

# NUMERICAL SOLUTION OF LINEAR MODELS IN ECONOMICS: THE SP- DG MODEL REVISITED

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# Numerical solution of linear models in economics: The SP-DG model revisited

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## Abstract

In general, complex and large dimensional models are needed to solve real economic problems. Due to these characteristics, there is either no analytical solution for them or they are not attainable. As a result, solutions can be only obtained through numerical methods. Thus, the growing importance of computers in Economics is not surprising. This paper focuses on an implementation of the SP-DG model, using Matlab, developed by the students as part of the Computational Economics course. We also discuss some of our teaching/learning experience within the course, given for the first time in the FEP Doctoral Programme in Economics.

**Key words:** SP-DG Model, Output, Inflation, Numerical Simulation, Teaching of Economics.

**JEL Classification:** A12, A23, C61, C63, E24, E31, E32.

## 1 Introduction

The Computational Economics course in the Doctoral Programme in Economics deals with the modelling and simulation of economic problems. The aim is to

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provide students with the computational skills and numerical techniques necessary to model, implement and solve economic problems through computer.

The course is organised in a modular way. Each module begins with an economic problem, illustrates its mathematical modelling and discusses its computational form. Computational implementation of the problem allows it to be simulated in various scenarios and therefore enables economic interpretation of the results. Students are challenged to modify the computational programs following proposals to change the baseline parameter values of the models in order to analyse the economic implications and fully understand the respective mechanisms. At the end of the course, students have the necessary computational skills to understand and analyse economic models with ease, overcoming limitations such as the size of the problem and/or the non-existence of explicit solution. This expertise may then be used by students to produce their own research.

Basic techniques of numerical analysis are covered: nonlinear optimisation, linear and nonlinear systems of equations, numerical solution of differential equations and numerical dynamic programming. In addition, programming skills are taught to students as well as some basics of error theory and floating-point arithmetic. The economic models studied include, among other, economic growth, business cycle, optimal fiscal and monetary policy, optimal portfolio choice and option pricing models.

The course is managed using blended-learning, that is, it is developed in class but complemented by an “on-line” course, profiting from all the advantages offered by distance training. The use of Information and Communication Technologies is guaranteed by the contents developed by the instructors, through hardware and software available via Faculty of Economics and the WebCT e-learning platform provided by the University of Porto.

This present work is the result of a common effort to unify one of the required consolidation assignments done by the students, as part of their evaluation pro-

cess.<sup>1</sup>

In section 2, we describe the problem and the SP-DG model in line with Gordon (2005), referring to the central equations and main variables. The computational implementation is analysed and the general structure of the program is presented. We finish this section with the simulation and interpretation of the implications arising from demand and supply shocks. Along with traditional scenarios, a new one is proposed, which emerges from taking together positive and negative demand shocks. Finally, in section 3, we conclude and discuss some future work.

## 2 Modelling and simulation of the SP-DG model

### 2.1 The problem and the model

The problem consists of the analysis of the dynamics of inflation and output gap in three cases: (i) permanent demand shock, in which we study the dynamics of the state variables assuming different processes of expectation formation by economic agents; (ii) disinflation strategies, with an aggressive strategy and with a more gradual one; (iii) temporary supply shock, considering three different policymaker's responses: neutral, accommodating and extinguishing.

The SP-DG model has three central equations.

The first one characterises the short-run aggregate supply, which is described by the SP (abbreviation for short-run expectations augmented Phillips) curve. This curve takes into consideration: (i) the positive relationship between the inflation rate and the actual output; (ii) the expected inflation rate such that a change in the expected inflation induces a change in the SP curve; (iii) that a supply shock generates a change in the inflation rate.

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<sup>1</sup>More detailed information on the Computational Economics course is available in the web page of the Doctoral Programme in Economics: <http://www.fep.up.pt/cursos/doutoramentos/economia/>

A possible expression for the SP curve is:

$$\pi_t = \pi_t^e + \alpha \widehat{Y}_t + z_t^s, \quad (1)$$

where  $\pi_t$  is the inflation rate at time  $t$ ,  $\pi_t^e$  is the expected inflation rate for  $t$ ,  $\widehat{Y}_t$  is the log of output gap in  $t$  defined as the percentage deviation between actual output in  $t$  and the economy natural output,  $Y^N$ ,<sup>2</sup> and  $z_t^s$  represents the impact of a supply shock in the inflation rate at time  $t$ .

