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DOI: https://doi.org/10.14195/2183-203X_55_2

Business Cycle Accounting for the COVID-19 Recession

Contabilidade de Ciclos Económicos na Recessão Covid-19

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Received for publication: January 14, 2022
Revision accepted for publication: April 15, 2022

ABSTRACT
We apply the Business Cycle Accounting framework to the COVID-19 recession in the Euro Area and the United States of America. We conclude that the efficiency wedge had the most important role in the Euro Area, followed by the labor and investment wedges. In the United States, the labor wedge was most crucial, with the investment wedge coming in second. We present hypotheses, supported by our theoretical framework, for the dichotomy of the role of the efficiency wedge between the studied regions.
Keywords: COVID-19; business cycle accounting; macroeconomics; financial crises; financial frictions; wedges.

JEL Classification: E32; E44

Acknowledgements: I am grateful for funding provided by Fundação para a Ciência e a Tecnologia (UID/ECO/00124/2013, UID/ECO/00124/2019 and Social Sciences DataLab, LISBOA 01 0145 FEDER 022209), POR Lisboa (LISBOA 01 0145 FEDER 007722, LISBOA 01 0145 FEDER 022209), POR Norte (LISBOA 01 0145 FEDER 022209) and CEECIND/02747/2018. A special thanks is also due to Prof. Pedro Brinca.

1. Introduction

The COVID-19 pandemic has objectively left a heavy mark on the world: as of December 2021, 272 million people have been infected by it, and more than 5 million people have deceased due to it, worldwide. However, the consequences of this pandemic were not only health-related as global supply chains were also dismantled, record high uncertainty stroke financial markets, and, to control the spread of the virus and its consequential loss of life, countries all over the world implemented social distancing norms. Most countries, during the initial and most severe phases of the pandemic, set restrictions to non-essential economic activities, thus disrupting consumption channels and labor markets.

Given the unconventional nature of this recession, and the difficulty of comparing its corresponding shocks with past studied events, researchers have struggled to decide which kinds of market frictions to add, when structuring their models. This creates space in covid-related literature to Business Cycle Accounting (BCA) exercises. BCA has its theoretical background on the neoclassical growth model, an area of economics pioneered by Abramovitz (1956) and Solow (1957). More specifically, it builds on Real Business Cycle modeling, introduced by Kydland and Prescott (1982), by deviating from the modelling of perfectly competitive markets with its introduction of wedges, which are representations of distortions of the equilibrium decisions of economic agents.

BCA, first introduced by Chari et al. (2002), is a method to infer which frictions are the most relevant in explaining macroeconomic fluctuations. It consists in two stages: 1) using a prototype economy to calculate wedges, and inputting them back in it, individually or in groups, to conclude which have the most quantitative relevance for economic observables; 2) implementing equivalence theorems, which are equivalence links between detailed economies/models and the prototype economy.

This paper applies this type of exercise to the economies of the Euro Area and United States, on the aftermath of the inception of the COVID-19 pandemic (2019:Q4-2021:Q2, in the case of the Euro Area, 2019:Q4-2021:Q3, in the case of the United States). We estimate four wedges: the efficiency wedge, the labor wedge, the investment wedge, and the government wedge. Since the literature for this most recent pandemic is still developing, there are no models to prove the equivalence results. Therefore, the focus of this paper is not the investigation of the origins of the economic shock caused by the pandemic, but to infer how each economy absorbed the shocks. This paper not only adds to the literature by directing interested researchers to the mechanisms most useful to understand fluctuations of economic indicators, but also hypothesizes how these mechanisms played out during the COVID-19 recession and its consequent recovery.

The rest of this paper is structured as follows: first, we summarize the research developments made in the area of BCA; second, we present the theoretical framework behind the used model; subsequently, we delineate the methods and sources used to come to the variables we describe in the theoretical framework; third, we present the results and analyze which wedges perform the best; and, finally, the conclusion summarizes the discussion.

2. Literature Review

Chari et al. (2002) introduces the first Business Cycle Accounting (BCA) exercise as an approach to model macroeconomic fluctuations using market distortions which were discussed in the literature as useful and realistic additions to the neoclassical growth model. Chari et al. (2005) adds to the BCA literature by introducing a government wedge. Chari et al. (2007a) consolidates previous BCA literature and builds on its theoretical framework.

Christiano and Davis (2006) criticizes the BCA exercise presented in Chari et al. (2007a) on two fronts: 1) some spillovers may be left out, since the model only identifies the transmission mechanisms of shocks, not the source of shocks; 2) the investment wedge's involvement, due to its specification, seems to be hindered by environmental changes (sometimes shifting the manifestation of financial shocks to other wedges, for example), with the authors suggesting a new distortion, the capital wedge. Chari et al. (2007b) responds to these criticisms with three arguments: 1) they prove that changing between the investment and capital wedges does not change equilibrium allocations; 2) they justify how their theoretical framework has a stronger footing in the literature; 3) using variance decomposition of forecast errors, they prove that the investment wedge does, in fact, absorb a moderate share of a financial shock.

Since Chari et al. (2007a), BCA has been applied to a wide range of periods, countries, and regions.[1] In addition, several alternative BCA methods were introduced, namely: Open-Economy BCA, which introduces distortions related to the international flows of debt, and was pioneered by He et al. (2009) and Otsu (2010b); International BCA, which adds frictions related to international prices and international trade, thus separating net exports from government spending, and was introduced by Otsu (2010a) and Hirata & Otsu (2011); and Monetary BCA, which includes disturbances associated with asset holdings and monetary policy, first applied by Sustek (2011) and Brinca (2013). Brinca et al. (2020) summarizes the theoretical background of these alternative methods, while providing an extensive review of the BCA literature.

3. Methodology

The BCA exercise proposed by Chari et al. (2007a) can be segmented in two different procedures: the accounting procedure and the equivalence result.

