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MASTER THESIS

Modelling of government spending and endogenous tax rates in New Keynesian models – the case of Czech Republic

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Declaration of Authorship

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Abstract

The topic of fiscal policy has been long neglected in terms of fiscal policy´s interdependence with other main macroeconomic variables. Presented thesis therefore analyses the validity of different fiscal policy models for the case of Czech Republic. Dynamic stochastic general equilibrium (DSGE) framework is used throughout the thesis. Different fiscal policy rules are put into otherwise identical – benchmark - model and the models are compared to each other and to the benchmark model. The analysed fiscal policy models are an acyclical, counter-cyclical, two pro-cyclical and dichotomous spending models. We find that the most plausible fiscal policy rule is of pro-cyclical type and closely follows the model of Alesina et al. (2008). The model assumes that interest groups can steal part of government income through corruption and voters cannot observe it, so they demand maximum fiscal spending in the good times. The logic of this model is in accordance with the current state of fiscal and economic behaviour in Czech Republic.

JEL Classification	E17, E21, E22, E23, E24, E62
Keywords	New Keynesian Economics, Fiscal policy, DSGE

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Abstrakt

Problematika fiskální politiky je v literatuře dlouhodobě zanedbávána v kontextu vzájemné závislosti fiskální politiky a ostatních klíčových maroekonomických veličin. Předkládaná diplomová práce tudíž analyzuje funkčnost vybraných modelů fiskální politiky pro Českou republiku. Modelování je prováděno pomocí tzv. DSGE modelování. Jednotlivá pravidla fiskální politiky jsou dosazeny do jinak identického výchozího modelu a následně jsou výsledky těchto modelů porovnány navzájem a s výchozím modelem. Testované modely fiskální politiky jsou postupně acyklický, proti-cyklický, model dichotomních výdajů a dva pro-cyklické. Výsledky ukazují, že pravidlo s nejvyšší výpovědní hodnotou je pravidlo pro-cyklické, které odpovídá modelu (viz Alesina et al.,2008). Tento model předpokládá, že existují zájmové skupiny schopné odebrat část vládních příjmu prostřednictvím korupce a voliči toto

nemohou přesně pozorovat. Voliči tudíž poptávají maximum vládních výdajů v dobrých časech. Logika tohoto modelu dobře odpovídá pozorovanému stavu v ČR.

Klasifikace	E17, E21, E22, E23, E24, E62
Klíčová slova	DSGE, Nová Keynesiánská Ekonomie, Fiskální politika

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Contents

List of Tables

List of Figures

Acronyms

DSGE Dynamic Stochastic General Equilibrium

D-S Dixit Stiglitz

CES Constant Elasticity of Substitution

GDP Gross Domestic Product

AR(1) Auto-regressive process of degree one

NKE New Keynesian Economics

Master Thesis Proposal

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Proposed Topic:

Modelling of government spending and endogenous tax rates in New Keynesian models – the case of Czech Republic

Topic Characteristics:

The government spending, along with taxes are some of the most neglected parts of the real business cycle and new Keynesian models. While that may not matter so much for the fully developed economies, it remains a question whether the government spending and tax rate allocation may not be substantially more important for emerging economies such as the Czech Republic. The importance of government spending and their structure increased after the recent development after recession in 2008 – the economies have recovered growth in GDP but at the cost of towering government debt. This "fake" growth and its effect on the other main factors of the economy definitely does deserve attention.

New Keynesian models are the perfect tool for modelling of the effects of the government spending and the tax rate rules on the economy. In order to utilize these models, the government spending and, more importantly, tax rate rules must be estimated in such form that it might be incorporated into the models. Further, the benchmark New Keynesian model must be created. This model will then be enhanced by various government spending and tax setting rules. Subsequently, the efficiency of the enhanced models will be compared to the benchmark one. We will therefore establish whether the modelling of government spending and tax setting does increase the models ability to explain real data – whether the moments fit better than those of the benchmark model. This comparison will be done for multiple countries to check, whether the tax rate rule is the most efficient only in the case of Czech Republic or universally.

Hypotheses:

1. Precise modelling of government spending and tax rate setting can increase the precision of New Keynesian models.

2. Government spending and tax setting rules are country specific.

Methodology:

First part of the thesis reviews the literature on government spending models and tax setting processes. The goal is to find competing theories on the government spending and tax rate setting and to check whether they are useful for the case of Czech Republic – if their predictions are, at least partially, coherent with the real data on government spending.

In the second part, we will create a benchmark New Keynesian model for the Czech Republic. This model will be enhanced by the rules from first part. Consequently, we will compare the results of enhanced models with the results of the benchmark model. Finally, we will identify which government spending and tax setting rule combination is the most suitable one for the case of Czech Republic and to check its universality for other countries.

Outline:

1. Introduction
2. Literature review on New Keynesian models, government spending modelling and taxation rules
3. Government spending and tax setting rules
    i. Rule 1
    ii. Rule 2 ..etc
4. The benchmark NKE model
    i. Basic model
    ii. Calvo pricing
    iii. Inclusion of random rigidities
    iv. Calibration for Czech Republic
    v. Calibration for other countries
5. The enhanced NKE models with the government and the tax rules
    i. Rule 1
    ii. Rule 2 ..etc
6. Models comparison
    i. Fitting the moments of data of Czech Republic
    ii. Fitting the moments of data of other countries
7. Discussion
    i. NKE model enhancement by government spending modelling

and taxation rules

ii. Universality of government spending and taxation

8. Conclusion

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Introduction

In this thesis, we will compare various fiscal policy and tax setting rules for the case of Czech Republic using of DSGE modelling framework. Fiscal policy has been a relatively separate topic in macroeconomics since related literature offer only limited analysis of interdependence of fiscal policy and other main factors in the economy. For most countries, however, government represents an extremely important economic agent that influences a large part of GDP through its spending. Thus the interaction between fiscal policy and other variables is a topic worth analysing. Moreover, the DSGE modelling is particularly lacking proper definition of fiscal policy as the government spending is often modelled as exogenous AR(1) process. This thesis attempts to explore this interaction in a greater detail for the case of Czech Republic. We will attempt to find the fiscal policy rule that corresponds to the current fiscal and economic behaviour in Czech Republic and that is compatible with DSGE framework.

In particular, we will select different types of fiscal policy rules from related literature, then we will construct the benchmark DSGE model. Finally, we will compare the efficiency of chosen fiscal policy rules through implementing them into the benchmark model and comparing the results. The thesis is structured accordingly. In the first part, we select the most common acyclical, pro-cyclical and counter-cyclical fiscal policy rules.. We choose Barro (1979) as the best representation of the acyclical fiscal policy rules. This model assumes that the government attempts to keep tax collection costs constant. The pro-cyclical rules are the most likely candidates for the optimal model, so we choose two of them. First, Talvi and Vegh (2005) introduce a pro-cyclical fiscal policy rule based on voracity effect. This means that the government is unable to generate budget surplus, because of weak institutional background, which makes it easy for any interest groups to steal away the surplus. Alesina et al. (2008) show the same effect as a simple result of corruption. The voters are unable to elect non-corrupt parties as they lack full information. Therefore they take the state of the economy as the main indicator and demand more spending during a boom. As for the counter-cyclical policy rule, we will opt to use Coate et al. (2010) as they define the policy rule basing on an imperfectly deciding government. Weak assumptions on the rationality of the government seem like the best way to proceed for the case of Czech Republic, so the rule is of high interest despite it is very complicated. In the end of the first part, we will reconstruct the fiscal spending rule by Baxter (1993), who supposes that the government can make both productive and unproductive spending. The productive spending is accumulating 'government capital' and unproductive is the politically motivated spending like war expenditures. We will remodel the original version of the model into DSGE framework so the rule is implementable into the benchmark model.

In the second part, we construct a benchmark DSGE model. The model is a relatively standard DSGE model, which is based on classical CES utility function with infinitely living households. To introduce rigidities to the model, we assume transaction costs to consumption. Households keep some money in form of money holdings, instead of the standard capital and bond as the transaction costs create a preference for liquidity. Considering firms, we assume standard Dixit-Stiglitz monopolistic competition with extra added rigidity in the form of price adjustment costs. For the fiscal and monetary policy we also assume the simplest version, in particular we model both the government spending and tax setting as exogenous AR(1) processes, while for the monetary policy we use simple Taylor rule. We calibrate the model for the case of Czech Republic.