When there are no supply shocks, i.e.,  $z_t^s = 0$ , and the output is at its natural level, i.e.,  $\widehat{Y}_t = 0$ , the economy is at its long-run equilibrium. In this situation, the aggregate supply is graphically represented by a vertical line in the space  $(\widehat{Y}_t, \pi_t)$ , with  $\widehat{Y}_t = 0$  and  $\pi_t = \pi_t^e$ .

The second equation of the SP-DG model describes the expectation formation process of the inflation rate, which Gordon (2005) assumes to be of the backward-looking type:

$$\pi_t^e = \lambda \pi_{t-1} + (1 - \lambda) \pi_{t-1}^e, \quad (2)$$

where parameter  $\lambda$  represents the speed of the adjustment process of the inflation rate expectations. Two extreme scenarios arise when  $\lambda = 0$  and  $\lambda = 1$ . The former implies that economic agents do not adjust their expectations ( $\pi_t^e = \pi_{t-1}^e$ ), whereas in the latter, expectations are adaptive and the speed of their adjustment is maximum ( $\pi_t^e = \pi_{t-1}$ ).

The adjustment process induces changes in the SP curve towards the steady state.

The SP curve is obtained through the inclusion of the  $\pi_t^e$  expression given by equation (2) in equation (1):

$$\pi_t = \lambda \pi_{t-1} + (1 - \lambda) \pi_{t-1}^e + \alpha \widehat{Y}_t + z_t^s, \quad (3)$$

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<sup>2</sup>Following Gordon (2005),  $\widehat{Y} = 100 \times \left[ \ln \left( \frac{Y}{Y^N} \right) \right]$ .

The SP curve represents the set of combinations  $(\widehat{Y}_t, \pi_t)$  for a given  $\pi_t^e$ . However, at time  $t$  and for a given  $\pi_t^e$ , which is the exact point  $(\widehat{Y}_t, \pi_t)$  that characterises the economy? In order to answer this question, an additional expression is required.

Taking the logarithms of each side of the equality  $X = PY$ , where  $X$  and  $P$  are the nominal output and the general level of prices, we obtain:

$$x = \pi + y, \quad (4)$$

where  $x$  represents the nominal GDP growth rate and  $y$  the real GDP growth rate.

After that, by subtracting the growth rate of natural real GDP,  $y^N$ , from each side of equation (4), we obtain:

$$x - y^N = \pi + y - y^N. \quad (5)$$

Finally, two replacements in equation (5) are necessary: (i) replace  $x - y^N$  by  $\widehat{x}$ , which represents the “excess nominal GDP growth” and (ii) replace the excess of actual over natural real GDP growth ( $y - y^N$ ) by the change in the log of output gap  $(\widehat{Y}_t)$  from its previous temporal value  $(\widehat{Y}_{t-1})$ .<sup>3</sup> After these replacements the third equation of the SP-DG model emerges:

$$\widehat{x}_t = \pi_t + \widehat{Y}_t - \widehat{Y}_{t-1} + z_t^d, \quad (6)$$

where  $z_t^d$  represents a demand shock.

This expression sets the DG (‘demand growth’) curve, which represents the set of combinations  $(\widehat{Y}_t, \pi_t)$  for a given demand growth rate.

Finally, the equilibrium corresponds to the intersection of the SP and DG curves. The equilibrium values of the state variables for each moment  $t$ , can be

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<sup>3</sup>This results from the definition of a growth rate from one period to another as the change in logs; i.e., as  $y = \log Y - \log Y_{-1}$  and  $y^N = \log Y^N - \log Y_{-1}^N$ , then subtracting the second expression from the first, we obtain:  $y - y^N = \log Y - \log Y^N - [\log Y_{-1} - \log Y_{-1}^N] = \widehat{Y} - \widehat{Y}_{-1}$ .

analytically obtained by:

$$\pi_t = \left( \frac{1}{1 + \alpha} \right) \left[ \lambda \pi_{t-1} + (1 - \lambda) \pi_{t-1}^e + \alpha \left( \hat{x}_t + \hat{Y}_{t-1} - z_t^d \right) + z_t^s \right]. \quad (7)$$

When  $\hat{Y}_t < 0$  ( $\hat{Y}_t > 0$ ), the expected and observed inflation rate decreases (increases) until  $\hat{Y}_t = 0$  and  $\pi_t = \pi_t^e$ .

## 2.2 Computational implementation

In all analysed cases it is assumed that the economy is initially in long-run equilibrium, i.e., the output gap is zero ( $\hat{Y}_0 = 0$ ) and  $\pi_0 = \pi_0^e$ . Regardless of the shock that affects the economy, either from the supply or demand side,  $\pi_t$  and  $\hat{Y}_t$  will follow a convergence path towards a new steady-state, in which  $\hat{Y}_t$  will again be zero and  $\pi_t = \pi_t^e$ .

