

## ABSTRACT

This article analyzes the sources of business cycle fluctuations in Portugal using the business cycle accounting methodology developed by Chari *et al.*, (2007). In this approach, various types of distortions are represented as “wedges” in standard equilibrium relationships. This allows a quantitative assessment of the relative importance of those wedges. It is found that distortions affecting total factor productivity play a key role in explaining the behavior of output from 1998 through 2012.

## 1. Introduction

In this article I apply the business cycle accounting methodology developed by Chari *et al.*, (2007) to Portuguese data from 1998 through 2012. The objective of the analysis is to determine the type of distortions that are necessary for models of the Portuguese economy to be able to generate business cycle fluctuations similar to those observed in the data. In a nutshell, the methodology consists of introducing several time-varying wedges to a standard real business cycle model and analyzing their contributions to observed fluctuations in aggregate macroeconomic variables. As Chari *et al.*, (2007) show, many dynamic economic models, with various types of frictions and structural shocks, are equivalent to a prototype model with four wedges that enter in the model as time-varying productivity, labor income taxes, investment taxes and government consumption. For example, the effects of investment-financing frictions, taxes on consumption or capital income are captured by the investment wedge. The efficiency wedge may reflect variations in total factor productivity or input-financing frictions. Also, a monetary model with sticky wages or labor unions is observationally equivalent to a real business cycle model with a labor wedge. These equivalence results imply that the effects of shocks and frictions in a detailed model can be replicated in the prototype model as movements in one or more of the wedges. By construction, the combined effect of the four wedges accounts for all of the observed movements in the data. Applying the accounting procedure shows the importance of each wedge and thus of the underlying types of frictions that are captured by it. Hence, this approach can be used to identify the classes of models and mechanisms that are promising venues for future research and those that are not.

Applying the business cycle accounting methodology to Portuguese data shows that while three of the wedges - efficiency, labor and investment, play a role during different business cycle episodes, the efficiency wedge is consistently the main factor driving output during the period from 1998 through 2012. Interestingly, very similar conclusions were reached by Cavalcanti (2007) who also applied the business cycle accounting procedure to the Portuguese economy. The difference between this article and Cavalcanti (2007) is that he studies an earlier period, from 1979 until 2000, and uses annual instead of quarterly data as in this paper.

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\* The opinions expressed in the article are those of the author and do not necessarily coincide with those of Banco de Portugal or the Eurosystem. Any errors and omissions are his sole responsibility.

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## 2. Methodology

The business cycle accounting approach consists of three steps. First, a prototype model economy perturbed by various distortions, or wedges, is introduced. Second, the model is estimated and the realized processes for the wedges are recovered. Third, the marginal importance of each wedge is evaluated by decomposing the observed fluctuations in data into movements due to each wedge. These steps are described in detail next.

### 2.1. The model

The model economy consists of a representative consumer, a representative producer and a government. In each period  $t$  the economy experiences one of finitely many events  $s_t$ . At time  $t$  the history of events is denoted by  $s^t = (s_0, \dots, s_t)$ . The probability at time 0 of history  $s^t$  is  $\pi_t(s^t)$  with the initial realization of event  $s_0$  being exogenously given. The economy has four exogenous stochastic variables, all of which are functions of the history of events  $s^t$ : an efficiency wedge  $A_t(s^t)$ , a labor wedge  $1 - \tau_l(s^t)$ , an investment wedge  $1 / (1 + \tau_x(s^t))$  and a government consumption wedge  $g_t(s^t)$ .<sup>1</sup>

The representative consumer chooses per capita consumption ( $c_t$ ) and labor ( $l_t$ ) to maximize her discounted lifetime utility

$$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi_t(s^t) \left( \log(c_t) + \psi \log(1 - l_t) \right) N_t \quad (1.1)$$

subject to the budget constraint

$$c_t(s^t) + (1 + \tau_x(s^t))x_t(s^t) = (1 - \tau_l(s^t))w_t(s^t)l_t(s^t) + r_t(s^t)k_t(s^{t-1}) + T_t(s^t) \quad (1.2)$$

and the capital accumulation equation

$$N_{t+1}k_{t+1}(s^t) = (x_t(s^t) + (1 - \delta)k_t(s^{t-1}))N_t \quad (1.3)$$

where  $x_t$  is per capita investment,  $k_t$  is per capita capital,  $T_t$  is per capita lump-sum taxes or transfers,  $w_t$  is the wage rate,  $r_t$  is the rental rate of capital, and  $N_t$  is the working age population.