In the third and final part of the thesis, we compare the fiscal policies determined in the first part through the benchmark model created in the second part. The comparison is done by plugging the fiscal policy and relevant tax setting rules into benchmark DSGE model.. The two pro-cyclical models are the most suitable with the corruption model of Alesina et al. (2008) being the best one and causing, as the theory would suggest, a greater volatility in the movement of variables through the business cycle due to pro-cyclical fiscal policy. The second pro-cyclical model is the one of Talvi and Vegh (2005), which achieves rather counter-intuitive results. The model assumes a rather strict budget constraint on the government, with that the government does follow the voracity effect, but gets quickly tamed by having lower taxes and being unable to increase them due to introduced rigidities. As a result, the model actually shortens the business cycle and smoothens it during the process.

Fiscal policy rule

In this chapter we will define the various strategies to model the fiscal policy. When modelling fiscal policy, there is a single variable which needs to be addressed as precisely as possible and that is public debt. While standard government spending indeed has an impact on the real economy, it still is a different type of consumption as if there were no government. Consumers would have the money that government takes by taxes and use them on consumption or savings. By taxation, the consumption and savings spending is done with the same money but by the government, which ensures different allocation and possible sub-optimality. However, the impact of such difference is usually modelled to be small. What makes the government role unique in the economy is its ability to accumulate very large long term debt, which is exactly what most governments in the western world tend to do and indeed the Czech government does not differ in this respect. When choosing the fiscal policy rule, it is therefore of utmost importance to see how well it handles the public debt as that is the most important attribute. Since the public debt in essence transfers future assets into the presence under the penalty of an interest rate, the debt and its future repaying is expected to have a significant impact on the real economy. The first concept of fiscal policy which we will consider is the tax smoothing.

Tax smoothing model

The originator of the tax smoothing approach is Barro (1979). The basic idea is that government tries to minimize the costs caused by taxation while pursuing it goals, which are embodied in its spending G. The collection costs minimization is supported by multiple reasons, such as a model of self-interested government under perfect electoral control (the voters would change the policy makers if they did not minimize the collection costs) or even a model of a dictator who tries to maximize his own utility (any extra collection costs are his costs). To formalize this discussion, Barro (1979) assumes a single national government, which does not partake in the question of migration and which finances its expenditures G through taxes τ and public debt b. Taxes include both the transfer of purchasing power from consumers to the government, but also collection costs and/or the misallocation costs imposed on the real economy by the government taxation. Government pays interest rate r that is constant over time from its debt. For simplicity, output Y is taken as exogenous. The government budget equation in each period is then:

$$G_t + rb_{t-1} = \tau_t + \left(b_t - b_{t-1}\right) \qquad (2.1)$$

Now we add the restriction to perpetual debt financing. (i. e. the assumption that government doesn't/is unable to finance debt through more debt ad infinity - that sounds perfectly logical, but it is currently difficult to support empirically). We will extend this discussion further on and we will attempt to relax the assumptions later in this work. The restriction in this part is necessary since the assumptions of constant interest rate on debt and no debt ceiling leads to infinite debt financing (Barro, 1979). We therefore get the overall budget constraint in the form of:

$$\sum_{t=1}^{\infty}\left(\frac{G_t}{(1+r)^t}\right) + b_0 = \sum_{t=1}^{\infty}\left(\frac{\tau_t}{(1+r)^t}\right) \qquad (2.2)$$

This equation represents that value of government expenditure plus initial debt must equal to the present value of taxes. The optimization on the government side is done on tax collection costs, which under the assumption of homogeneity are expressed by the function *Z*:

$$Z_t = F\left(\tau_t, Y_t\right) = \tau_t f\left(\tau_t / Y_t\right) \qquad (2.3)$$

Where functional form *f* is assumed to be invariant over time, monotonous and increasing. The present value of collection costs is then:

$$Z_{t_0} = \sum_{t=t_0}^{\infty} \frac{\tau_t f\left(\tau_t / Y_t\right)}{(1+r)^t} \qquad (2.4)$$

Now in order to minimize the collection costs, the first order condition is that $\frac{\partial Z_t}{\partial \tau_t}$ is equal for all *t*. This is the final condition that fully specifies the problem. The government takes values of *G* and *Y* as exogenous and sets the tax rate accordingly while making up for missing money by generating debt and repays the debt when it collects more than the expenditures. To fulfil all conditions, the government in the end keeps the ratio $\frac{\tau_t}{Y_t}$ constant. This conclusion is testable and Barro (1979) tests the hypothesis on US data up to the year 1976. The results are mostly in favour of his hypothesis, concluding that tax smoothing actually happens in the case of US for the given dataset. For our purposes, this fiscal policy rule has a primary advantage in being simple, to calibrate and also to be incorporate into the model. However, the resulting policy is acyclical in fiscal spending, meaning that it does not respond to the business cycle itself. Numerous studies, however, either take the Keynesian approach of counter-cyclical fiscal policy (Coate et al., 2010) prove to be mostly correct in the case of developed countries (Talvi and Vegh, 2005), but the results are unclear in the case of developing countries as their fiscal policy tends to be pro-cyclical (Gavin and Perotti, 1997). For the purpose of this work, we will keep the tax smoothing model of Barro (1979) as the baseline acyclical fiscal policy model and switch the focus to pro-cyclical models.

Pro-cyclical model

Pro-cyclical models are generally of two types. Both types are designed to show pro-cyclicality of fiscal policy in developing countries, but type one shows it as a rational answer to the specific conditions of developing countries, while type two show it as a result of imperfect political decision making. We will refer to the second type of pro-cyclical models in the following subchapter. Starting with type one, our main examples come from Gavin and Perotti (1997) and Talvi and Vegh (2005). Galving and Perotti (1997) examine the data of Latin countries and show high pro-cyclicality in fiscal policy especially in a period of recession. Talvi and Vegh (2005) then extend the discussion to a sample of 56 countries, where they show that G7 countries are quite compliant with mild tax smoothing in Barro (1979) style while the rest of the countries has fiscal policy rather pro-cyclical. Latin America has many unique traits, but most notable ones are very high volatility of main macroeconomic variables, virtually no response of fiscal policy to GDP change. Talvi and Vegh (2005) estimate that developed countries increase fiscal spending by about 0.37 percentage point of GDP when GDP increases by 1 %, while in the case of Latin America the reaction is estimated at 0.042 and not statistically significant from 0. That implies that fiscal balance naturally gets better in good times and worse in bad times and thus is pro-cyclical. Finally, the fiscal imbalances in Latin America are significantly less persistent than in the developed countries, an increase to fiscal imbalance has the average life span estimated at 7 years developed countries and 4 years for Latin America. The actual pro-cyclicality of fiscal policy is then relatively low in periods of booms, as those are accompanied by decreased taxes and very high in periods of recession, where major tax increases and drops in public spending are observed.

Possible explanation is our main interest. Galvin and Perotti (1997) offer three: neoclassical explanation, voracity effect and endogenous borrowing constraint. The neoclassical explanation would be that there is reverse causality present and therefore the recessions are actually caused by the drops in government spending. This argument, however, fails when particular cases are examined in detail. For example in the case of 1995 crisis in Argentina and Mexico, the shock was with little doubt external. Indeed, the decrease in government expenditure and increase of taxes did not help to avert or at least soften the following recession. The effect of the policy change was anything between no effect and negative effect, however it does not mean that the reaction wasn't the optimal one. This point will be supported by the other two possible explanations. Even though restrictive fiscal policy worsens recessions, it might be the optimal government behaviour. The neoclassical answer also lacks the explanation of the asymmetry of fiscal policy adjustment to changes in economic activity.