In order to introduce this feature in the computational implementation, the convergence process for the new long-run equilibrium level is obtained through a while cycle: the program continues iterating until the output gap,  $\hat{Y}$ , is inferior to a pre-defined tolerance. The general structure of our program consists of the following steps:

1. the parameters of the model are initialised:  $\alpha$  (SP curve slope),  $\lambda$  (expectations formation) and tolerance value ( $1/M$ , where the value of  $M$  is large, for example,  $10^6$ );
2. the exogenous variables of the model are initialised:  $\hat{x}_t, \pi_{t-1}, \hat{Y}_{t-1}, z_t^d, z_t^s$ ;
3. before the iteration, the value for the output gap in the first period is computed;
4. within the cycle, the output gap and the inflation rate are computed at each time  $t$ ;<sup>4</sup>

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<sup>4</sup>At this step of the algorithm, the Gaussian elimination method with partial pivoting can be used to compute the solution of the linear system involved.

5. once the iteration process has finished, the program plots the results in the state variables space  $(\widehat{Y}_t, \pi_t)$  and the Impulse Response Functions (IRFs) of each state variable.

## 2.3 Simulation and numerical results

In this section, we summarise the numerical results arising from the simulations carried out by the implementation of the SP-DG model.

### 2.3.1 Demand shocks

We start by analysing the implications due to changes in the growth rate of aggregate demand – “demand shocks”.

Let us consider a situation in which the country is in steady state, i.e.,  $\widehat{Y}_t = 0$  and  $\pi_t = \pi_t^e = 6$ , (and there are no “supply shocks”,  $z_t^S = 0$ ). Then, for some reason a positive change in external demand for domestic goods increases permanently 3% (i.e., the nominal demand growth becomes  $z_t^d = 3$ ). The simulation of this impact is illustrated by considering  $\alpha = 0.5$  and two different values for the coefficient of adjustment ( $\lambda = 0.5$  and  $\lambda = 1$ ). The result of this simulation is presented in Figure 1.

As a result,  $\pi_t$  converges in the long-run towards 9%, regardless of the characteristics of the expectations’ adjustment process. As we can see from Figure 1, the stronger the economy inertia in the expectations’ adjustment process (lower  $\lambda$ ) is, the slower the convergence towards the new steady state. In other words, the economy has higher positive output gaps and a smoother inflation path.

Moreover, taking also into account negative demand shocks we depict the behaviour of the economy towards the steady state (Figure 2). This new illustration enlightens the long-run equilibrium for both types of demand shocks. We call this new kind of illustration “symmetrical stylised treble clef effect”, in view of the graphical effect.