The accounting procedure comprises two different processes. The first, focuses in identifying four wedges: the efficiency wedge, the labor wedge, the investment wedge, and the government wedge. They were named this way, because at face-value they could be interpreted as productivity, labor income taxes, investment taxes and government consumption, respectively. Researchers should, nonetheless, be wary of interpreting the fluctuations of wedges as being caused by the variables referenced in their face-value names, since, for example, Mendoza (2010) shows that input-financing frictions are manifested through the efficiency, labor, and investment wedges, and not only through the investment wedge. The wedges should not thus be interpreted as identifiers of the origin of a given shock, but rather as a

[1] See Brinca (2014) and Dooyeon and Doblas-Madrid (2012) for two examples.

transmission mechanism, a channel through which the economy absorbs the shock. Wedges are calculated using a prototype economy. Given the origins of this accounting exercise being so closely linked to the neoclassical growth model, we assume that, inside the boundaries of our theoretical framework, agents are rational and that their resource-allocation decision in each period is based on the history of past realizations of said wedges in the economy.

The second process involves inputting the wedges back into the prototype economy, either one at a time, or by group. Since, by construction, the four wedges account for the entirety of macroeconomic fluctuations, feeding them all back would result in the replication of the observed data. The goal of this section is to understand which wedges (or group of wedges) can be the better predictors of some of the main economic indicators: output, labor, investment, and private consumption.

The equivalence result consists on the possibility of mapping a detailed economy with frictions into a prototype model with wedges. These mappings ensure that equilibrium allocations in both economies are the same, making the models observationally equivalent. The usefulness of the procedure is that by understanding which wedge is quantitatively more relevant, the appropriate equivalence theorems (for example between a detailed economy with sticky prices and the prototype economy with a labor wedge) can guide researchers into introducing additional mechanisms in the proper derivates of a standard Business Cycle Model. Chari et al. (2007a) and Brinca et al. (2016) present the theoretical proof of the equivalence result between the prototype economy and several detailed economies.

3.1. The prototype economy

Much like Chari et al. (2007) and Brinca et al. (2016), the model I use to represent the prototype economy is a stochastic growth model, where in each period t the economy will be impacted by a finite number of different events, s_t. The historical of all events in the economy up to moment t is denoted by $S^t = (s_0, \dots, s_t)$. The economic historical, S^t, determines current values of economic variables and is considered by the economic agents when predicting future values. The consumer population will maximize their expected lifetime utility, that is:

$$\sum_{t=0}^{\infty} \sum_{s^t} \pi_t(S^t)\beta^t U(c_t(S^t),\, l_t(S^t))N_t, \tag{1}$$

where $\pi_t(S^t)$ is the probability of S^t, β is the discounting factor, $U(.)$ is the utility function of a representative consumer, $c_t(S^t)$ is consumption per capita, $l_t(S^t)$ is labor supplied per capita, and N_t is the population size. The utility function is represented by:

$$U(c_t(S^t), l_t(S^t)) = \ln[c_t(S^t)] + \psi \ln[1 - l_t(S^t)], \tag{2}$$

where ψ is the time allocation parameter. Each representative consumer's utility will be limited by the following budget constraint:

$$c_t(S^t) + (1 + \tau_{x,t}(S^t))\, x_t(S^t) = (1 - \tau_{l,t}(S^t))\, w_t(S^t) l_t(S^t) + r_t(S^t) k_t(S^t) + T_t(S^t), \tag{3}$$

where $1/(1 + \tau_{tx})$ is the investment wedge, x_t is investment per capita, $(1 - \tau_{lx})$ is the labor wedge, w_t is the real wage rate, r_t is the real rate of return of capital, k_t is capital holdings per capita and T_t are lump-sum subsidies from the government per capita. In this model, the law of capital accumulation follows the following equation:

$$(1 - \gamma_N)k_{t+1}(S^t) = (1 - \delta)k_t(S^t) + x_t(S^t) + \Phi\left(\frac{x_t(S^t)}{k_{t-1}(S^t)}\right), \quad (4)$$

where δ is the depreciation rate and $\Phi\left(\frac{x_t(S^t)}{k_{t-1}(S^t)}\right)$ is the adjustment cost of capital, given by (Brinca et al., 2020):

$$\phi\left(\frac{x_t(S^t)}{k_{t-1}(S^t)}\right) = \frac{a}{2}\left(\frac{x_t(S^t)}{k_{t-1}(S^t)} - \delta - \gamma - \gamma_N\right)^2, \quad (5)$$

where a determines the marginal capital adjustment costs, γ is the growth rate of the technical ability of labor and γ_N is the population growth rate. In this economy, there are also firms, which produce according to the following equation:

$$\gamma_t(S^t) = A_t(S^t)F(k_t(S^{t-1}), (1 + \gamma)^t l_t(S^t)), \quad (6)$$

where $A_t(S^t)$ is the efficiency wedge and $F(.)$ is the production function, represented by:

$$F(k_t(S^{t-1}), (1 + \gamma)^t l_t(S^t)) = k_t(S^{t-1})^a[(1 + \gamma)^t l_t(S^t)]^{1-a}, \quad (7)$$

where α is the share of capital.

Finally, the firms' profit function is:

$$\Pi_t(S^t) = \gamma_t(S^t) - w_t(S^t)l_t(S^t) - r_t(S^t)k_t(S^{t-1}). \quad (8)$$

The equilibrium of the prototype economy can then be found with four equations: the production function (6); the national resource constraint:

$$y_t(S^t) = c_t(S^t) + g_t(S^t) + x_t(S^t), \quad (9)$$

where $g_t(S^t)$ is the government wedge; the function that captures the intra-temporal decision between labor and leisure:

$$-\frac{U_{l,t}(S^t)}{U_{c,t}(S^t)} = (1 - \tau_{lt}(S^t))A_t(S^t)(1 + \gamma)F_{l,t}, \quad (10)$$

where $U_{l,t}$ is the first-order derivative of the utility function with respect to labor, $U_{c,t}$ is the first-order derivative of the utility function with respect to consumption and $F_{l,t}$ is the first-order derivative of the production function with respect to labor; and the function that captures the inter-temporal decision between consumption and savings:

$$U_{c,t}(S^t)(1 + \tau_{xt}(S^t)) = \beta\sum_{S^t}\pi_t(S^{t+1} \mid S^t)\left[U_{c,t}(S^t)(A_{t+1}(S^{t+1})F_{k,t} + (1 - \delta)(1 + \tau_{x,t+1}(S^{t+1})) + \phi_{k,t+1}\right], \quad (11)$$

where $\pi_t(S^{t+1} | S^t)$ is the conditional probability of S^{t+1} given S^t and can also be represented by $\pi_t(S^{t+1})/\pi_t(S^t)$, and $\Phi_{k,t+1}$is the first order derivate of the capital adjustment cost function with respect to capital. Equations(10) and (11) are respectively obtained by the utility and profit maximizing decisions of consumers and firms. Solving each equation for a wedge, we have:

$$A_t(S^t) = \frac{F\left(k_t(S^{t-1}),(1+\gamma)^t l_t(S^t)\right)}{y_t(S^t)}, \tag{12}$$

$$g_t(S^t) = y_t(S^t) - c_t(S^t) - x_t(S^t), \tag{13}$$

$$\left(1-\tau_{l,t}(S^t)\right) = -\frac{U_{l,t}(S^t)}{U_{c,t}(S^t)A_t(S^t)(1+\gamma)F_{l,t}}, \tag{14}$$

$$\frac{1}{\left(1+\tau_{x,t}(S^t)\right)} = \frac{U_{c,t}(S^t)}{\beta \Sigma S^t \pi_t(S^{t+1} | S^t)\left[U_{c,t}(S^t)\left(A_{t+1}(S^{t+1})F_{k,t} + (1-\delta)\left(1+\tau_{x,t+1}(S^{t+1})\right) + \phi_{k,t+1}\right]\right.} \tag{15}$$

To get the equilibrium of the prototype economy, we need to do some assumptions. First, we assume:

$$k_0 = x_0, \tag{16}$$

to be able to get a value for capital for period 0. I will also assume values for parameters in the following chapter. With data on l_t, x_t, y_t, g_t and c_t, we can solve equations (12), (13) and (14), but not (15), since it holds an expectation term, $\pi_t(S^{t+1} | S^t)$. Just as Chari et al. (2007a) and Brinca et al. (2016), we will assume that expectations follow a first-order Markov process:

$$\pi_t(s_t | S^{t-1}) = \pi_t(s_t | s_{t-1}), \tag{17}$$

meaning that the conditional probability of S^t is the same whether we are taking in account all the historical events prior to the current period, S^{t-1}, or only the events of the previous period S_{t-1}. Hence, expectations for period $t + 1$ can be estimated with only S_t. If we also assume that the events S_t are mapped one-to-one to the wedges:

$$s_t = \left[A_t, 1-\tau_{l,t}, \frac{1}{(1+\tau_{x,t})}, g_t\right], \tag{18}$$

we can create a first-order autoregressive process for S_{t+1}:

$$s_{t+1} = P_0 + P s_t + \varepsilon_{t+1}, \tag{19}$$

where P_0 is a vector of constants, P is a 4x4 matrix of coefficients, and ε_{t+1} is a zero mean, independent and identically distributed, error term vector, which represents randomized exogenous shocks to the economy. The previously referenced stochastic character of the prototype economy has its root in this autoregressive process. ε_{t+1} 's covariance matrix, V, is semi-definite positive by construct. This way, there will be spillover effects between the wedges, not only due to the coefficient matrix, P, but also due to the error term's covariance matrix, *V*. This autoregressive process will be solved by applying a standard maximum likelihood procedure using the log-linear versions of the previously presented decision rules and six final variables which we describe in the next chapter.

4. Data and Application Details

We use quarterly data between 1995:Q1-2021:Q2, for the Euro Area, and 1965:Q1-2021:Q3, for the United States. The estimated periods were solely determined by the intersection of the periods with available data between the used data sources. The fifteen countries included to compute the aggregate values for the Euro Area were also determined by the intersection of the countries with available data, and are available in Annex I. Even though the USA states are much more synchronized in terms of business cycles than the Euro Area countries, the latter also shows a considerable degree of synchronization,[2] especially in core countries, which motivates this comparative exercise.

To be able to simulate the *prototype economy* and estimate the wedges, we use data for the United States and the Euro Area, of the following variables, with the following sources: gross capital formation (investment), GDP (output), private final consumption, government final consumption, exports of goods and services, imports of goods and services, hours worked, total employment and the GDP deflator, from the *OECD Economics Outlook* database, with the exception of exports and imports of goods and services for the Euro Area, which are from the *IMF Data* database; size of population aged between 15-64 from the *OECD.Stat* database; consumption of durable goods from the *OECD National Account Statistics* database; and average tax rate on goods and services from *OECD Data* database. The *IMF Data* database was used to calculate exports and imports out of and to the Euro Area, because it has a feature which discriminates the exports (imports) to (from) the country chosen by the user. This way, we can subtract the goods and services that the Euro Area exports and imports to and from itself from the aggregate values, as well as adjust for the exclusion of some of the Euro Area countries.

Hours worked and total employment will be used to calculate total labor. Net exports will be combined with government expenditure and be considered as one variable, g_t. Therefore, the *government wedge* will also capture fluctuations of the participation of the *prototype economy* in the international market of goods and services. For equivalence result purposes, an open economy model can be mapped into a closed economy in which net exports are added with government consumption, as proven in Chari et al. (2005). This also allows the study of international transmission of shocks.[3] The GDP deflator will be used as the price level, to obtain the real values of the economic variables.

To approach the economic decisions that most resemble the ones described in the last sub-chapter, we will need to do several adjustments to our variables. We will consider the consumption of durable goods as investment, needing thus to subtract the consumption of durable goods from total consumption and add it to investment. Assuming a depreciation

[2] See Aguiar-Conraria et al. (2017).

[3] See Brinca and Costa-Filho (2021a).

rate, δ_D, and a return rate, r_D, for the stock of consumption durables, we will also add back the depreciation and return values to consumption and, to maintain the resource constraint [equation (9)], to output too. We will also subtract the taxes of goods and services regarding the consumption of durables from investment and will subtract the rest from private consumption. To maintain the resource constraint [equation (9)], total taxes on consumption of goods and services will also be subtracted from output. Finally, the population size aged between 15-64 will be used to obtain the per capita version of the economic variables and population growth rate, γ_N, instead of total population size.