Voracity effect is the other possible explanation and seems very plausible. The basis of the argument is that the institutions, particularly the law enforcement, are weaker in the Latin America than in the developed countries. Since Czech Republic might be a similar case, the importance of this effect is further emphasised. The idea is that due to weaker institutions, regulator is not independent on the interest groups that are present in the economy. Therefore any increase in spending results primarily in increased rent of the interest group rather than the intended result of the fiscal expansion. Moreover, exactly the same argument applies when the government intends to accumulate budget surplus. Interest groups would lobby heavily for using the money for spending rather than repaying debt or simply keeping a surplus. For the interest groups, that is a perfect profit maximizing behaviour. Facing this situation, should the government actually want to be beneficial for the economy, what would the optimal fiscal policy decision be during a boom? To decrease taxes, so the private sector as a whole (not just the interest groups) invest/generate surplus for the worse years of recession when the government, should it need to, can extract back some of the surplus through increase of taxes. And that is exactly the case of Latin America, as the government does indeed decrease taxes during a boom and then takes the money back by increasing taxes during a recession. The benefits of this approach and the need to get extra finances during a recession are then supported by the third explanation – endogenous borrowing constraint.

While the original authors, Galvin and Perotti (1997), did not call it like that, we now see the endogenous borrowing constraint as the best name for the given phenomenon. The investors who provide government with money through buying its bonds are extra vigilant in time of crisis as they face risk of loses. As the countries in Latin America, much alike Czech Republic, are economically weak compared to the fully developed countries, they face a loss of credibility in times of recession. Therefore, creation of government debt faces higher interest rate during a recession. Since recession is usually marked as a drop of GDP, the interest rate and therefore the borrowing constraint governments face is depends on output, which makes it endogenous. Now to optimize its financing, it is cheaper for the government to gain finances through increase of taxes during a recession than to generate debt on the market, especially when the private sector who pays the taxes had an opportunity to prepare thanks to the lower taxes during the preceding boom. Contrary to Barro (1979), this is where the main difference comes from as here the interest rate on public debt is endogenous and varies with time. While Galvin and Perotti (1997) make a very instructive case, they do not formalize it and the restriction to Latin America countries might be not enough general for our needs, therefore we turn to Talvi and Vegh (2005) to get an exact expression for such model of government expenditures.

Talvi and Vegh (2005) take the standard optimal fiscal policy model of Lucas and Stokey (1983) and add a restriction that makes it costly to generate large budget surpluses, in other words the voracity effect. In this paper the endogenous borrowing constraint is not implemented. The characteristic behaviour is observed in the model even with simple restriction on surplus accumulation and thus it remains unclear whether the endogenous borrowing constraint really needs to be implemented. Talvi and Vegh (2005) also consider pro-cyclical fiscal policy also for countries which have little issues with selling their bonds on financial markets as their credibility is high enough even in the time of recession. To be specific, the voracity effect is modelled so that government expenditure is split into two parts, one part is exogenous component $\bar{g}$ and represents the political part of the spending, the other part is endogenous and assumed to be non-negative, increasing and convex function of the primary surplus:

$$g_t = \bar{g} + f\left(PS_t\right) \qquad (2.5)$$

Where:

$$PS_t = \tau_t c_t + z_t - g_t \qquad (2.6)$$

τ represents taxation of consumption, c is consumption, z is flow of endowment that government receives (for example natural resources of given country) and g is total government expenditure. Here it is important to note that the case when $f\left(PS_t\right)=0$ is exactly the case of Barro (1979), which we listed earlier. The original paper solves the model for economy made of representative consumer and government, but that is of no importance for us as we will use DSGE framework. What is, however, of great importance is the empirical testing by Talvi and Vegh (2005) did and its possible interpretations.

The results of testing the model on data show that the null hypothesis is valid and therefore the G7 countries behave as if they followed taxation smoothing rule and the rest of the countries are affected by the voracity effect. This simple interpretation like this is very tempting, but not very plausible. There is simply no reason to believe that the voracity effect, or in other words lobbying pressure of interest groups, is a phenomenon unique to developing countries and does not happen at all in G7. Talvi and Vegh (2005) therefore offer a different explanation – the variability of tax base. The variability of tax base is double in the developing countries when compared to G7 (triple if consumption is taken as tax base). As far according to the model, when the variations in tax base are small, the political pressures to spend are relatively negligible as the budget surplus deviates little from the average value. The Barro (1979) rule is therefore a good approximation. On the other hand , when the tax base fluctuation is high, the government would generate large surpluses in good periods, which naturally increases the political pressure to spend. To avoid such wasteful spending, policymakers' best reaction is to execute a heavily pro-cyclical policy as described above. Inability to generate large surpluses in good times combined with high variation of tax base ensures serious contractions in the bad times. The difficulty to create sufficient budget surplus for perfect tax smoothing during good times is proportional to the amount of variation in the tax base. Moreover, the political pressure that appears in good periods is also dependent on political fragmentation of the given country. As supported by a model of various ministries fighting for resources without caring for the total budget, higher political polarization and instability do increase the lobbying pressure on spending (Aizenman, 1992).

Imperfect political decision making model

This model is a different type of pro-cyclical model. While the standard model of Talvi and Vegh (2005) and Galvin and Perotti (1997) sees the government decision making as optimal, the model of Alesina et al. (2008) gives a completely different background reasoning for the same final phenomenon – the government decision making is corrupt in the way that it spends part of the revenue on unproductive spending (political rents) and the pro-cyclicality is caused by the optimal demand from voters (consumers). The basis of the model is that there is information asymmetry in a sense that consumers do not observe true value of government borrowing on its margin, but do observe the state of the economy. Voters can replace the government, but cannot push the rents to zero. With this setup, consumers do observe the true state of the economy and therefore demand some extra utility during the times of boom with a "starve the leviathan" style of argument – when the consumers know that the government has a surplus due to economy being in good shape, it is perfectly rational to want to extract as much of the money for otherwise it would be spent on political rents. This makes government run a pro-cyclical fiscal policy and generate too much debt. Thus the policy arises from voters' demands. But voters do not demand irrational policies: through a reelection constraint on the government, they obtain a second-best solution to an agency problem in an environment of corruption and imperfect information (Alesina et al., 2008).

Model wise, the government budget constraint is the following:

$$g_t + r_t + b_t \leq \tau_t y_t + \beta b_{t+1} \qquad (2.7)$$

g is classically the government expenditure, r is political rent, b is public debt, τ are taxes, y is output and β is discount rate. There is an upper limit to how much government can steal through rents, $r_t \leq q_t$ where $q_t = \overline{q} + \rho y_t$. In the simple case ρ is assumed to be constant and $\rho > 0$, in more general cases it is a decreasing and concave function. It is also assumed, that there exists an upper limit on government debt, under which there is no risk of default and which never gets broken. Applying the standard representative consumer model then gives the desired pro-cyclical behaviour conditional on the amount of corruption. The empirical testing of the model then confirms its hypotheses. A strong positive relationship between amount of corruption and amount of pro-cyclicality is shown and moreover, it holds only under democratic regimes. That is a strong indirect evidence in support of the corruption hypothesis, especially coupled with low evidence for the direct alternative in form of endogenous borrowing constraint.

Counter-cyclical model

There are plenty models of counter-cyclical fiscal policy. We choose the one presented by Coate et al. (2010) because it is the most recent and already uses modern real business cycle framework, which makes it easy to implement into our DSGE model. The new model originates from Barro (1979), but includes several changes. Firstly, it assumes that policymaker is not a benevolent planner but instead simple legislature. Also, shocks are modelled as persistent shocks to productivity (through technology) instead of shocks to public spending. Persistence of shocks is crucial in this case, as economy entering a boom or recession has impact on policymaker´s expectations of future tax income. The model characterisation of legislature is that it comprises of representatives from one-member geographically distributed districts. Government can raise revenues through taxes or issue one period bonds and it uses the revenues for public goods or pork-barrel spending. Finally, the decision making is done through majority voting, while the policy making is modelled as non-cooperative bargaining. Much like in the previous models, perfect foresight economy with a representative consumer and the government is considered. The model includes three restrictions on government spending, namely that revenues must be sufficient to cover expenditures, district specific transfers might be non-negative (a necessary condition stemming up from the introduction of districts, otherwise the policymaker could finance all his expenditures by heavy lump sum taxes imposed on one district, which is a situation that would clearly arise since decision making is done by voting and all the other districts would then outvote the one district that gets to pay for the bill) and that government borrowing must be feasible (there exists and upper limit of bonds that government can sell $\overline{x}$, the limit represents the unwillingness of investors to hold bonds which will most likely not be repaid).