Figure 1: Positive demand shock

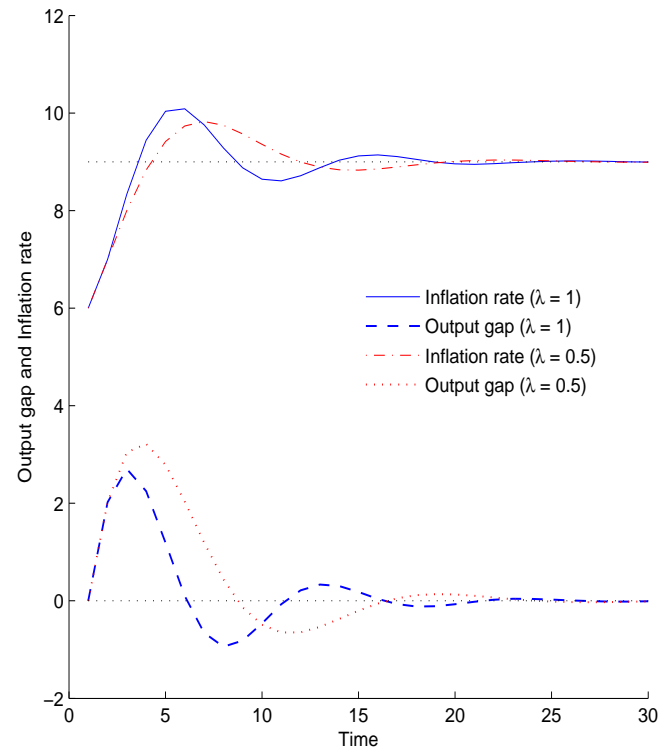
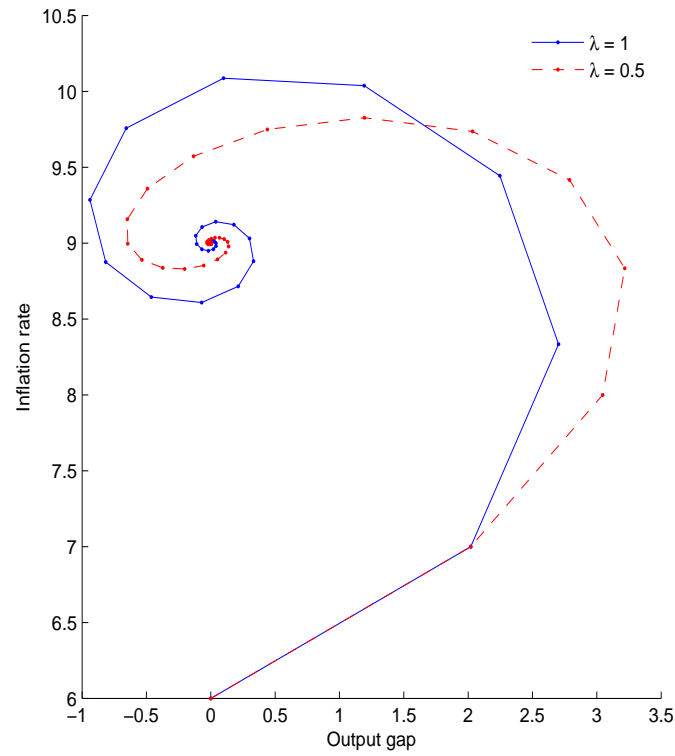
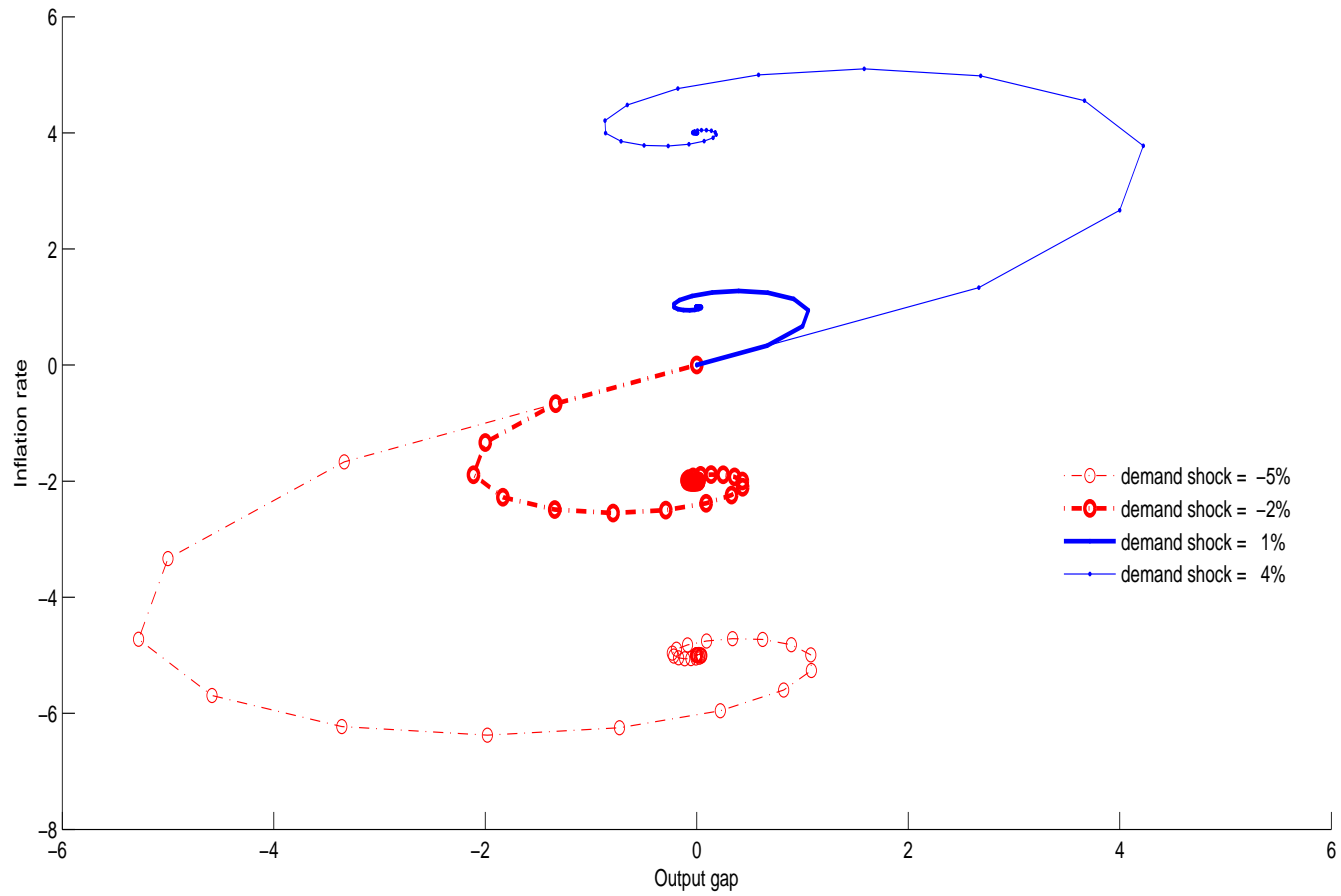