After all initial computations, we remain with five final variables which will be used to solve the maximum likelihood procedure described in the last section: output per capita; investment per capita; hours worked per capita; government consumption per capita; and private consumption per capita. These variables are logged and from them is removed their country/region-specific trend.

Looking at the fluctuation of the final variables during our period of study, during the first half of 2020, we can see a similar pattern in both studied regions: government consumption slightly increases, while the rest of the variables plummet. In spite of this, the recovery of these four indicators in each economy is contrasting: In the Euro Area, after a quick recovery, the most affected indicators either stagnate or fluctuate back downwards and upward; In the United States, the recovery process is much more successful, with hours worked being the only variable that couldn't retain its 2019:Q4 value. The initial drop in indicators in both regions, and subsequent drop of private consumption in the Euro Area coincides with the first and third wave of the pandemic, which indicate restrictions of economic activities as its main cause. The hike of U.S. investment can be partially explained by the 30% increase of consumption of durables, but more on that later.

Another interesting differentiation is the initial impact of hours worked, which, out of the initially affected variables, was the one with the smallest drop in the Euro Area, albeit being the most affected in the United States. This may be due to two reasons: 1) the more effective job retention schemes which European countries implemented, which alleviated the impact of the pandemic on the labor market and household income; 2) differentiation in unemployment accounting, as in the U.S., workers in lay-off are considered unemployed, while in the Euro Area, they are not (Anderton et. al 2020). Finally, the United States experienced a major decline of government consumption. This can be explained by net exports since it decreased almost 70% during the studied period.

Table 1: Model parameters

Region/Country	γ_N	γ	a	β	ψ	δ	α	δ_D	r_D
Euro Area	0.0003	0.0026	16.025	0.9937	2.5	0.0127	0.3333	0.0574	0.01
United States	0.0027	0.0045	12.563						

Notes: Parameters are rounded to the fourth decimal place; γ_N, γ are endogenous to the model.

The exogenous values of the model parameters, given in Table 1, were taken from Brinca et al. (2016) and chosen such that the annualized discounting factor, β, is 0.975; the annualized depreciation rate δ, is around 5%; the annualized depreciation rate of durables, δ_D, is 25%; and the annualized return rate of durables, r_D, is close to 4%. Following Bernanke et al. (1999) the parameter which determines the marginal capital adjustment costs, a, is such that the elasticity, $\eta = a(\delta + \gamma + \gamma_N)$, of the price of capital in regard to the investment-capital ratio, $\rho = \dfrac{1}{1-\phi(.)}$, equals 0.25.

5. **Results**

In Table 2 we display the parameters' matrixes regarding equation (19), which are estimated using a maximum likelihood process. The coefficient matrix of the Euro Area presents higher spillover effects between the variables, in comparison with the coefficient matrix of the United States.[4]

The rest of this chapter will be divided in three sub-chapters, the first two analyze the results for each region, and the third discusses the results. The wedges and economic variables presented in this section are all detrended and indexed with the peak quarter as its base, which as reported by the National Bureau of Economic Research, is the fourth quarter of 2019.

Table 2: Parameters of the stochastic AR(1) process, estimated using maximum likelihood

Coefficient Matrix, P					Standard Deviation Matrix, Q ($V = Q.Q'$)			
Euro Area (1995:Q1-2021:Q2)								
0.867	0.280	0.027	0.007		0.016	-0.007	0.011	0.002
0.072	0.956	0.133	-0.003		-0.007	0.005	-0.009	0.001
-0.145	0.0157	0.666	-0.013		0.011	-0.009	-0.004	-0.002
0	-0.167	-0.194	0.976		0.002	0.001	-0.002	0.007
Mean of States, $\bar{s}_t$ = [1.088, 0.512, -0.221, 0.182]					P_0 = [-0.1139, 0.0409, -0.0920, 0.0014]			
United States (1965:Q1-2021:Q3)								
0.937	0.042	0.045	-0.017		0.010	0.001	0.002	0
-0.033	1	0.054	-0.006		0.001	0.011	-0.004	0.001
0.063	-0.031	0.941	0.015		0.002	-0.004	0.013	0.016
0.090	-0.045	-0.022	1.012		0	0.001	0.016	-0.014
Mean of States, $\bar{s}_t$ = [1.144, 0.348, 0.090, 0.165]					P_0 = [-0.0411, -0.0113, 0.0340, 0.0280]			

Notes: Parameters are rounded to the third decimal place. Mean of States are given in absolute values.

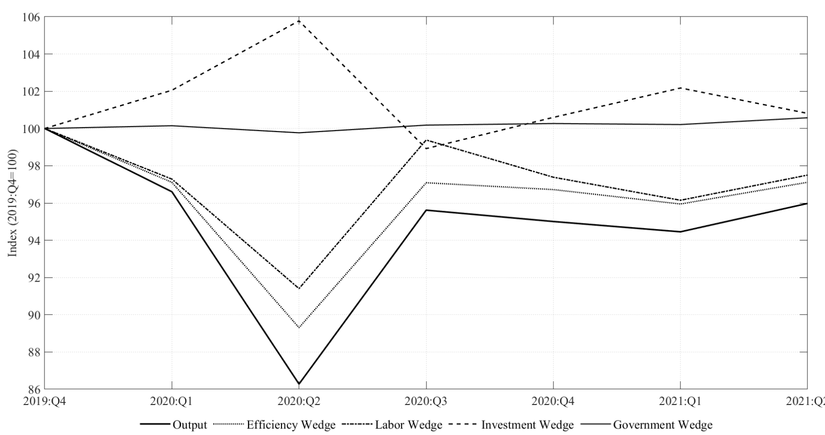
[4] For parameter identification issues, see Brinca et al. (2022).