The representative firm chooses per capita capital  $k_t(s^{t-1})$  and labor  $l_t(s^t)$  to maximize its profits

$$y_t(s^t) - r_t(s^t)k_t(s^{t-1}) - w_t(s^t)l_t(s^t) \quad (1.4)$$

where  $y_t(s^t)$  is per capita output produced by a constant returns to scale production function

$$y_t(s^t) = A_t(s^t)k_t(s^{t-1})^\alpha l_t(s^t)^{1-\alpha} \quad (1.5)$$

and the efficiency wedge  $A_t$  captures the fluctuations of productivity.

The equilibrium of this economy is characterized by the resource constraint

$$c(s^t) + x_t(s^t) + g_t(s^t) = y_t(s^t) \quad (1.6)$$

and the first order conditions for labor and capital

$$\frac{\psi c_t(s^t)}{1 - l_t(s^t)} = (1 - \tau_l(s^t))(1 - \alpha) \frac{y_t(s^t)}{l_t(s^t)} \quad (1.7)$$

<sup>1</sup> Defining the labor and investment wedges as  $1 - \tau_l$  and  $1 / (1 + \tau_x)$  aims at facilitating their visual inspection and make them comparable to the efficiency wedge in that an increase is beneficial for growth.

$$\frac{(1 + \tau_{xt}(s^t))}{c_t(s^t)} = \beta \sum_{s^{t+1}} \pi_t(s^{t+1} | s^t) \frac{1}{c_{t+1}(s^{t+1})} \left( A_{t+1}(s^{t+1}) \alpha \frac{y_{t+1}(s^{t+1})}{k_{t+1}(s^{t+1})} + (1 - \delta)(1 + \tau_{xt+1}(s^{t+1})) \right) \quad (1.8)$$

Equation (1.7) says that the marginal rate of substitution between consumption and leisure equals the marginal product of labor, distorted by the wedge  $1 - \tau_{lt}$ . Equation (1.8) states that the intertemporal marginal rate of substitution in consumption equals the marginal product of capital, distorted by the wedge  $1 / (1 + \tau_{xt})$ . Even though  $\tau_{lt}$  and  $\tau_{xt}$  resemble taxes on labor and investment income, they represent all distortions affecting the respective equilibrium conditions. The labor wedge captures frictions that affect both the supply side and demand side, *i.e.*, consumers as well as firms. For example, the effects of monetary policy shocks in a model with sticky wages will show up in the prototype model as fluctuations in the labor wedge. The investment wedge also represents frictions affecting the intertemporal conditions of both the consumers and the firms. More detailed models with taxes on consumption or investment as well as liquidity constraints on consumers or investment-financing frictions on firms are equivalent to the prototype model with an investment wedge. The efficiency wedge  $A(s^t)$  represents the effects of a wide range of institutions and policies that affect the efficiency with which the factors of productions are used. For example, a model with frictions which distort the allocation of inputs towards less efficient firms would have the same equilibrium allocations as the prototype model with an efficiency wedge. Finally, the government consumption wedge  $g(s^t)$  in the prototype closed-economy model can be regarded as an income accounting wedge in an open economy setup. Therefore, it captures fluctuations in both government consumption and net exports.<sup>2</sup>

Following CKM, I assume that the mapping between the event  $s_t$  and the vector of wedges is one to one and onto. This means that the agents in the economy can uniquely infer  $s_t$  from observing the values of  $A(s^t)$ ,  $\tau_{lt}(s^t)$ ,  $\tau_{xt}(s^t)$  and  $g_t(s^t)$ . Furthermore, I assume that  $s_t$  follows a stationary VAR(1) process

$$s_t = P_0 + P s_{t-1} + Q \epsilon_t, \quad \epsilon_t \sim N(0, I) \quad (1.9)$$

where  $QQ'$  is a positive definite matrix.

