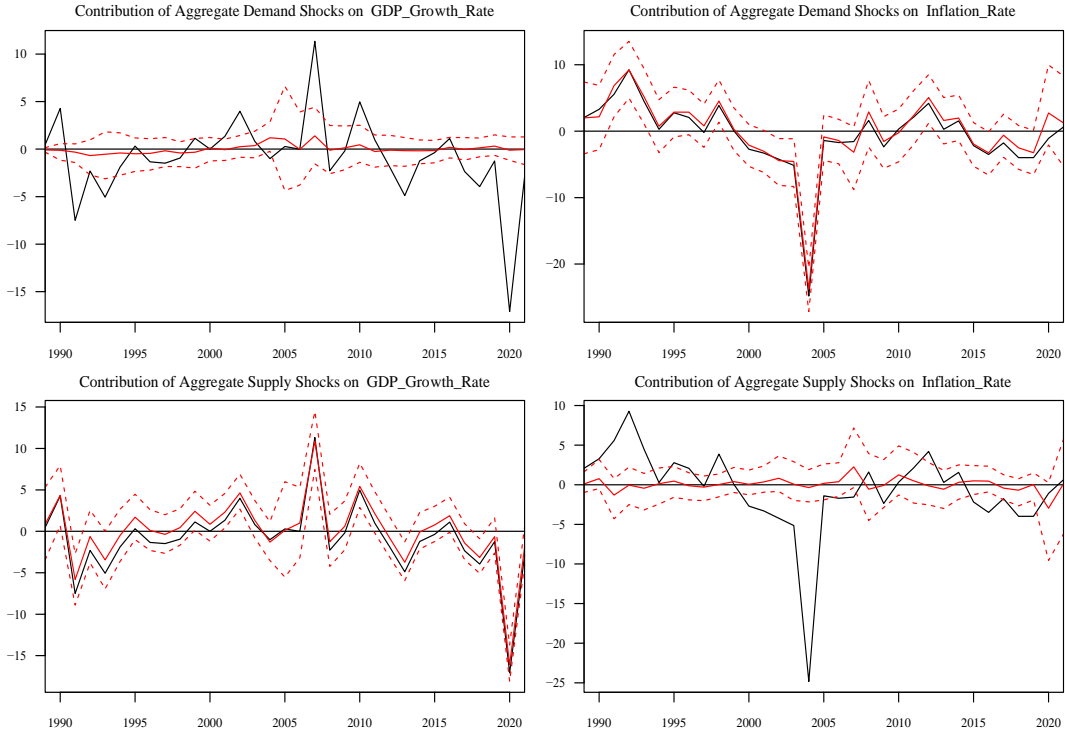
From early 2012 to 2013, Bhutan suffered from an acute shortage of Indian Rupees in its reserves (Rupee Crunch). With Rupees needing to be used to pay for the large quantity of imports from India as well as a large Rupee-denominated debt, an unparalleled level of stress was placed on the government's reserves of the Indian Rupee (Ura, 2015). The GDP growth fell from 8 percent in 2011 to 5.1 percent in 2012. The following year saw an even greater contraction with the political transition between the first and second-elected governments. An interim administration only performed the routine administrative duties creating an economic vacuum. The stress on businesses created another aggregate supply shock. Similarly, another

¹³ The first unit was operationalized in July 2006 and the last unit in March 2007 (see <https://www.drukgreen.bt/tala-hydropower-plant/>)

politically induced downturn is seen in 2018, once again, was felt by a large aggregate supply shock.

In summary as shown in Figure 3, Bhutan’s economic output movements were largely driven by aggregate supply shocks.

Figure 3: Historical Decomposition Plot -1989-2021¹⁴.



¹⁴ **Note:** The Horizontal axis indicates actual dates. Vertical axis indicates percent change. Black solid lines indicate mean-centered endogenous variables. Red solid line indicates the posterior median. Red dashed lines indicate credibility intervals.

4.2.2 The COVID-19 Episode

The downturn from the COVID-19 pandemic hit Bhutan hard. The mean-centered¹⁵ GDP growth plummeted to -17 percent in 2020, almost all of it (-16 or 94%) stemmed from the aggregate supply shock. The contribution from the aggregate demand shock remained highly negligible. As for inflation, it has increased to 5.63 percent in 2020 from 2.73 percent in 2019. Higher inflation during a downturn further points to aggregate supply shock as the dominant factor to explain business cycle movements.

Studies looking at other countries often find that the COVID-19 pandemic is best characterized as a supply shock (Bekaert, Engstrom, & Ermolov, 2020; del Rio-Chanona, Mealy, Pichler, Lafond, & Farmer, 2020; Fornaro & Wolf, 2020; Guerrieri, Lorenzoni, Straub, & Werning, 2020; Brinca, Duarte, & Faria-e-Castro, 2021; Baqae & Farhi, 2020; Patnaik, 2022). Similar findings here arise for Bhutan.