The authors solve the model for both social planner and the actual political process. The Euler equation for the political process solution is :

$$\frac{1-\tau_{\theta}(b)}{1-\tau_{\theta}(b)(1+\varepsilon)} \leq \alpha_{\theta H} \frac{1-\tau_{H}(x(b))}{1-\tau_{H}(x(b))(1+\varepsilon)} + \alpha_{\theta L} \frac{1-\tau_{L}(x(b))}{1-\tau_{L}(x(b))(1+\varepsilon)} \quad (2.8)$$

Where θ is the state of the economy, and *L* and *H* are its lower and upper bound, in a sense that *L* represents the time of recession and *H* represents the time of boom, so that $\theta \in \{L, H\}$. τ is taxation, *b* is amount of bonds the government has sold and not repaid yet, ε is the elasticity of labour supply, *x* is the amount of borrowing and finally $\alpha_{\theta H}$ is the probability that the economy will be in boom in the next period and $\alpha_{\theta L}$ is the probability that it will be in recession in the next period. The social planners solution is then exactly the same, except the equation is an equality instead of inequality. Since $\frac{1-\tau_{\theta}(b)}{1-\tau_{\theta}(b)(1+\varepsilon)}$ is the marginal cost of public funds, the equation basically says that under social planners solution the marginal cost of public funds is a martingale, while under the political solution it is a sub-martingale. The behaviour of the debt is then counter-cyclical, it decreases during booms and increases during recessions. That is a direct opposite result to Talvi and Vegh (2005) model for developing countries, as those increase debt in booms through lowering taxes and decrease debt in recessions through increasing taxes and cutting spending. The explanation of Coate at al. (2010) is that under infinite time horizon, voracity effect cannot happen as the debt created would have permanent effect and thus decrease future wealth of the government so that in the next period of boom it would be unable to afford a repetition. While this argumentation is perfectly economically logical, it doesn’t necessarily mean that the voracity effect doesn’t happen in reality – in the real world there is nothing really preventing the governments in developing countries to run an unsustainable public debt policy for an extended period of time.

The empirical testing of the model brings mixed results. Since the model is calibrated for the US economy, the dataset is US data for years 1979-2009. The model displays exceptional results in terms of debt/GDP ratio prediction and the estimation of persistence Yet the model gives empirically unsupported predictions about pro-cyclicality of public spending, which is actually in line with all the previous models and gives opposite prediction to tax setting (the model predicts is as counter-cyclical while in the US data it appears acyclical), which is again in line with the previous models. So despite the model does give useful insight into the process that generates public debt and the level of persistence involved in the fiscal policy, it does not invalidate the other models of Barro (1979) and Talvi and Vegh (2005).

Dichotomous spending model

In this part we move on from simple literature review to original research. Dichotomous spending model is best represented by Baxter and King (1993), who claims that government spending can be divided into two parts - an exogenous part, which is the political spending done on the basis of purely political demand and the economically efficient spending, which is basically investments by the government. Unfortunately, the methodology used to describe the model makes it difficult or even impossible to fit into DSGE framework. Therefore the model will be recreated using DSGE methodology, with a small modification - commonly observed factor of persistence.

The persistence factor is supported by all previous models (Talvi and Vegh (2005), Alesina et al (2008), Barro (1979), Galving and Perotti (1997) and Coate et al. (2010)). We will therefore model the political government spending as completely exogenous with a persistence factor – as an AR(1) process. For the economically reasonable government expenditure, we can imagine any government investments and public goods like health care and education, which have long term positive effect on both the consumer’s utility and the overall productivity of the economy. In order to finance these expenditures, the government collects taxes and conducts series of redistributing transfers. Considering those transfers, the key thing to remember is that there is always a bit lost due to the administration, so they always end up as extra income for the government.

War expenditures are the most stellar example of the purely political expenditures as they have little to do with economic reasoning and are almost exclusively determined by external factors. Government spending is assumed to be path dependent, meaning that there cannot be large shifts in it due to political continuity and the fact that politicians need to worry about the popularity of their steps. Any persistent government expenditures will create business opportunities – for example war expenditures cause a boom in weapon industry. Government can, theoretically, cut down its expenses in given field virtually instantaneously, on the other hand industry itself can hardly do so as there are both fixed costs and complications with mass releasing of workers. So should the government cut its expenditures suddenly, great amount of people would suffer loses and lose jobs, which would create a great wave of unpopularity. Even if government wants to cut the expenditures, they are forced to decrease them only slowly to not create a wave of protests. The same constraint applies on transfers - it is unthinkable for the policy maker to just cut the transfers by large margins at once as the formerly receiving portion of population would be extremely unhappy about it and readily replace him during next elections.

The model

In this section we will explain the basic setup of our model, which will give us the solutions to previously asked questions.

We closely follow Baxter and King (1993) and therefore we choose non-separable multiplicative utility function:

$$u_t = \frac{\left(C_t^{1-\gamma} N_t^{\gamma}\right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} \tag{2.9}$$

It is a too simple choice since (opposed to the classical CES function which we will use later on in the work) important calibration parameter N – the amount of leisure in steady state - cancels out from the equations so the model doesn't give a clear answer to the substitution between consumption and labour.

$$Y_t = A_t K_t^{\theta_k} N_t^{\theta_n} \left(K_t^{g}\right)^{\theta_g} \tag{2.10}$$

Production function, which is almost standard, features a new factor – the government capital. The idea behind is that the government does contribute towards output, but due to governments inherent allocation inefficiency (Hayek (1944)), coefficeint θ_g which is basically the factor by how much does the government influence the output through its capital.

$$K_{t+1} = \left(1-\delta\right) K_t + I_t \tag{2.11}$$

$$K_{t+1}^G = \left(1-\delta\right) K_t^G + I_t^G \tag{2.12}$$

These are the laws of motion of the two capitals, for simplicity we choose the same rate of depreciation δ, however the model would not become overly more complicated with two different depreciation rates.

$$C_t + I_t = \left(1-\tau\right) Y_t + TR_t \tag{2.13}$$

This equation represents the budget constraint of the non-government side of the economy. In order to get the total budget constraint, we need to plug in the government budget constraint, which follows:

$$\tau Y_t = G_t + TR_t \qquad (2.14)$$

τ represents tax rate in this settings. Now plugging (14) into (13) we get:

$$C_t + I_t + G_t = Y_t \qquad (2.15)$$

Which is the standard budget constraint. So far, our model is fairly standard except for the division of capital between private and government owned, but now we introduce the more specific features of our model.

$$G_t = G_t^A + I_t^G \qquad (2.16)$$

This equation contains one of the main hypotheses of the model, which follows from Baxter and King (1993), that government spending can be split into two parts. One part represents the economically spent money, which is the government investment I_t^G, which is made with sole profit (utility) in mind. On the other hand G_t^A is what we call autonomous government expenditures. Those expenditures are not made with economic incentives and they do not enter neither the production nor the utility function in a direct way. Now we introduce the other main hypothesis of this part – the persistence in productivity and government decision making.

$$\log(A_t) = \rho_A \log(A_{t-1}) + (1-\rho_A)\log(A) + \varepsilon_t \qquad (2.17)$$

$$\log(G_t^A) = \rho_G \log(G_{t-1}^A) + (1-\rho_G)\log(G^A) + \nu_t \qquad (2.18)$$

$$\log(TR_t) = \rho_{TR} \log(TR_{t-1}) + (1-\rho_{TR})\log(TR) + \upsilon_t \qquad (2\text{-}19)$$

The level of persistence is captured by different ρ parameters of respective variables. Notice that we take all three variables as exogenous. Since there is no “decision process” for technology – A, it is exogenous as it is common in the literature. For autonomous government spending and transfers, here we assume that the decision making is not done purely with economic reasoning behind it and thus stands outside of the model´s internal process. Now, we have too many budget constraints to work with, so we take the social planner’s approach and simplify our model into one collapsed budget constraint. By plugging (2.11) into (2.13) and (2.13) into (2.16) and the resulting equation into (2.12), we obtain:

$$K_{t+1} = (1-\delta)K_t + (1-\tau)Y_t - C_t + TR_t \qquad (2.20)$$

$$K_{t+1}^G = (1-\delta)K_t^G - G_t^A + \tau Y_t - TR_t \qquad (2.21)$$

Solving the model

In this section we show the solution of the model down, i.e. the final set of equations, which can be easily put into MATLAB and calculated through a script. First we write down the Lagrangian, we write it down in the expanded form for a greater clarity of future computations.