## 2.2. Estimation

To estimate the model, the equilibrium conditions are linearized around the steady state of the economy, and the endogenous variables are expressed as linear functions of the state variables  $k_t$  and  $s_t$ . This results in a linear state space system for a vector of observables given by  $[\log(y_t), \log(x_t), \log(l_t), \log(g_t)]$ . Then, using data on output, investment, hours worked and government consumption<sup>3</sup> and the fact that the system is Gaussian, the likelihood function is constructed using the Kalman filter and maximized with respect to the unknown parameters. The estimated model together with the data is then used to construct the four wedges. Specifically, the efficiency wedge  $A_t$  is constructed from the production function; the labor wedge  $1 - \tau_l$  is derived from the intratemporal first order condition and the investment wedge  $1 / (1 + \tau_x)$  is derived from the intertemporal first order condition, where the expectations are based on the estimated model. The government consumption wedge  $g_t$  is obtained directly using data on government spending and net exports.

<sup>2</sup> In another extension to an open economy setup, time variations in the tariffs on imports of intermediate inputs, or fluctuations in the world price of these inputs, would be captured by the efficiency wedge in the prototype closed economy model (see Ahearne *et al.*, (2006).)

<sup>3</sup> Note that we abstract from growth in the model and assume that a deterministic steady state exists. To match the data with the definitions of the variables in the model, all variables are expressed in per capita terms and de-trended using the Hodrick-Prescott filter.

### 2.3. Evaluating the importance of the wedges

The measured wedges by construction account for the observed movements of all variables in the model. The purpose of the business cycle accounting procedure is to investigate the importance of a given wedge, or a combination of wedges, for the dynamics of the macroeconomic variables, such as output, investment and hours worked. This is done by feeding the estimated wedges to the model and estimating its responses to the wedges individually or in combinations. In particular, to measure the separate distortionary effect of a given wedge, the original model is solved holding all other wedges constant at their steady state values. Note that the agents in the economy still form expectations using the full multivariate process for wedges in (1.9) and therefore the predicted dynamics of the active wedge is the same as in the economy with all wedges. This results in obtaining the dynamics of the model variables due to a given wedge. Similarly, the effect of combinations of wedges is obtained by holding the other wedges fixed. A combination of all wedges produces the same behavior of the variables as observed in the data.

### 3. Business cycle accounting for Portugal

The model from Section 2 is estimated using quarterly data for Portugal for the period from 1998:Q1 through 2012:Q3. The estimation results are then used to compute the equilibrium of the model and to measure the realizations of the wedges implied by the data. Chart 1 gives a visual presentation of these wedges<sup>4</sup> while Table 1 summarizes their business cycle properties by showing their correlations with output at several leads and lags. The table also shows the standard deviation of each wedge relative to that of output which is 1.12. The efficiency, labor and government consumption wedges are positively correlated with output, contemporaneously as well as at several leads and lags. The investment wedge, on the other hand, is negatively correlated with output at all lags and becomes positively correlated at leads beyond the second one. The efficiency wedge is the most strongly correlated with output in the data, with contemporaneous correlation of 0.84, and tends to lead the cycle as it is more strongly and positively correlated with future output than past output.

Chart 2 plots output in the data together with the predictions of the model for output when a single wedge is included. As we can see, the component of output due to the efficiency wedge alone is strongly correlated with output in the data and somewhat more volatile than it. The other three components of output, due to either the labor, investment or government consumption wedges are much less volatile and not very strongly correlated with the observed output.

In fact, as can be seen from Table 2, which shows the cyclical properties of the output components, output due to investment and government consumption wedges are negatively correlated with output in the data, and much less volatile than it. Output due to the labor wedge alone is more strongly and positively correlated with output in the data and fluctuates 60% as much as it. Finally, as the first panel in Chart 2 suggests, output due to the efficiency wedge alone fluctuates 13% more than output in the data and is strongly and positively correlated with it, especially with future output.