With the detection of the first COVID-19 case in Bhutan on the 6th of March 2020, a series of lockdowns including strict public health curfews were enacted. Much of the economy was initially shut down followed by a series of regional and zonal lockdowns until the middle of 2021. Services account for 43.5 percent of GDP followed by industry (36%) and agriculture, forestry, and livestock (15.8%) in 2019. The industry sector recorded the highest drop at -13.10 percent followed by services at -10.74 percent while the primary sector recorded growth at 4.57

¹⁵ Mean-centered values are obtained by subtracting the variable's mean from all observations on that variable in the dataset such that the variable's new mean is zero. For instance, the mean for the GDP growth dataset is 7.006 and subtracting the mean of 7.006 from -10.08 (GDP growth of 2020) gives -17.08 as the mean-centered GDP growth for 2020.

percent in 2020 compared to 2019. As the pandemic persisted and the situation became uncertain, almost 33,000 workers in the service and industry sectors were laid off, raising unemployment from 2.7 percent in 2019 to 5 percent in 2020. Many of the retained employees received partial paychecks. Although these falls in income decreased demand for goods and services, my results show that these events can best be explained as outcomes from the aggregate supply shock.

The government under the guidance of His Majesty the King responded to the downturn by establishing the National Resilience Fund totaling Nu. 30 billion. The fund was used to help households defer loan payments and to provide temporary cash transfers to vulnerable segments of the population.¹⁶ Such measures helped prop up aggregate demand. With the lifting of curfews and relaxation of the lockdowns, growth rebounded to 4.1 percent in 2021 in part due to the government intervention under the direct command and supervision of His Majesty the King.

¹⁶See <https://royalkidu.bt/category/news-press-release/index.html>

CHAPTER 5

CONCLUSION

This paper employs a Structural VAR from Baumeister and Hamilton (2015, 2019) to estimate aggregate demand and supply shocks from the COVID-19 pandemic on output and inflation in Bhutan. The empirical results show that Bhutan's output movements for both the pre-COVID-19 episodes and the COVID-19 episode were primarily driven by large aggregate supply shocks. Also, the higher inflation during the COVID-19 episode also implies that the aggregate supply shock dominated as the explanation for business cycle movements.

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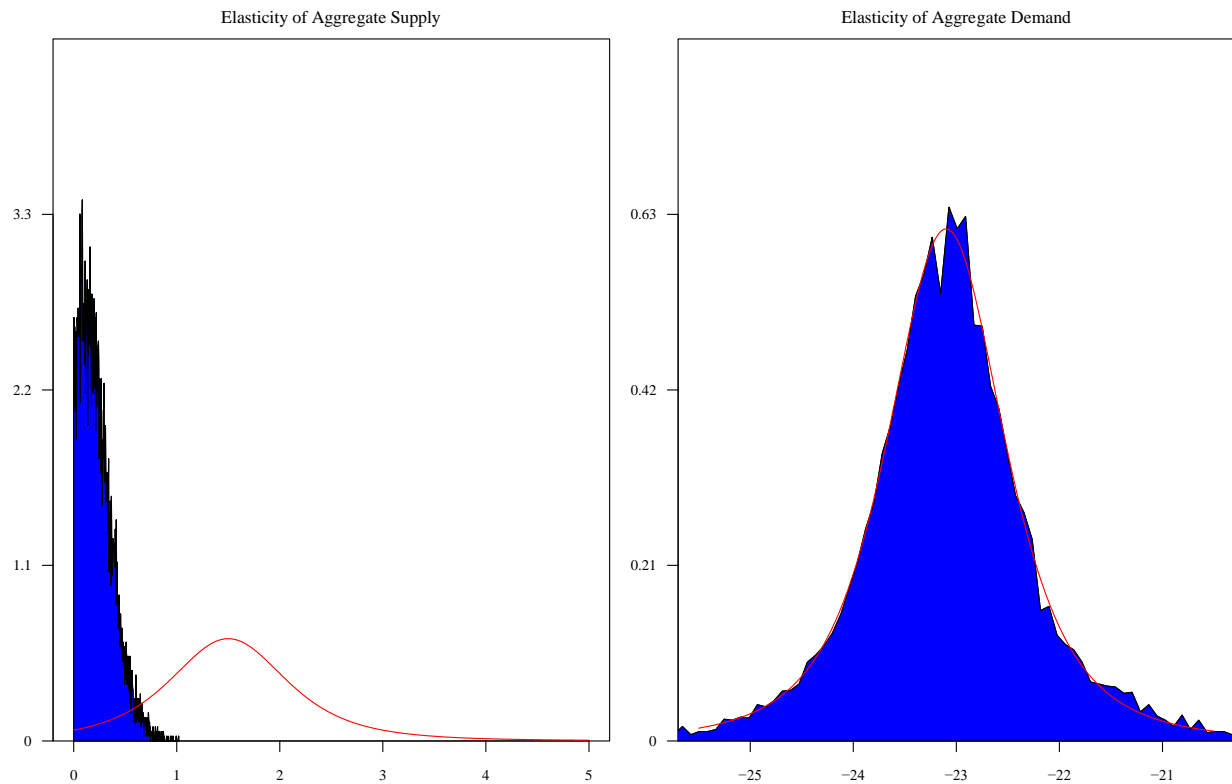
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APPENDIX A