Lagrangian

$$\Upsilon = \sum_{t=0}^{\infty} \beta^t \left(\frac{\left(C_t^{1-\gamma} N_t^{\gamma}\right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} + \lambda_t \left((1-\delta)\left(K_t + K_t^G\right) + Y_t - C_t - G_t^A - K_{t+1} - K_{t+1}^G \right) \right)$$

FOCs

Now we proceed to calculate the first order conditions. By differentiating Υ with respect to C, we obtain the relationship of consumption and the Lagrange multiplier:

$$\left(C_t^{1-\gamma} N_t^{\gamma}\right)^{1-\frac{1}{\sigma}} \frac{1-\gamma}{C_t} = \lambda_t \qquad (2.23)$$

By doing the differentiation of Υ with respect to N, we obtain similar relation for leisure.

$$-\gamma \left(C_t^{1-\gamma} N_t^{\gamma}\right)^{1-\frac{1}{\sigma}} = \lambda_t \theta_n Y_t \qquad (2.24)$$

Now, when eliminate Lagrange multiplier, we should obtain the equation for substitution between leisure and consumption.

$$-\gamma = -\theta_n \frac{1-\gamma}{C_t} Y_t \qquad (2.25a)$$

$$\frac{C_t}{Y_t} = -\theta_n \frac{1-\gamma}{\gamma} \qquad (2.25b)$$

which we cannot get due to the poor choice of the utility function. The only remedy to this problem of the model is to apply standard CES function instead of the multiplicative version. Nonetheless, we proceed with the FOCs by differentiating Υ with respect to K_{t+1} to obtain the Euler equation:

$\beta \lambda_{t+1} \left(1 - \delta + \theta_k \frac{Y_{t+1}}{K_{t+1}} \right) = \lambda_t$ which, by plugging in (2.23), turns into:

$$\beta\left(C^{1-\gamma}N^{\gamma}\right)^{\frac{\sigma}{\sigma-1}}C_t\left(1-\delta+\theta_k\frac{Y_{t+1}}{K_{t+1}}\right)=E_tC_{t+1}\left(C_{t+1}^{1-\gamma}N_{t+1}^{\gamma}\right)^{\frac{\sigma}{\sigma-1}} \tag{2.26}$$

And since we have split the capital into two, we need to differentiate Υ with respect to K_{t+1}^{G} as well. Fortunately, the problem is symmetric, so we obtain a very similar condition just with different parameters:

$$\beta C_t\left(1-\delta+\theta_g\frac{Y_{t+1}}{K_{t+1}^{G}}\right)=E_tC_{t+1} \tag{2.27}$$

Steady state

In order to solve the model, we need a numeric value for basic steady state ratios of the model. We show them in this section.

From (2.25) we get $$\frac{C}{Y}=-\theta_n\frac{1-\gamma}{\gamma} \tag{2.28}$$

From (2.26) we get $$\frac{K}{Y}=\frac{\theta_k}{\frac{1}{\beta}-1+\delta} \tag{2.29}$$

Similarly, From (2.27) we get $$\frac{K^g}{Y}=\frac{\theta_g}{\frac{1}{\beta}-1+\delta} \tag{2.30}$$

Since $I=\delta K$ from (2.11), we just plug this into (2.29):

$$\frac{I}{Y}=\frac{\delta\theta_k}{\frac{1}{\beta}+1-\delta} \tag{2.31}$$

Symmetrically, we use (2.12) and from (2.30) we get:

$$\frac{I^g}{Y}=\frac{\delta\theta_g}{\frac{1}{\beta}+1-\delta} \tag{2.32}$$

From (2.13) we obtain:

$$\frac{TR}{Y}=\frac{\delta\theta_k}{\frac{1}{\beta}+1-\delta}-\theta_n\frac{1-\gamma}{\gamma}-1+\tau \qquad (2.33)$$

From (2.33) and (2.15) we get

$$\frac{G}{Y}=1-\frac{\delta\theta_k}{\frac{1}{\beta}+1-\delta}+\theta_n\frac{1-\gamma}{\gamma} \qquad (2.34)$$

From (2.32), (2.30) and (2.18) we finally reach

$$\frac{G^a}{Y}=1-\frac{\delta}{\frac{1}{\beta}+1-\delta}(\theta_k-\theta_g)+\theta_n\frac{1-\gamma}{\gamma} \qquad (2.35)$$

Log linearization

In order to be able to solve the model numerically, we need it in a different form. Such form is a system of log-linearized equations. That means that we change the equations to be linear in logarithms through the before mentioned process. Any variable $\tilde{x}_t$ means a difference from steady state in logarithms at time t.

From (2.25) we instantly get $\tilde{c}_t=\tilde{a}_t+\theta_k\tilde{k}_t+\theta_n\tilde{n}_t+\theta_g\tilde{k}_t^g\tilde{x}_t$ (2.36)

From (2.26) we get

$$(1-\delta)\tilde{c}_t+\left(\frac{1}{\beta}+1-\delta\right)\left(\tilde{c}_t+\tilde{a}_{t+1}+(\theta_k-1)\tilde{k}_{t+1}+\theta_n\tilde{n}_{t+1}+\theta_g\tilde{k}_{t+1}^g\right)=E_t\frac{\tilde{c}_{t+1}}{\beta} \qquad (2.37)$$

From (2.27) we get an almost identical expression

$$(1-\delta)\tilde{c}_t+\left(\frac{1}{\beta}+1-\delta\right)\left(\tilde{c}_t+\tilde{a}_{t+1}+\theta_k\tilde{k}_{t+1}+\theta_n\tilde{n}_{t+1}+(\theta_g-1)\tilde{k}_{t+1}^g\right)=E_t\frac{\tilde{c}_{t+1}}{\beta} \qquad (2.38)$$

as from (2.26).

From (2.22) we get

$$\frac{K}{Y}\tilde{k}_t+\frac{K^G}{Y}\tilde{k}_t^g=\left((1-\delta)\frac{K}{Y}+\theta_k\right)\tilde{k}_t+\left((1-\delta)\frac{K^G}{Y}+\theta_g\right)\tilde{k}_t^g+\tilde{a}_t+\theta_n\tilde{n}_t-\frac{C}{Y}\tilde{c}_t-\frac{G^a}{Y}\tilde{g}_t$$

(2.39)

Finally, we need to log-linearize the government budget constraint (2.15) to get an equation for TR:

$$\tau\tilde{y}_t = \frac{G^a}{Y}\tilde{g}_t + \delta\frac{K^G}{Y}\tilde{k}_t^g + \frac{TR}{Y}t\tilde{r}_t \qquad (2.40)$$

So the full model to solve is made of the following system of equations:

$$\tau\tilde{y}_t = \frac{G^a}{Y}\tilde{g}_t^a + \delta\frac{K^G}{Y}\tilde{k}_t^g + \frac{TR}{Y}t\tilde{r}_t$$

$$\tilde{c}_t = \tilde{a}_t + \theta_k\tilde{k}_t + \theta_n\tilde{n}_t + \theta_g\tilde{k}_t^g$$

$$\tilde{a}_t = \rho_a\tilde{a}_{t-1} + \varepsilon_t$$

$$\tilde{g}_t^a = \rho_g\tilde{g}_{t-1}^a + \upsilon_t$$

$$t\tilde{r}_t = \rho_{tr}t\tilde{r}_{t-1} + \nu_t$$

$$\frac{K}{Y}\tilde{k}_{t+1} + \frac{K^G}{Y}\tilde{k}_{t+1}^g = \left((1-\delta)\frac{K}{Y} + \theta_k\right)\tilde{k}_t + \left((1-\delta)\frac{K^G}{Y} + \theta_g\right)\tilde{k}_t^g + \tilde{a}_t + \theta_n\tilde{n}_t - \frac{C}{Y}\tilde{c}_t - \frac{G^a}{Y}\tilde{g}_t$$

$$(1-\delta)\tilde{c}_t + \left(\frac{1}{\beta} + 1 - \delta\right)\left(\tilde{c}_t + \tilde{a}_{t+1} + \theta_k\tilde{k}_{t+1} + \theta_n\tilde{n}_{t+1} + (\theta_g - 1)\tilde{k}_{t+1}^g\right) = E_t\frac{\tilde{c}_{t+1}}{\beta}$$

$$(1-\delta)\tilde{c}_t + \left(\frac{1}{\beta} + 1 - \delta\right)\left(\tilde{c}_t + \tilde{a}_{t+1} + (\theta_k - 1)\tilde{k}_{t+1} + \theta_n\tilde{n}_{t+1} + \theta_g\tilde{k}_{t+1}^g\right) = E_t\frac{\tilde{c}_{t+1}}{\beta}$$