The importance of each wedge for accounting in the behaviour of output can be assessed by holding that wedge fixed while keeping the other three wedges moving. The results are presented in Chart 3 and show that without the efficiency wedge, and to a lesser extent the labor wedge, the model fails to reproduce the observed fluctuations in output. In contrast, without the other two wedges, and in particular without the government spending wedge, output in the model matches very closely the data.

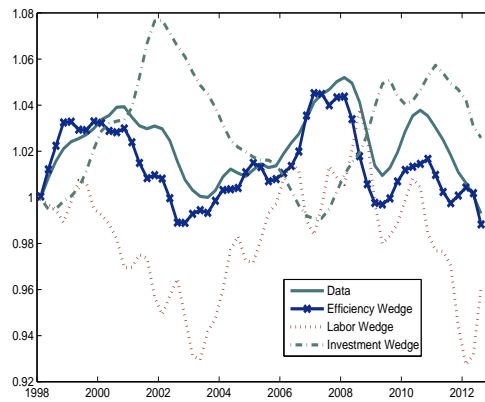
Next, I focus on two particular episodes: the period from 1998 through 2003 and the period from 2008 through 2012. For the first period, panel (a) of Chart 4 shows observed output together with the predictions of the model when only one of the wedges is present – the efficiency, the labor or the

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<sup>4</sup> The wedges are normalized to equal 1 in 1998.

Chart 1

OUTPUT AND MEASURED WEDGES



Source: Author's calculations.

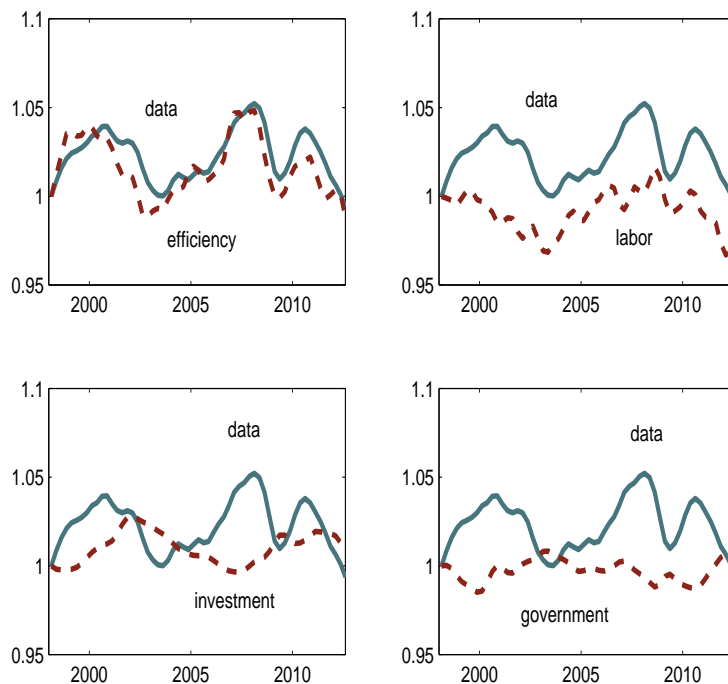
Table 1

Wedges	Rel. Std	Correlation of output in $t$ with wedges in $t + j$						
		-3	-2	-1	0	1	2	3
Efficiency	1.05	0.58	0.78	0.88	0.84	0.65	0.37	0.09
Labor	1.24	0.21	0.28	0.38	0.47	0.47	0.33	0.08
Investment	1.35	-0.47	-0.42	-0.35	-0.24	-0.09	0.10	0.29
Government	2.99	0.17	0.24	0.29	0.30	0.25	0.13	-0.04

Source: Author's calculations

Chart 2

OUTPUT IN THE DATA AND PREDICTIONS OF THE MODEL WITH A SINGLE WEDGE (1998-2012)



Source: Author's calculations.