Figure 2: Symmetrical stylised treble clef effect

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### 2.3.2 Disinflation

We now analyse how a policymaker can achieve disinflation, that is, a marked deceleration in the inflation rate. There are some economic motives for a policymaker to pursue a quantitative goal for the inflation rate. For example, participation in a Monetary Union usually requires a specified set of formal economic convergence criteria.<sup>5</sup>

The most straightforward way of reducing inflation can be reached by decreasing the demand growth. The policymaker can follow two different disinflation strategies: (i) a “cold turkey” strategy, where there is a sudden reduction in demand growth, or (ii) a gradual strategy, where the policymaker gradually reduces the demand growth.

In our simulation we study the convergence process of the state variables in both strategies. We consider that the initial inflation rate is 12%, the output gap is zero and the policymaker’s objective is to achieve a 3% inflation rate. Moreover, we set the parameters  $\alpha$  and  $\lambda$  equal to, respectively, 0.5 and 1 (that is, we consider the case of pure adaptive expectations). With a “cold turkey” strategy, the demand growth suddenly shifts from 12% to 3%, whereas with a gradual strategy the demand growth slowly decreases (1% a year) until it reaches a rate of 3%.

Figure 3 shows the convergence processes and the IRFs. As we can see, in both cases the inflation rate converges to the desired value. However, the process differs greatly during the transitional dynamics phase. The “cold turkey” strategy allows for a fast disinflation process of the economy, but it implies a higher negative output gap. Therefore, recession is more severe under this strategy. In fact, by following this strategy a sacrifice ratio of 2.72 is achieved,<sup>6</sup> which is greater than that one obtained under the gradual strategy, which is 2.18.<sup>7</sup>

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<sup>5</sup>The Maastricht Treaty requires that the inflation rate must be within 1.5 percentage points of the three European Union countries with the lowest inflation rates.

<sup>6</sup>Considering the time period that goes from the shock to the first time that  $\hat{Y}$  reaches again zero.

<sup>7</sup>Gordon (2005) defines the sacrifice ratio as the cumulative loss of output during a disin-

To sum up, the disinflation process is associated with some losses in terms of output and the choice between both strategies depends on the policymaker's preferences and objectives.

### 2.3.3 Supply shocks

The dynamic of inflation and output gap in the presence of a supply shock depends on the policymaker's preferences. We consider three possible strategies after a supply shock for one temporal period equal to 3%: (i) neutral, (ii) extinguishing and (iii) accommodating. During the length of the supply shock, the neutral, the extinguishing and the accommodating policy attempt to keep the nominal GDP growth, the inflation rate and the output gap unchanged, respectively.

Figure 4 shows the impact of positive and negative supply shocks on the output gap and inflation rate, considering the three different possible strategies. Again, we assume that the economy is initially in long-run equilibrium, in which the output gap is zero and inflation rate is 6%. We also consider that, after the dissipation of the shock, the government returns to its initial policy.

Under a neutral policy, a negative supply shock increases the inflation rate to 8% and simultaneously decreases the output gap to  $-2\%$ , in the first period after the shock. On the other hand, a positive supply shock decreases the inflation rate to 4% and increases the output gap to  $2\%$ , in the first period. Nevertheless, in both cases the initial equilibrium is restored.

Under the extinguishing policy, neither negative nor positive supply shock has impact on inflation during the first period. In such a context the impact on the output gap is stronger than in the previous case, both for a positive and a negative supply shock. In our simulation, a positive (negative) supply shock implies an increase (decrease) in the output gap of 6 percentage points against 2 percentage points in the neutral policy strategy.

Finally, if the policymaker follows the accommodating policy, neither nega-  
flation divided by the permanent reduction in the inflation rate.