5.1. Euro area

The investment wedge, contradicting its historical record, has a strong negative correlation with output, seemingly oppositely mirroring its movements. The government wedge holds absolutely no correlation with output, although historically it presents a modest negative correlation with output from the two preceding quarters, hinting at a lag of fiscal policy. The efficiency wedge is the one which most correlates with output, although its standard deviation is much smaller. The labor wedge's movement mimics that of output the most, due to its strong correlation and close standard deviation with output.

This, however, does not mean that the labor wedge is the best predictor of outcome, something that is best exemplified in Figure 1, which portrays output and the prototype economy's prediction of output when only inputting a wedge at a time. Actual output was worse than any wedge's prediction. The contribution of the efficiency wedge, as in last recessions, seems to be the strongest. Its predicted values of output are the closest to the actual values in all studied periods. Additionally, they virtually perfectly correlate with actual values, and their standard deviation is the closest to that of actual output. If the disturbance mechanism behind it was the only one in the economy, until 2020:Q2 output's decrease would have been 3% lower.

Figure 1: Output and modeled output with one wedge (Indexed, Euro Area, 2019:Q4-2021:Q2)



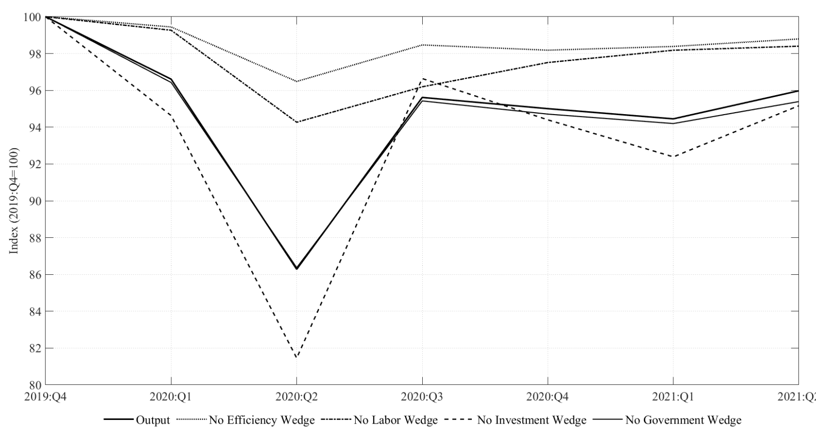
The labor wedge also seems to be a good predictor of output as well, as the correlation of its model values with output is 0.95. This, along with the 33% lower standard deviation, is an indication that, if it was the only wedge in the economy, output wouldn't have decreased has much during the first wave of the pandemic, by about 5%.

The government wedge's predicted values present the weakest correlation with and the farthest standard deviation of that of actual output, which is a signal that it does not capture any disruption mechanism that is essential to understand to study the economy of the Euro Area during the COVID-19 Recession. Historically, its contribution is negligible as well.

The investment wedge's predicted values differ the most from the real ones, with the correlation between them being -0.84. They also fluctuated significantly less than output, by about 47%. Historically, its correlation with output is mediocre, although its correlation with the prediction values of the labor wedge is a very strong -0.91, which can be a sign of a mechanism of decreased savings in bonanzas and increased savings in periods of higher labor uncertainty, or of compensation between labor and capital, when there are market disruptions.

This relation between the investment wedge's predictions and actual output should not lead to any conclusions that disruptions in the investment market are not an important component of output. In Figure 2, we display the prototype economy's predicted values of output when we input all but one of the wedges. As we can see, even though when we exclude the investment wedge, the model's predictions are the second best, it seems that its inclusion somewhat offsets the excessive negative impact that the combination of the efficiency and labor wedges have on output. When we exclude it, predicted output falls 4.2% more than actual output during the first half of 2020. The investment wedge's positive impact on outcome seem to coincide with the periods associated with the strongest restrictions to economic activity, during the first and third wave of the pandemic. Note also that financial frictions must not necessarily be mapped onto the investment wedge. The financial system has two main functions: channel resources to their most efficient uses and transfer resources across time and states of the world. Obstacles to the latter will show up as distortions to equation (11), and thus, the investment wedge. Nonetheless, the former is essentially a misallocation issue, and as such, it will be captured by the efficiency wedge.[5]

Figure 2: Output and modeled output with all but one wedge (Indexed, Euro Area, 2019:Q4-2021:Q2)



[5] For an example of a model with financial frictions that show up in the efficiency wedge, see Brinca and Costa--Filho (2021b).

The model's predictions when excluding the other wedges were much more predictable: when excluding the government wedge, the prototype economy nearly perfectly predicts actual values of output, diverging slightly during the last two studied quarters; when excluding the labor and efficiency wedges, the model's predictions are much more positive, which is a further indication of the negative impact these disruptions had on output during the analyzed period.

To conclude our inference on which wedges most influence output, we present each model prediction's θ statistic, as in Brinca et al. (2016):

$$\theta_i^Y = \frac{1/\Sigma_t \left(Y_t - Y_{t,i}\right)^2}{\Sigma_j 1/\Sigma_t \left(Yt - Y_{t,j}\right)^2}$$

where Y_t is detrended output and $Y_{t,i}$ is the prototype economy's prediction of output using wedge i (or all wedges with the exception of wedge i). The better the output prediction is, the smaller $(Y_t - Y_{t,i})$ will be, and hence, the closer the θ statistic will be from 1.

In Table 3 we display the θ statistics for the Euro Area. Taking in account one wedge economies, the efficiency wedge displays the biggest contribution to output, with the labor wedge taking a distant second place. Taking in account all but one wedge economies, however, only the government wedge appears to have an unimportant contribution to output. Considering our previous explanation of the dichotomy between the seemingly unimportance of the investment wedge in the one wedge economies and the modest contribution in the all but one wedge economies, it takes us to infer that only the government wedge had an insignificant effect on output, with the efficiency wedge taking center stage.