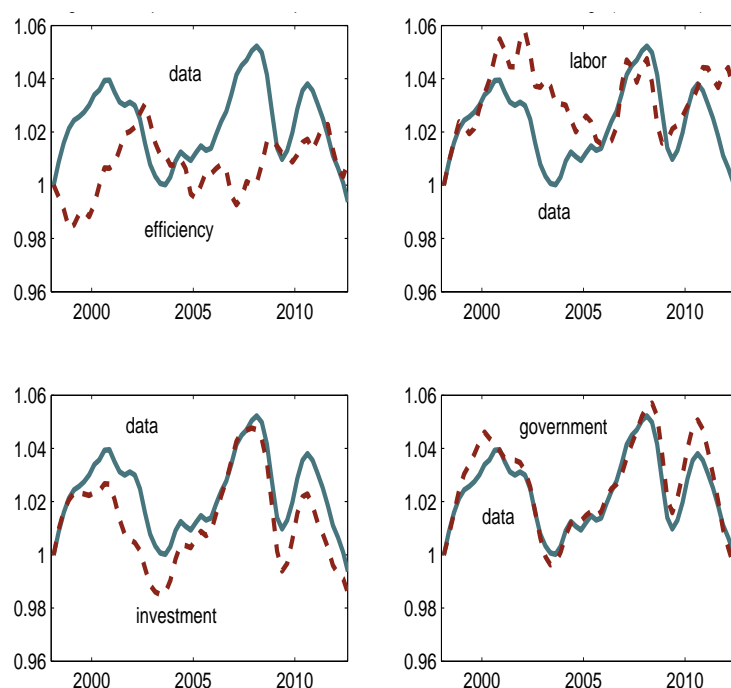
**Table 2**

BUSINESS CYCLE PROPERTIES OF OUTPUT COMPONENTS, 1998 Q1-2012 Q3									
Output components	Rel. Std	Correlation of output in $t$ with wedges in $t + j$							
		-3	-2	-1	0	1	2	3	
Efficiency	1.13	0.58	0.78	0.90	0.86	0.67	0.39	0.10	
Labor	0.60	0.21	0.29	0.37	0.46	0.46	0.31	0.06	
Investment	0.45	-0.50	-0.48	-0.42	-0.32	-0.15	0.07	0.29	
Government	0.41	-0.18	-0.25	-0.29	-0.30	-0.25	-0.14	0.04	

Source: Author's calculations

**Chart 3**

**OUTPUT IN THE DATA AND PREDICTION OF THE MODEL WITHOUT ONE WEDGE (1998-2012)**



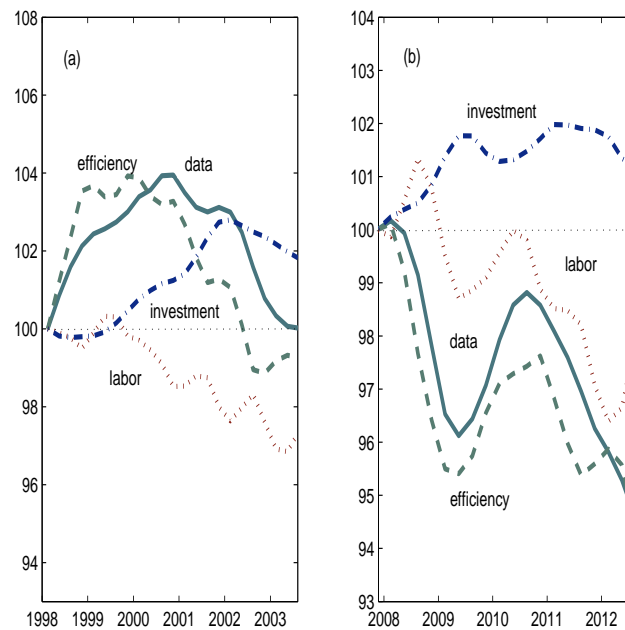
Source: Author's calculations.

investment wedge.<sup>5</sup> All of them are normalized to equal 100 in 1998. Between 1998 Q1 and 2000 Q3 output grew by 4% relative to trend and by 2003 fell back to trend. In the model with efficiency wedge alone output follows a broadly similar pattern, increasing faster in the first 3 quarters, and starting to fall sooner. With only the investment wedge output in the model grows by less than 3% relative to trend and remains 2% above trend in the end of 2003. The model with the labor wedge alone predicts a decline in output to about 3% below trend in 2003. These results indicate that the faster growth in the first half of the period is primarily driven by the efficiency wedge, while the decline in the second half would have started sooner and would have been steeper without the investment wedge.