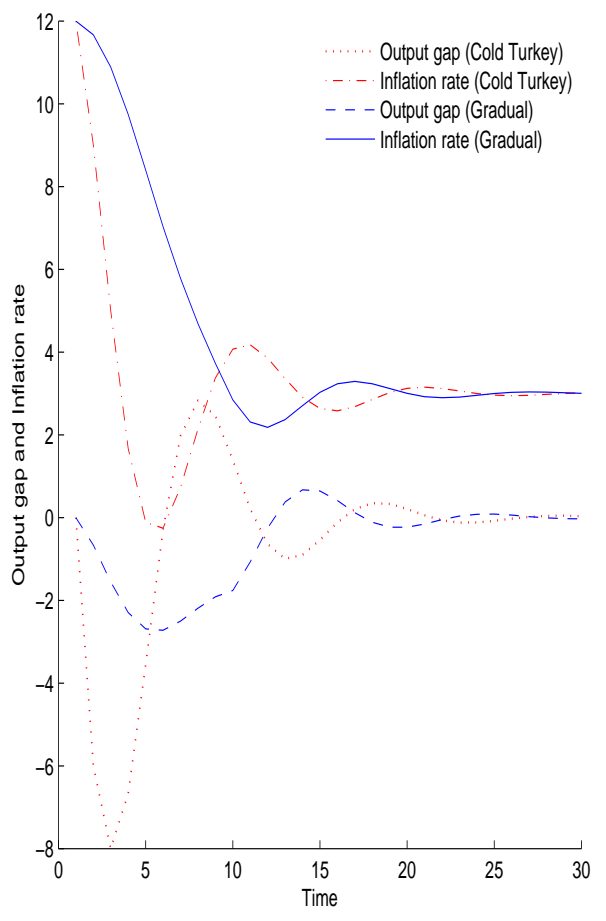
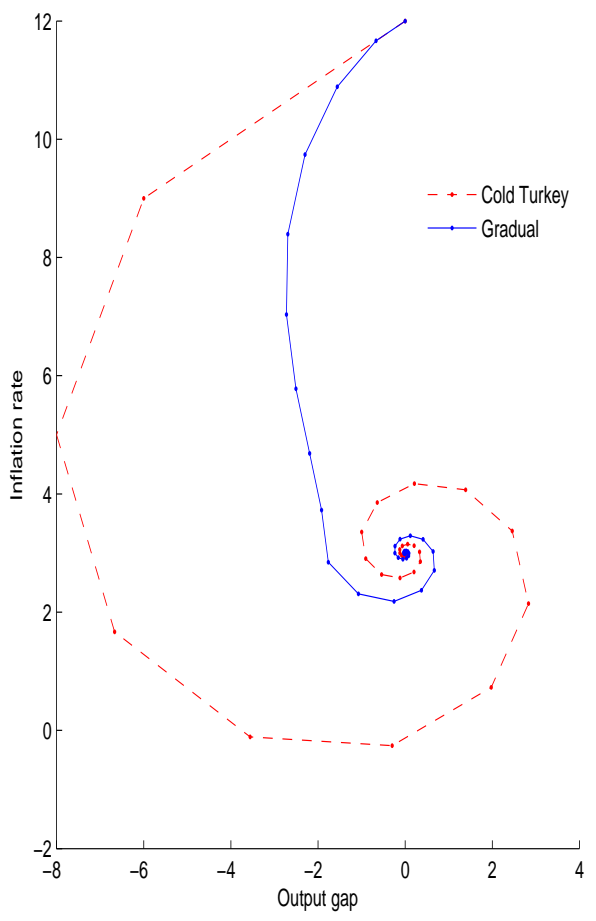