Table 3: The contribution of each wedge in the variation of output (Euro Area, 2019:Q4-2021:Q2)

θ_e^Y	θ_l^Y	θ_x^Y	θ_g^Y
One Wedge Economies			
69%	24%	2%	4%
All But One Wedge Economies			
86%	78%	36%	---- (Excluded from the calculation)

Notes: The reported values are rounded to the second decimal place. For better interpretation, the All But One Wedge Economies present $(1 - \theta)$, instead of θ. The predictive power of the model without this government wedge was too strong, distorting the θ statistic of other wedges, making them appear to contribute more than they actually do. Table with complete statistics can be found in Annex II.

In terms of other economic variables, the labor wedge, unsurprisingly, is the best predictor of detrended hours worked in one wedge economies. Its predicted values have a correlation of 0.90 with hours worked, only surpassed by the efficiency wedge's, which is 0.99. Nevertheless, the low standard deviation of the predicted values by the efficiency wedge, 54% lower than that of hours worked, hints at a weaker impact in the labor market, in comparison with the labor wedge.

Table 4: The contribution of each wedge in the variation of economic variables (Euro Area, 2019:Q4-2021:Q2)

θ_e^H	θ_l^H	θ_x^H	θ_g^H	θ_e^X	θ_l^X	θ_x^X	θ_g^X	θ_e^C	θ_l^C	θ_x^C	θ_g^C
One wedge economies											
36%	50%	4%	11%	62%	27%	2%	9%	29%	36%	50%	4%
All but one wedge economies											
26%	94%	81%	*----	79%	54%	68%	----	95%	96%	83%	26%

Notes: Parameters are rounded to the second decimal place. For better interpretation, the All but one wedge economies present (1 – θ), instead of θ; The predictive power of the model without the government wedge was too strong, distorting the θ statistic of other wedges, making them appear to contribute more than they actually do. The table with complete calculation can be found in Annex II.

In all but one wedge economies, a similar scenario as in output's modelling happens: the government wedge is the only disturbance whose impact is irrelevant, but this time the labor wedge takes center stage, with the investment wedge on a close second.

The investment wedge has the same offsetting effect as in output, as detrended hours worked would have decreased 7.5% more than the actual 9% if its fluctuation had been null.

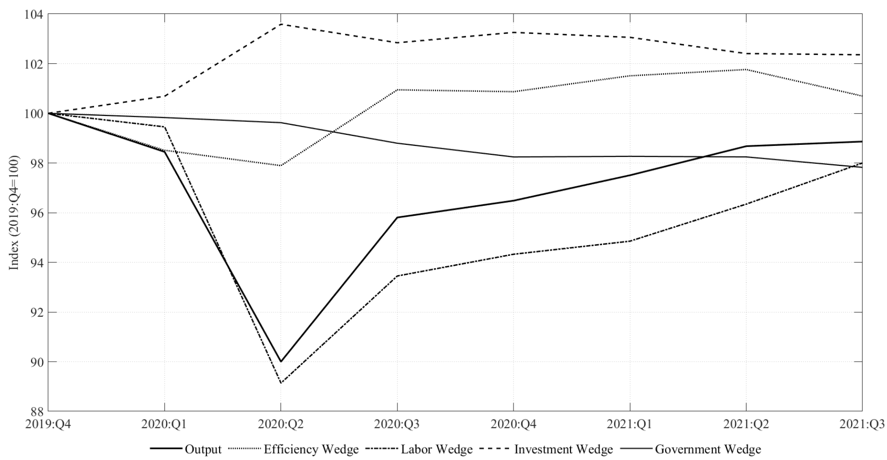
Investment's modelling follows a similar layout as output: in one wedge economies, the efficiency wedge's prediction values are the best, followed by the labor wedge, at a far second, while the investment wedge looks inconsequential; in all but one wedge economies, only the government wedge's effect is negligible, while the θ statistic indicates that the investment wedge contributes more than the labor wedge.

Private consumption's modelling has a varying feature in comparison with the other variables, which is a strong positive correlation between the investment wedge's predictions and actual values, of 0.96, so there is no offsetting mechanism. This, along with the closest standard deviation to actual consumption, makes it the best predictor in one wedge economies, although the contribution of the labor and efficiency wedges is much more evenly allocated, since their forecasts are the most correlated with actual values. In all but one wedge economies, and considering all wedges, the prototype economy manifests its most accurate predictions, although the government wedge still has the least vital contribution.

5.2. United States

Generally, we can say that the United States wedges are more heterogeneous than the Euro Area ones. Their relative fluctuation is higher too, with average standard deviation being 30% higher than that of its output, while in the Euro Area it is 16% lower. This is due to a more stable output. The investment wedge, as in the Euro Area, seems to be oppositely mirroring output, although historically, except during the Great Recession, it has no correlation with it. The government wedge has the weakest correlation with output and the standard deviation furthest away from that of output, being 101% higher. The efficiency wedge, despite having a moderate correlation with output, barely fluctuates. The labor wedge seems to be the one whose motion most closely imitates output, having the highest correlation with it. Historically, it also seems to be the most important wedge.

Figure 3: Output and modeled output with one wedge (Indexed, United States, 2019:Q4-2021:Q3)



The argument for the importance of the labor wedge continues in Figure 3, which presents output along with the one wedge economies' prediction of output. Not only the labor wedge's forecast values correlation of 0.93 with output is high, but its standard deviation only surpasses output's by 14%. If the labor market's disturbance mechanisms were the only in the economy, output would have decreased only 0.9% more than in reality, albeit it persisted below actual values between 2.3% and 2.6% of the base value, during the proceeding years. This apparent intense contribution to output variation may be due to the record high unemployment, whose rate increased from 4.4% to 14.8%, between March and April 2020.[6] Historically, it fluctuates along real values, having a correlation of 0.77 with them, despite diverging away from them only five years before the base period.

The government wedge seems to have a very negligible role in setting up output, as its predicted values decreased very gradually along the entire studied period, stagnating for three quarters, between the end of 2020 and middle of 2021. This is best exemplified by its standard deviation and correlation with output, both the lowest and weakest among the wedges' forecasts, being 73% lower than that of output and -0.18, respectively. Historically, it has a somewhat stronger negative correlation with output, with the 1990s and initial period of the Great Recession showcasing this relation the best.

[6] See Annex IV.