<sup>5</sup> As the earlier results show that the government consumption wedge accounts for very little of the fluctuations in output, it will not be discussed further.

Chart 4

OUTPUT IN THE DATA AND PREDICTIONS OF THE MODEL WITH A SINGLE WEDGE



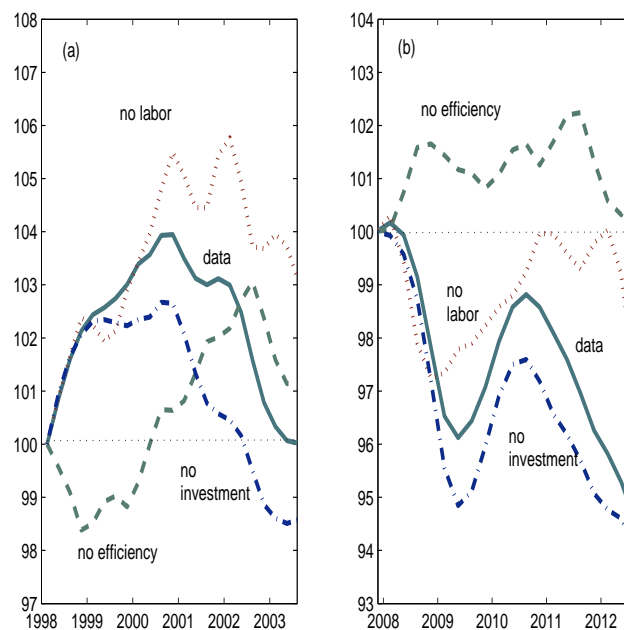
Source: Author's calculations.

Panel (b) of Chart 4 shows the dynamics of output and the separate effects of the three wedges during the period from 2008 through the third quarter of 2012. During that period output first falls 4% relative to trend, recovers for a while and then starts to fall again ending more than 5% below trend at the end of the period. As before, the efficiency wedge does the best job in predicting the fluctuations in output in this period. With it alone output in the model falls more than in the data and the temporary recovery in 2010 is less pronounced. Apart from this, the prediction of the model parallels the movements in the data. The labor wedge helps the efficiency wedge in accounting for the observed dynamics of output during the period. However, with it alone the fall in output starts a year later and is smaller than in the data, especially during 2009 and 2010. Also, it predicts a counterfactual recovery of output at the end of the period. With the investment wedge alone the model predicts a modest increase in output relative to the data. By 2009 predicted output increases about 2% while in the data output falls about 4%. By 2012 predicted output is about 1% above trend while in the data output is 5.5% below trend.

The necessity of each one of the three wedges for reproducing the observed output movements during the two business cycle episodes can be evaluated using Chart 5. For the 1998-2003 period, panel (a) show that without the efficiency wedge output in the model initially drops about 2% below trend, before starting to grow, reaching around 3% above trend in 2002. Without the labor or investment wedges, output in the model matches the general pattern of output in the data, but either overpredicts, in the first case, or underpredicts, in the second, the increase in output before it starts slowing down. The same observation can be made for the period between 2008 and 2012, as shown in panel (b) of Chart 6. Without labor and especially the investment wedge, output in the model matches quite closely output in the data. Without the efficiency wedge, however, instead of falling it grows 2% by 2011 and remains above trend throughout the whole period.

Chart 5

## OUTPUT IN THE DATA AND PREDICTIONS OF THE MODEL WITHOUT ONE WEDGE



Source: Author's calculations.

#### 4. Concluding remarks

The analysis in the previous section suggests that the efficiency wedge plays a dominant role in explaining the output fluctuations in Portugal throughout the 1998-2012 period. Thus, research on more detailed models should focus on frictions and shocks that show up as an efficiency wedge in the prototype model. However, although the labor and investment wedges are relatively less important for the analyzed period as a whole, they play an important role during particular business cycle episodes, such as 2001-2004 and after 2009. The labor wedge in particular has a strong negative impact on output during these periods. Therefore, the evidence suggests that policy discussions should focus on improving the functioning of the labor market institutions and strengthening the overall competitiveness of the economy.

#### References

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