Now we rewrite the system of equations into a matrix form. We remove the expectations and transform them into endogenous errors, which we put into the matrix Π. Similarly, we split the exogenous errors into the matrix Ψ. Denote $Q = \frac{1}{\beta} + 1 - \delta$ and the solution form of the model is:

$$\begin{pmatrix} \tau & 0 & 0 & -\frac{G^a}{Y} & -\frac{TR}{Y} & 0 & -\delta\frac{K^g}{Y} & 0 \\ 0 & -\theta_n & -1 & 0 & 0 & -\theta_k & -\theta_g & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{K}{Y} & \frac{K^g}{Y} & 0 \\ 0 & Q\theta_n & Q & 0 & 0 & Q(\theta_k - 1) & Q\theta_g & -\frac{1}{\beta} \\ 0 & Q\theta_n & Q & 0 & 0 & Q\theta_k & Q(\theta_k - 1) & -\frac{1}{\beta} \end{pmatrix} x \begin{pmatrix} \tilde{y}_{t+1} \\ \tilde{n}_{t+1} \\ \tilde{a}_{t+1} \\ \tilde{g}_{t+1} \\ t\tilde{r}_{t+1} \\ \tilde{k}_{t+1} \\ \tilde{k}_{t+1}^g \\ \tilde{c}_{t+1} \end{pmatrix} =$$

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_a & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_g & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_{tr} & 0 & 0 & 0 \\ 0 & \theta_n & 1 & -\frac{G^a}{Y} & 0 & (1-\delta)\frac{K}{Y}+\theta_k & (1-\delta)\frac{K^G}{Y}+\theta_g & -\frac{C}{Y} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{\beta}-2+2\delta \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{\beta}-2+2\delta \end{pmatrix} x \begin{pmatrix} \tilde{y}_t \\ \tilde{n}_t \\ \tilde{a}_t \\ \tilde{g}_t \\ t\tilde{r}_t \\ \tilde{k}_t \\ \tilde{k}_t^g \\ \tilde{c}_t \end{pmatrix} +$$

$$+\begin{pmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}\Psi + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \end{pmatrix}\Pi$$

Where Ψ is the matrix of exogenous errors and Π is the matrix of endogenous errors.

Calibration

Due to the size of the model, we have plenty of coefficients we need to address. For clarity, we have summarized them in the following table. We use data for the US economy as original Baxter and King (1993) model was indeed done specifically for it.

Table 1 – Dichotomous spending model calibration

	Calibration										
Parameter	θ^K	β	γ	δ	σ	θ^N	θ^G	ρ^A	ρ^G	ρ^{TR}	τ
Value	0.33	0.997	0.74	0.025	0.1	0.67	0.05	0.95	0.95	0.95	0.2

As for what these values mean, θ^K is the share of capital in production and is usually denoted as α in most RBC focused papers, but in order to stay consistent with the original paper we will stick to θ^K . Its value 0.33 is the usual value that has become standard among the literature. Similarly common is the value of quarterly depreciation of capital - δ = 0,025, this value adds up to about 10% a year. θ^N is the share of labour in production, so the value is just $\left(1-\theta^K\right)$ as only these two factors actually cause production. θ^G is one of the principal features of the model. It is basically the parameter of the influence of government capital on the output. It is outside of the "standard" capital as the decision making process, which determines its value is quite different from θ^K as it is partly exogenous. The value 0.05 is the value used by Baxter and King (1993) and we have little possibility of different choice in this parameter as it is rarely used in the literature. The rest of the parameters are a lot more standard. β is the discount rate. In order to get the value for late 20th century US economy, we refer to Marzo (2004) who focuses on this period as well. From Marzo (2004) we also get the parameters for the inseparable utility function. γ is the share of consumption in utility and its value of 0.74 is taken from Marzo (2004). The value of elasticity of intertemporal substitution is set to 0.1 which is a compromise between 0.17 of Rotemberg (1999) and 0.085 of Kim (2000). Chosen value of elasticity of intertemporal substitution gives the degree of risk aversion of the value 10. Finally, we need to set the persistence values. While 0.95 is rather standard in the literature for the persistence in technology ρ^A , it is too large for our newly introduced coefficients – the persistence in government policy setting ρ^G and ρ^{TR}. Still, there is not much of a difference whether we use 0.95 or the more likely value of 0,85 or similar, so we rather have it synchronized with the persistence in technology. Finally, we need to set the value for taxes, which we simply take from Baxter (1996) who sets it at 0.2, meaning that the government finances itself through lump sum taxes which take 20% of the output.

Solution method

The solution itself is based on Schur decomposition method. We will provide a deeper explanation of it in the following chapter, the benchmark model, for a greater consistency of this thesis.

Impulse response functions

In this part of this chapter we plot the impulse response functions of the model, which are the clearest way to represent the functionality of the model, its message and to confirm the match of our remake with the original work of Baxter and King (1993). We split the analysis into two cases – case 1 when there is no persistence in the model - $\rho_a = \rho_g = \rho_{tr} = 0$ and the case with added persistence, where the parameters follow the calibration to the letter. All impulses are shocks to the autonomous government spending and we differentiate between two types of shocks – temporary one and permanent one. All shocks are one-period 1% increase to autonomous government spending.

Temporary shock to a model without persistence

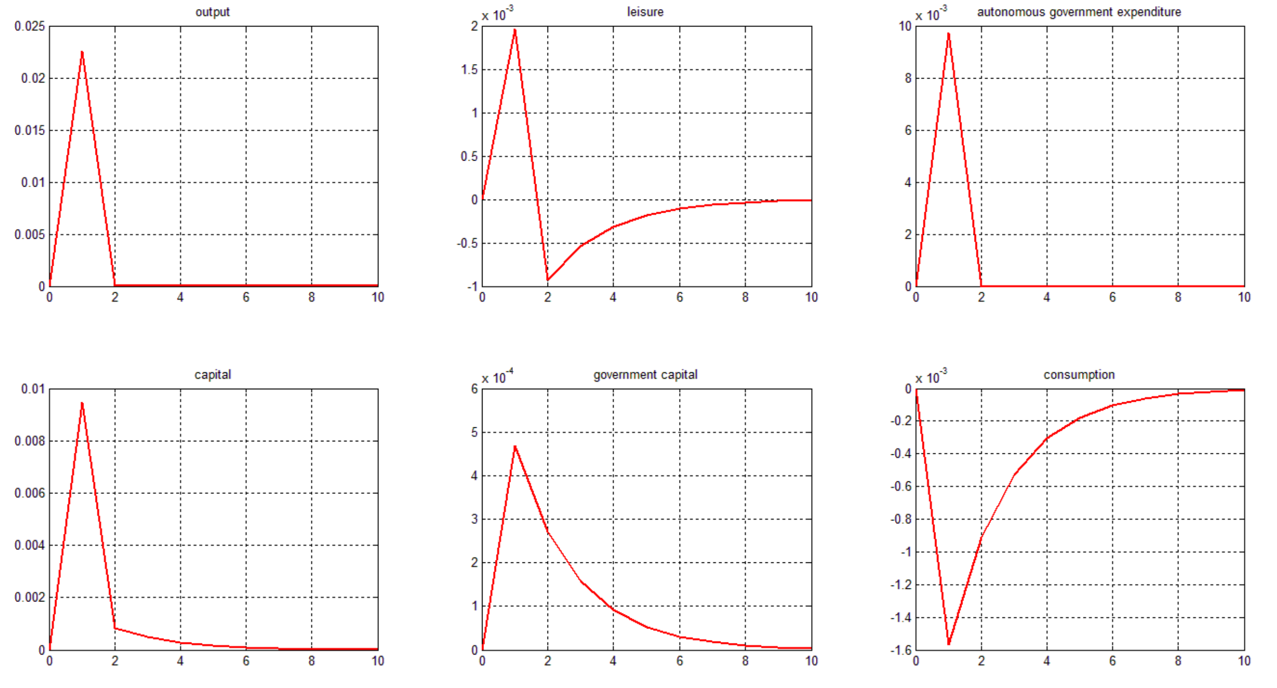

Figure 1: Dichotomous spending model impulse response functions to temporary shock without persistence