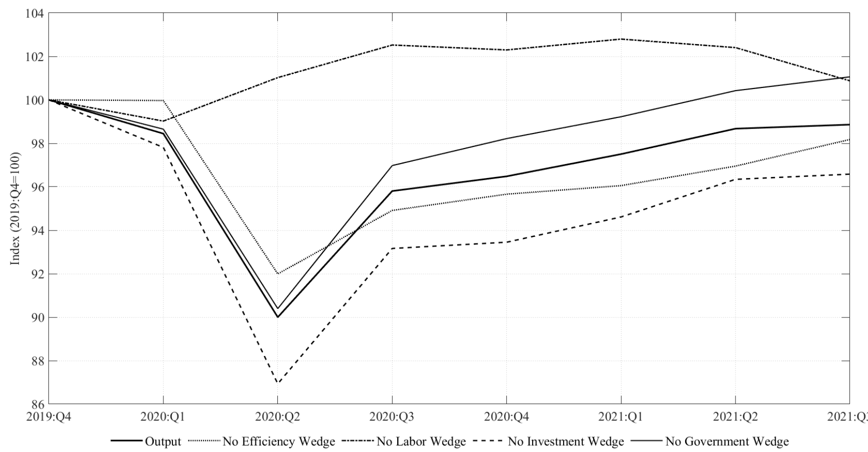
The investment wedge also seems to be a poor sole predictor of output: when only imputing it back in the prototype economy, it estimates output fluctuations which oppositely mirror actual output, increasing 3.6% until 2020:Q2 and then consistently and slowly decreasing until reaching a value 2.4% higher than the base value. Its negative correlation with output is moderately strong, although its standard deviation is 59% lower than that of output. Historically, it has a negligible correlation with output, although it fluctuated along it during the Great Recession and the preceding years.

The efficiency wedge's contribution to output in the United States contrasts with that of the Euro Area, as it has a much lower correlation with its output and a much lower relative standard deviation, 54.5% lower than that of output. Nonetheless, with the exception of the last studied quarter, it fluctuates similarly as output, although it surpasses and endures above its base value during and after 2020:Q3. Historically, it has the weakest correlation with output, in spite of having the standard deviation most similar to that of output. Just like the efficiency wedge its fluctuation matches that of output until the middle of the 1980s decade.

For further examination, we display the estimations of output of all but one wedge economies in Figure 4. Excluding the labor wedge results in the biggest discrepancy in predictions, in comparison with the actual values. Had it not been for labor market disruptions, detrended output would actually increase 1% over the first half of 2020, reaching its maximum point of 2.8% above its base value, in the first quarter of 2021, before converging back near its 2019:Q4 reference point until the end of the sample. This is an indication that the labor wedge is a crucial mechanism to study to be able to understand the COVID-19 Recession in the United States. Historically the labor wedge seems unimportant from the 1990s up to the pre-Great Recession period, but the most relevant wedge from the beginning of the sample up the end to of the 1980s, and from the Great Recession until 2017.

Just like in the Euro Area, the investment wedge has an offsetting effect on output. In the absence of investment market disturbances, output would have decreased 13.1% until 2020:Q2, 3.1% more than in reality. This divergence from real values continues until the end of the sample. Estimated output does, however, fluctuate similarly as actual output. This can be justified with the hike in credit deferral during the first wave of the pandemic and the subsequent persistence of a reasonable percentage of deferrals. Historically the absence of the investment wedge seems to affect output the least out of all wedges.

Figure 4: Output and modeled output with all but one wedge (Indexed, United States, 2019:Q4-2021:Q3)



On the opposite side, the government and efficiency wedges have the slightest influence on output: with the absence of government disruptions, output would have barely changed through the first couple quarters of the pandemic, although it overestimates it by a margin of 1.2% to 2.2% until the last quarter of our studied period; with the absence of efficiency disturbances, output would have only decreased 8% until 2020:Q2, although its weaker relative recuperation means it would fall behind actual output by 0.7% and 1.7% until the end of the sample. The government wedge's negative effect on output on the aftermath of the initial economic shock can easily be explained by the strong decrease of net exports depicted in the last chapter.

Table 5: The contribution of each wedge in the variation of output (United States, 2019:Q4-2021:Q3)

θ_e^Y	θ_l^Y	θ_x^Y	θ_g^Y
One Wedge Economies			
12%	67%	5%	16%
All But One Wedge Economies			
55%	98%	87%	61%

Note: The reported values are rounded to the second decimal place. For better interpretation, the All But One Wedge Economies present $(1-\theta)$, instead of θ.

Looking at the θ statistics for one wedge and all but one wedge economies, shown in Table 5, we can support our argument that, in the U.S., the labor wedge overwhelmingly provides the biggest contribution in explaining fluctuations in output. At a far second place, we would place the investment wedge, whose low θ statistic in one wedge economies can be excused, given the formula's averse character in dealing with values which contrast real output. In reality, the investment wedge's offsetting feature provides strong complementary predictive value to the labor wedge. The government and efficiency wedges, however, seem to have an ineffective conduct during this last recession. Interestingly enough, the efficiency wedge, which is found to be the one with least explanatory power, is the wedge which is found to be most important in past literature.[7] This further adds to the unconventional nature of the economic shock caused by the COVID-19 pandemic.

Table 6: The contribution of each wedge in the variation of other economic variables (United States, 2019:Q4-2021:Q3)

θ_e^H	θ_l^H	θ_x^H	θ_g^H	θ_e^X	θ_l^X	θ_x^X	θ_g^X	θ_e^C	θ_l^C	θ_x^C	θ_g^C
One Wedge Economies											
8%	76%	3%	13%	73%	5%	3%	20%	6%	57%	31%	5%
All But One Wedge Economies											
----	96%	75%	29%	55%	98.2%	98.1%	49%	50%	95%	94%	62%

Notes: The reported values are rounded to the second decimal place, for values below 98%, and rounded to the third decimal place, for values above 98%. For better interpretation, the All But One Wedge Economies present $(1 - \theta)$, instead of θ. The predictive power of the economy without the efficiency wedge was too strong this wedge was too strong, distorting the θ statistic of other wedges, making them appear to contribute more than they actually do. Table with complete calculation can be found in Annex III.