Figure 3: Disinflation strategies  
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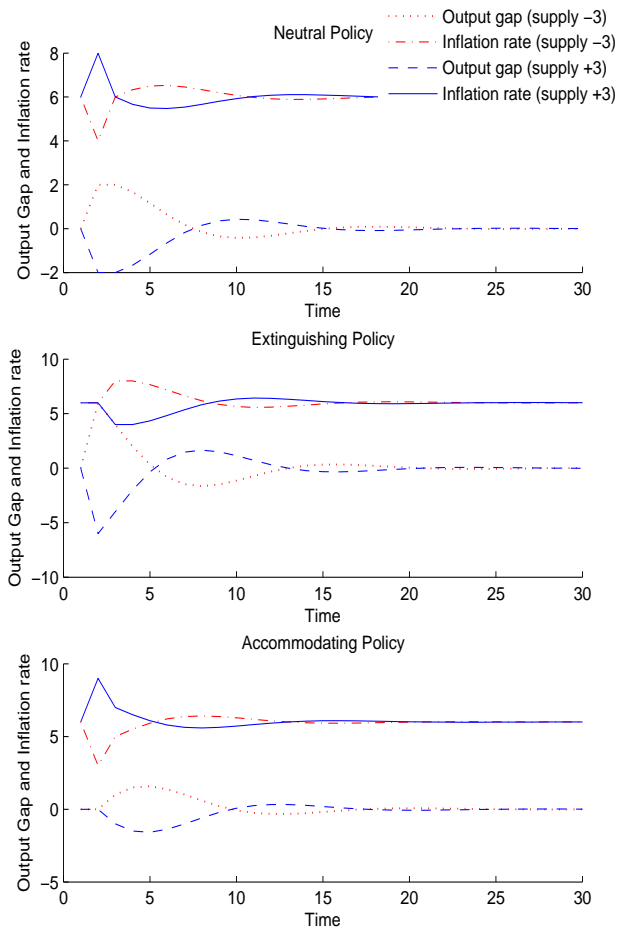
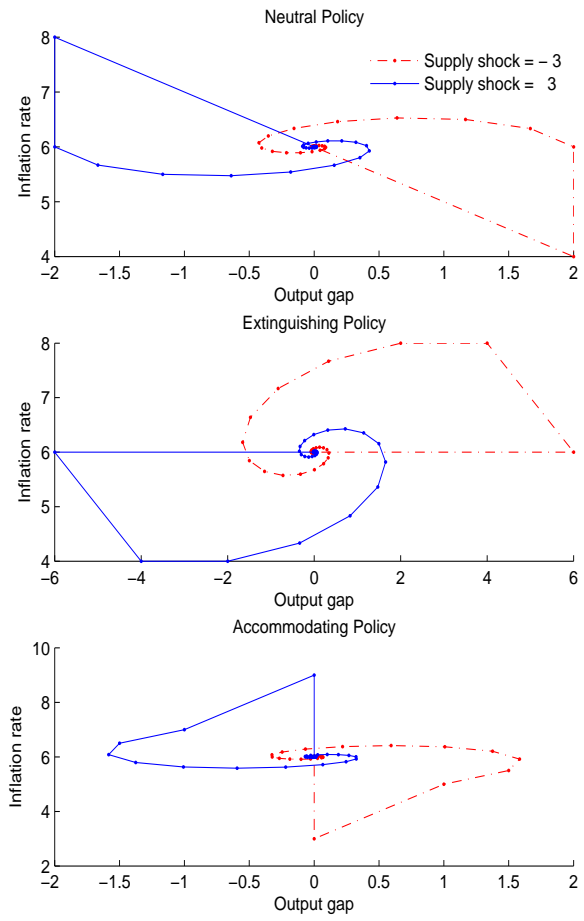
tive nor positive supply shock has impact on output gap during the first period. In the simulation plotted in Figure 4 we can see that the impact on the inflation rate is the strongest, either for a positive or a negative supply shock, considering all the possible policymaker strategies. In our simulation, a negative (positive) supply shock implies an increase (decrease) of the inflation rate by 3 percentage points against 2 percentage points in the neutral policy strategy.

### 3 Concluding remarks

The SP-DG model was studied, implemented and simulated bearing in mind three cases: (i) permanent demand shock in the economy, considering different different processes of expectation formation by economic agents; (ii) disinflation strategies and (iii) temporary supply shocks, studying different policymaker strategies. Other simulations can be made in future research. For example, the impact on the dynamic of the inflation rate and output gap from: (i) different values of the SP slope value; (ii) different expectation formation process, namely those from the “learning” literature; (iii) the introduction into the SP-DG model of a stochastic process for the supply and demand shocks; (iv) permanent supply shocks.

Economics has mostly been taught making use of economic interpretation and some mathematics. However, the use of computers is crucial for the solution of real economic problems. Furthermore, with a course like Computational Economics, students can develop their creative capabilities, acquire model development skills, gain autonomy and self-confidence in dealing with complex models and in different scenarios. Courses like Computational Economics greatly emphasise the learning-by-doing paradigm and they are therefore a natural way to implement the Bologna process.