The shock to autonomous government expenditures greatly increases the price of consumption, which makes people substitute everything else for it so everything goes up other than consumption. Once the shock is over, the re-equilibrating process begins and as agents would like to smooth consumption, they need to work more to achieve that. There are two points important to notice, first of all the consumption smoothing tendency is given by our setup of the utility function and the ability of agents to transfer consumption through time thanks to accumulating capital. Should the agents not have that option, the consumption smoothing wouldn't happen. There is significant literature (Zeldes (1989), Wilcox (1989)) on the consumption smoothing not happening for all agents. A proposed "fix" is to introduce heterogenous agents, meaning that there are at least two groups of agents, one that is able to behave freely according to our initial setup and one that is constrained in their behaviour. The second group tends to be called rule-of-thumb agents and they may only consume all their endowment in each period. This way of modelling practically puts "poor people" into the model, people who need all their income to cover their basic requirements and thus they are not able to optimize consumption over time. Second point of interest is the initial jump in leisure in direction opposite of the adjustment. That is caused by the agents mistaking the initial increase in output for an increase in productivity and adjusting their behaviour to that. At the end of period they find out it was due to the shock in government expenditure and they jump to the optimal path. Output goes immediately back to steady state as there is no reason for it to not be in it anymore, the capital investments and government investments are up above the steady state level due to consumption recovering from becoming more expensive – they are all substitutes for it up to a certain point. If we were to count "welfare" of such shock, then the evaluation could not be easier – as a result people have to work more in order to be able to consume less so there is no way they are not worse off. The welfare effect of such shock is clear – people work more and their consumption is lower, therefore they are obviously worse-off. Our results correspond to the ones of Baxter and King (1993).

Temporary shock to a model with persistence

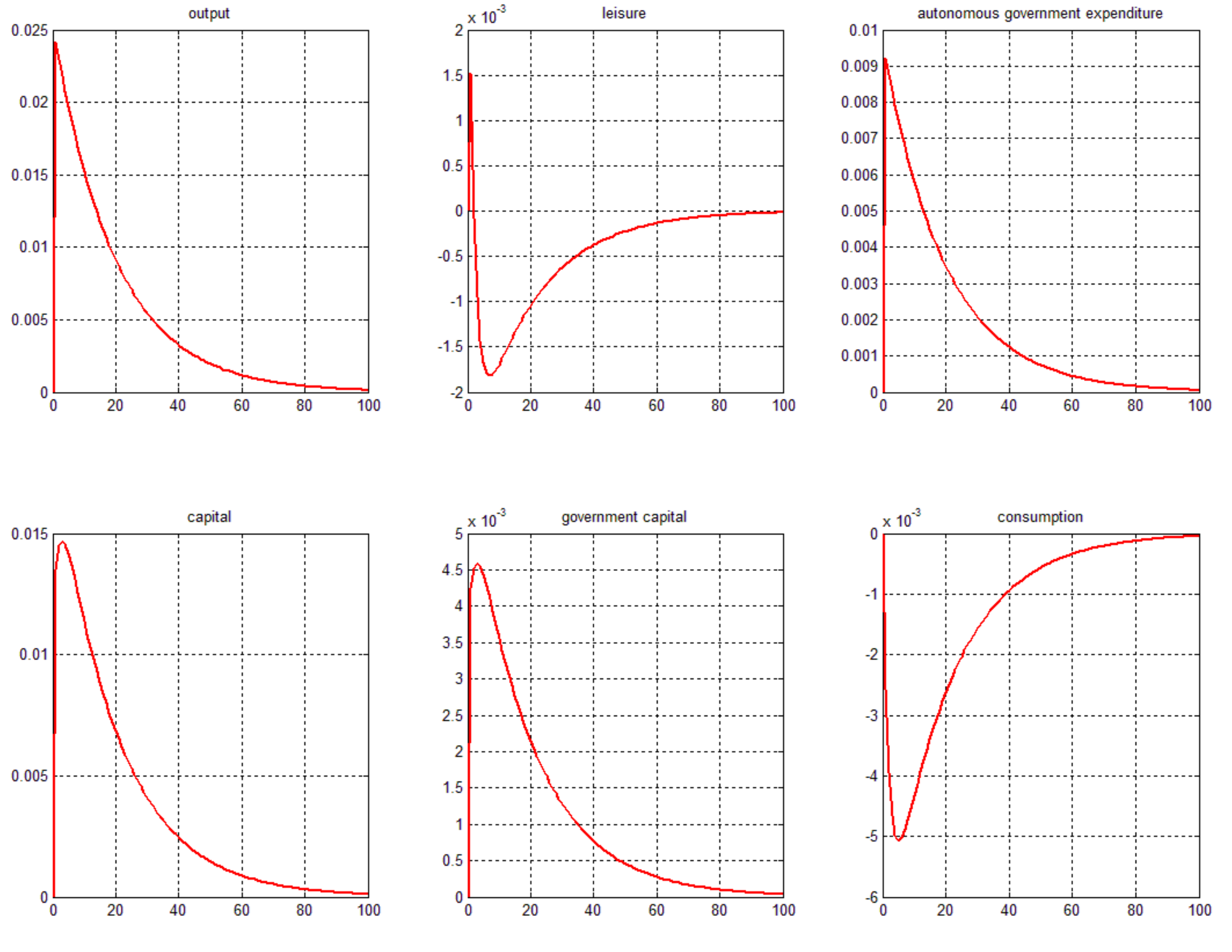

Figure 2 – Dichotomous spending model impulse respons functions to temporary shock with persistence

Now we added the persistence factor to the specification of the model to see the difference. The amount of delay in adjustment that the added persistence created is truly remarkable. Originally, the model returned to the steady state in less than 10 periods (2.5 years), now it takes about 100 periods (25 years) to get there. The difference is most notable in output, which adjusted instantly in the original model but now takes full 100 periods. Otherwise the direction of the adjustments and the logic behind them has not changed at all.