In terms of estimating other variables, the labor and investment wedges clearly hold the main predictive power for hours worked, with their forecast values having the biggest correlations with it, of 0.92 and -0.52 respectively, and the standard deviations closest to that of it, being 38% higher and 12.1% lower, respectively. The labor wedge seems to be a better estimator though, with the investment wedge taking a moderately distant second place. The efficiency wedge's role here is absolutely null, while the government wedge seems to have a very slight negative effect as net exports plummeted.

In predicting investment values, an interesting anomaly arises: the efficiency and government wedges, which look to be the disturbances with the biggest predictive power in one wedge economies, turn out to be the disturbances with the weakest forecasting power in all but one wedge economies. This happens for two reasons: 1) the labor and investment wedges have very strong contributions of nearly even power, but with much different effects, with labor and investment market disruptions respectively pushing investment downwards and upwards, which results in investment fluctuating around its base value; 2) the forecasts of the efficiency and government wedges hold low standard deviations, respectively 53% and 81% lower than that of investment, which retains them near their base values, thus resulting in a low $(Y_t - Y_{t,i})^2$, and consequently, a high θ statistic. Interestingly enough, the efficiency wedge's estimation values also hold by far the biggest correlation with investment, of 0.91, although that does not seem to translate into predictive power.

[7] See Brinca et al. (2020).

The labor and investment wedges also seem to be the best predictors of private consumption, with their forecasts holding the highest correlations and the standard deviations closest to actual values. Just as with hours worked, the labor wedge hold the strongest predictive power, while the efficiency and government wedges' contribution is unimportant.

5.3. Discussion

Comparing the shock-absorption mechanisms of the studied regions, we can start to paint the bigger picture. The pandemic rose unemployment to record levels in recent history[8], not only due to temporary and permanent closures of businesses, as a consequence of restrictions to economic activity, but also due to older laborers leaving the workforce, to avoid the risk of contagion (Coibion et al., 2020). This decrease of labor was heterogeneous between the U.S. and the Euro Area: in the former, from January 2020 until its peak, seasonally adjusted unemployment surged from 3.5% to 14.8%, while in the latter it only grew from 7.1% to 8.7%[8]. This is due to two reasons: 1) the more effective job retention programs implemented in Europe, since in April, an estimated 32 million workers, which is three times the number of unemployed, were part of these schemes; 2) the different accounting methods between both regions, as, in the U.S., workers in temporary lay-off are considered unemployed, while in the Euro Area, they are not (Anderton et al., 2020). Despite this second point, hours worked decreased 12% in the U.S. (the highest among the main economic variables), in comparison with the 9% of the Euro Area (the lowest among the main economic variables, excluding government consumption). So, although the U.S. also had several job retention schemes, they seem to not have been as effective.

Another important point for the relevance of the *labor wedge* in the U.S. is that two thirds of the of the fall in the growth rate of hours worked, between March and April of 2020, can be attributed to labor supply. The reasoning behind this, as hinted before, may be workers wanting to avoid risk of contagion, since sectors with a smaller share of employees working from home experienced the highest labor supply decreases (Brinca et al. 2021).

This is crucial to understand the mechanism behind our wedges. Assuming a production function as in Equation 6, faced with a negative shock demand, output, Y_t, decreases. If we also assume sticky wages and rental rates, firms' optimal choice would be to decrease the quantity of its inputs, k_t and l_t. This was what happened in the United States, as detrended investment and labor respectively decreased 11.9% and 12% during the first half of 2020, in comparison with output's 10%. Our prototype economy then majorly composes the shock through the labor and investment wedges. In the Euro Area, however, since such a substantial decrease of labor was prevented with job retention programs, for equation (6) to hold, capital, k_t, and/or the efficiency wedge, A_t, had to compensate.

The investment wedge, however, had a positive impact on output of both regions, meaning that, to decrease the capital stock to the firm's optimal level, investment should have dropped even further. The interpretation for this phenomenon may be supported by on one and/or three lines of thinking: 1) given the temporary nature of the recession, firms maintained a

[8] See online appendix, Annex IV.

higher percentage of their capital stock to be prepared for the reopening of the economy; 2) credit deferral and moratorium programs, which contributed to distort the intertemporal decision between consumption and savings (equations (11) and (3)) historically low interest rates, which decreased not only due to the recession, as a consequence of the combination of a decrease in aggregate demand and increase in savings (Jordà et al., 2020), but also due to central banking intervention, as the monetary aggregates were largely increased. The extraordinary increase of the savings rate may be attributed to the consumption channels being blocked due to restrictions to economic activity, but its persistence to remain above pre-pandemic levels, even in periods of economic reopening may be due to record high levels of uncertainty (Baker et al., 2020). In view of investment's reaction, the *efficiency wedge* was forced downwards in the Euro Area.

6. **Conclusion**

This paper intends to provide value added to the BCA literature by guiding researchers to which kinds of disturbances and market frictions they should try to model in order to better examine the economic shock caused by the COVID-19 pandemic, both in the Euro Area and the United States.

Using a prototype economy similar as that displayed in Chari et al. (2007a), we estimated wedges which represent disruptions associated with government consumption, labor markets, investment markets and efficiency. We found that in the Euro Area, the efficiency wedge had a crucial role, while the labor wedge was substantial and the investment wedge was relevant, albeit having a relatively smaller influence. In the United States, however, the labor wedge was the most important disruption, with the investment wedge taking a moderate second place.

In particular, we found that: the differences of the effect the efficiency wedge in each region seems to be originated in the higher effectiveness of European job retention schemes; the labor wedge's fluctuations were largely influenced by restrictions to economic activity which accompanied the pandemic; and the investment wedge's upwards effect on output seems to be rooted by a higher-than-expected capital retention rate, possibly moved by expectations of quick liftings of the restrictions to economic activity, moratorium and credit deferral program, and/or also possibly moved by low interest rates.

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Annex

Annexes I, II, III, and IV are available from the author upon request.