THE PRIOR AND POSTERIOR DISTRIBUTION OF PRICE ELASTICITY OF OF AGGREGATE SUPPLY AND PRICE ELASTICITY OF AGGREGATE DEMAND



Note: The horizontal axis indicates the percentage change and the vertical axis indicates the density. The larger mass of solid blue region indicates posterior distribution and the fine red line indicates the prior distribution. If the blue region and the red line displays a good sync, then it indicates that the information priors were informative and benefits the data well.

APPENDIX B

MODEL SETUP DESCRIPTION

Consider the following expanded form of GDP growth equations which is subject to aggregate supply shock (U_t^s) and aggregate demand shock (U_t^d) respectively.

$$y_t = \beta_{10} + \beta_{12}\pi_t + \sum_{i=1}^m Y_{11} y_{t-i} + \sum_{i=1}^m Y_{12} \pi_{t-i} + U_t^s \text{-----}(1)$$

$$y_t = \beta_{20} - \beta_{22}\pi_t + \sum_{i=1}^m Y_{21} y_{t-i} + \sum_{i=1}^m Y_{22} \pi_{t-i} + U_t^d \text{-----}(2)$$

Where, y_t denotes GDP growth at time t ; β_{12} denotes price elasticity of aggregate supply which is taken as a positive value based on the informative prior indicating that the supply curve is upward sloping; π_t denotes inflation at time t ; m denotes number of lags for both GDP growth and inflation; Y_{11} and Y_{21} denote the structural coefficients of m lags GDP growth (y_{t-i}) and Y_{12} and Y_{22} denote the structural coefficients of m lags of inflation (π_{t-i}). $-\beta_{22}$ denotes price elasticity of aggregate demand which is taken as a negative value based on the prior belief indicating that the demand curve is downward sloping. β_{10} and β_{20} are intercepts for GDP growth equations corresponding to supply and demand shock respectively.

Converting equations (1) and (2) into matrix form:

$$y_t - \beta_{12}\pi_t = \beta_{10} + \sum_{i=1}^m Y_{11} y_{t-i} + \sum_{i=1}^m Y_{12} \pi_{t-i} + U_t^s \text{----Rearrangement of (1)}$$

$$y_t + \beta_{22}\pi_t = \beta_{20} + \sum_{i=1}^m Y_{21} y_{t-i} + \sum_{i=1}^m Y_{22} \pi_{t-i} + U_t^d \text{----Rearrangement of (2)}$$

$$\begin{bmatrix} 1 & -\beta_{12} \\ 1 & \beta_{22} \end{bmatrix} \begin{bmatrix} y_t \\ \pi_t \end{bmatrix} = \begin{bmatrix} \beta_{10} \\ \beta_{20} \end{bmatrix} + \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} y_{t-i} \\ \pi_{t-i} \end{bmatrix} + \begin{bmatrix} U_t^s \\ U_t^d \end{bmatrix} \text{-----}(3)$$

Deriving a dynamic Structural Vector Autoregressive (SVAR) model from the matrices in (3), we obtain:

$$Ax_t = B_0 + \sum_{i=1}^m B_i z_{t-i} + U_t \text{-----}(4)$$

Where, $A = \begin{bmatrix} 1 & -\beta_{12} \\ 1 & \beta_{22} \end{bmatrix}$; $x_t = \begin{bmatrix} y_t \\ \pi_t \end{bmatrix}$; $B_0 = \begin{bmatrix} \beta_{10} \\ \beta_{20} \end{bmatrix}$; $B_i = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}$; $z_{t-i} = \begin{bmatrix} y_{t-i} \\ \pi_{t-i} \end{bmatrix}$; $U_t = \begin{bmatrix} U_t^s \\ U_t^d \end{bmatrix}$

Transforming the equation (4) to its reduced VAR form:

$$x_t = \Phi z_{t-1} + \varepsilon_t \text{-----}(2)$$

where, $\Phi = A^{-1}B$ and $\varepsilon_t = A^{-1}U_t$

Similarly, we can replicate these steps to derive equations, convert into matrix form, obtain SVAR model and reduced VAR model for Inflation as well.

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