Figure 4: Different policy responses to supply shock



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## Appendix

### Programme presentation

```
%-----  
% SP-DG Model  
% Disinflation (cold turkey and gradual) version  
% Implemented by: T. Andrade, G. Faria, V. Leite, F. Verona, M. Viegas,  
%                 O. Afonso, P.B. Vasconcelos  
%-----
```

```
clear; clf;  
disp('SP-DG Model: Disinflation (cold turkey and gradual) version');
```

### Parameters initialization

```
alpha = 0.5; % SP slope curve  
M = 100000; tolerance= 1/M; lambda = 1;
```

### Cold Turkey Strategy

```
% variables initialization  
inflation(1) = 12; expected_inflation(1) = 12;  
output_gap(1) = 0; output_growth(1) = 0;  
demand(1) = 12; demand_gap(1) = demand(1)-output_growth(1);  
  
% shock  
t = 2;  
demand_gap(2) = 3;  
inflation(t) = 1/(1+alpha)*(lambda*inflation(t-1)+...  
                    (1-lambda)*expected_inflation(t-1)+...  
                    alpha*(output_gap(t-1)+demand_gap(t)));  
expected_inflation(t) = lambda*inflation(t-1)+...  
                    (1-lambda)*expected_inflation(t-1);
```

```

output_gap(t) = output_gap(t-1)+demand_gap(t)-inflation(t);

% Loop for Ouput gap and Inflation rate
while abs(output_gap(t)) > tolerance
    t = t+1;
    demand_gap(t) = demand_gap(t-1);
    expected_inflation(t) = lambda*inflation(t-1)+...
                            (1-lambda)*expected_inflation(t-1);
    inflation(t) = 1/(1+alpha)*(lambda*inflation(t-1)+...
                            (1-lambda)*expected_inflation(t-1)+...
                            alpha*(output_gap(t-1)+demand_gap(t)));
    output_gap(t) = output_gap(t-1)+demand_gap(t)-inflation(t);
end

Sacrifice_Ratio_ColdTurkey_Strategy = sum(output_gap(1:6))/9;
output_gap_CT = output_gap; inflation_CT = inflation;

```

## Gradual strategy

```

% variables initialization
inflation(1) = 12; expected_inflation(1) = 12;
output_gap(1) = 0; output_growth(1) = 0;
demand(1) = 12; demand_gap = 0;
demand_gap(1) = demand(1)-output_growth(1);

% Loop for Ouput gap and Inflation rate
for t = 2:10
    demand_gap(t) = demand_gap(t-1)-1;
    inflation(t) = 1/(1+alpha)*(lambda*inflation(t-1)+...
                            (1-lambda)*expected_inflation(t-1)+...

```

```

        alpha*(output_gap(t-1)+demand_gap(t)));
    expected_inflation(t) = lambda*inflation(t-1)+(1-lambda)*...
        expected_inflation(t-1);
    output_gap(t) = output_gap(t-1)+demand_gap(t)-inflation(t);
end

t = 10;
while abs(output_gap(t)) > tolerance
    t = t+1;
    demand_gap(t) = demand_gap(t-1);
    expected_inflation(t) = lambda*inflation(t-1)+(1-lambda)*...
        expected_inflation(t-1);
    inflation(t) = 1/(1+alpha)*(lambda*inflation(t-1)+(1-lambda)*...
        expected_inflation(t-1)+...
        alpha*(output_gap(t-1)+demand_gap(t)));
    output_gap(t) = output_gap(t-1)+demand_gap(t)-inflation(t);
end

Sacrifice_Ratio_Gradual_Strategy=sum(output_gap(1:12))/9;
output_gap_G = output_gap; inflation_G = inflation;

```

## Layout

```

subplot(1,2,1);
plot(output_gap_CT,inflation_CT,'r.-',output_gap_G,inflation_G,'b.-');
hold on;
xlabel('Output gap'); ylabel('Inflation rate');
legend('Cold Turkey','Gradual');
subplot(1,2,2);
tempo = linspace(1,t,t); tmax = 30;

```

```

recta1 = 3*ones(1,tmax); recta2 = zeros(1,tmax);
plot(tempo(1:tmax),recta1,'k+:',tempo(1:tmax),recta2,'k.:',...
      tempo(1:tmax),output_gap_G(1:tmax),'b--',tempo(1:tmax),...
      inflation_G(1:tmax),'b-',tempo(1:tmax),output_gap_CT(1:tmax),'r:',...
      tempo(1:tmax),inflation_CT(1:tmax),'r-.');
xlabel('Time'); ylabel('Output gap and Inflation rate');
legend('Steady state Inflation rate','Steady state Output gap',...
       'Output gap (Gradual)','Inflation rate (Gradual)',...
       'Output gap (Cold Turkey)','Inflation rate (Cold Turkey)');

```

%-----

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