Permanent shock to model with persistence

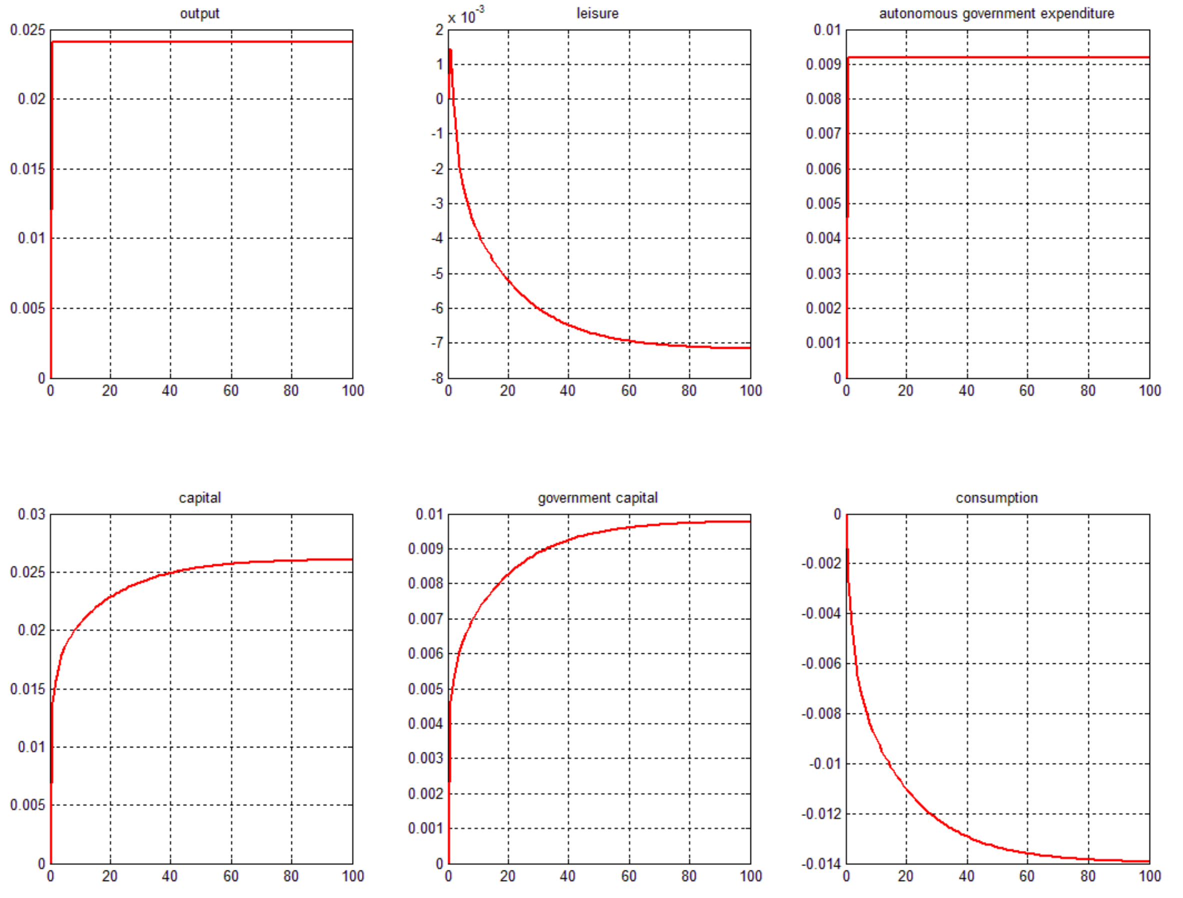

Figure 3 – Dichotomous spending model impulse respons functions to permanent shock with persistence

The response to permanent shock confirms our previous results as it follows exactly the same logic. They are the same in magnitude and final results, but the adjustment process again takes about 10 times longer. It is important to notice that the type of adjustment has remained the same despite completely different visage of the curves.

The reason is that in the previous examples the steady state remained the same and the economy was returning to it from the shock. In the new case, however, the steady state itself changes due to the permanent character of the shock so the economy adjusts as if it was shocked the other way around and were to return to the new steady state now.

Conclusion to dichotomous spending model

We have updated and reconstructed the split government spending model of Baxter and King (1993) using modern methodology of DSGE models. Then we tried to apply the hypothesis that the decision making over government expenditures is path dependent and thus carries large amount of persistence. To see the results we applied both temporary and permanent shocks to autonomous government spending and compared the results between the two models. Both models had the same type and magnitude of the response but differ greatly in the adjustment times. Furthermore, the way the model reacts is fully in line with most of empirical experience – indeed the increase in autonomous government spending in USA into war industry did decrease other consumption, made people work more and increased the amount of capital together with GDP. As for the results, adding 95% persistence – the government can only change its expenditure by up to 5% each period, which is still way above the experience of most countries as the government spending are highly inflexible on the downward path, increased the adjustment times to a shock about 10 times, which is significantly more than we had expected. The model, however, is lacking the individual consumers behaviour. In particular, the observation of consumption smoothing for all agents is, according to recent studies (Zeldes (1989, Wilcox (1989)) not entirely backed up by empirical evidence.

Conclusion to fiscal policy choice chapter

In this chapter we looked for and found suitable candidates for model algorithms for the fiscal policy in the Czech Republic. In order to keep the spectrum of possibilities as wide as possible, we did take one of each of the most sensible types of fiscal policy approximations, hoping that multiple rules of the same type would differ mostly in calibration. With that in mind, we picked an acyclical, counter-cyclical, pro-cyclical and dichotomous model of fiscal policy. The acyclical model is presented by Barro (1979) who claims and empirically supports that governments do primarily want to smooth out tax collection. Such approach well complements the attempts of the agents to smooth out their own consumption, so for the ruling body it is a very reasonable policy to implement in order have a good position for the next elections. The model is defined in a simple yet powerful way, this basic setup of tax smoothing combined with debt maximum size restriction and budget constraint.

For the pro-cyclical fiscal policy models, we consider two versions of it as this seems like the most likely candidate for a best fit policy. The reason is that the pro-cyclical fiscal policy models are usually supported by empirical data of not-top developed countries, which is indeed the case of Czech Republic as well. The two types are models of fiscal policy being a rational answer to the specific conditions of developing countries, while the second one does demonstrate it as a result of imperfect political decision making. The rational answer pro-cyclical models are perhaps best represented by Gavin and Perotti (1997) and Talvi and Vegh (2005). They claim that the pro-cyclicality is called by voracity effect, which means that governments are unable to generate surpluses in the good periods. The causes may vary from country to country, but the most common occurrence is the presence of weak institutions which allow the lobbying parties and related interest groups to drain the surplus. With such setup, the government cannot really stow the money away for worse times and instead is forced to spend it during the booms while having a lack in the recessions.

The second type of pro-cyclical model is the model of Alesina et al. (2008), which gives a different in reason but same in result model – the government decision making biased through corruption, which forces it to spend a part of the revenues on unproductive spending. The pro-pro-cyclicality is then caused by the demand from the voters, because they do observe the state of the economy and thus it is reasonable for them to expect higher benefits from the government when the economy is doing fine. Since the voters cannot reduce the rents to 0 through elections, this behaviour based on the real state of the economy is indeed optimal.

The counter-cyclical model of our choice is Coate et al. (2010). This model assumes policymaker to be a simple legislature instead of a benevolent planner. The pivotal point are the persistent shocks to productivity as economy entering a boom or recession has impact on policymakers expectations of future tax income. The model characterisation of legislature is that it comprises of representatives from one-member geographically distributed districts, it raises money through taxes or issues one period bonds, it uses the revenues for public goods or pork-barrel spending and finally the decision making is done through majority voting, while the policy making is modelled as non-cooperative bargaining. Overall the model is very sophisticated and assigns the government with great planning abilities.

Finally, we attempted to recreate a slightly modified version of a dichotomous fiscal spending model of Baxter and King (1993). In this model, the government has the expenditures split into two parts. First is the productive part, government capital and second the unproductive one – autonomous government spending. It is assumed that the autonomous government spending is used for political spending and therefore doesn't enter the production function. In this model the government plays a purely negative role as basically any increase to the autonomous government spending has negative results on the rest of the real aspects of the economy, especially consumption, despite seemingly increasing output.

With all the fiscal policy rules set, we need a tool to compare them. Such tool is the benchmark DSGE model calibrated for the Czech Republic, which we will introduce in the following chapter.

The benchmark model

In this chapter, we will define the baseline model which we will use to compare the various fiscal policy rules. For general usefulness, we will not make the model overly complicated so the potential specifics of the model cannot intervene with the added policy rules and more importantly, to ensure the model remains tractable despite changing of the government side of the model when we run the comparisons. The model shall be solved analytically as well as numerically, by using a specialized computer software (MATLAB), we will find the numerical solution of the model in form of impulse response functions and compare those to observation of real data through a matching comparison of moments of given series. For the analytical solution, we will initially split the model into the households part and the firms part. Afterward finding of the first order conditions of the solution, we will reconcile the two parts together with the government and central bank sides and find the full log-linearized specification of the model. This specification will then be solved numerically using a computer and the results, impulse response functions of used variables, will be compared to matching attributes of real data and carefully interpreted. All variables are assumed to be stationary, which would be detrended series in terms of real data. We shall now proceed with the households part of solution.

The households

The households are modelled through a representative agent. The representative agents are indexed on a real line by $i \in [0,1]$. The general idea behind this method is that on average, the households behave like the representative agents and that the deviation from such behaviour has iid N(0,X) distribution, so on average it can be ignored. We have no ambition to model each household`s behaviour separately, nor should such an effort be meaningful, so the statement about the average is sufficient for our purposes. The representative agent is assumed to be rational in his choices (he chooses the path yielding high utility, correctly estimates the utility obtained from each choice and forms rational expectations about the future. Rational expectations mean that he fully uses all information available to him and any deviation is again subject to iid N(0,X) distribution, so on average can be ignored. For simplicity of the model, we assume that households are infinitely lived and the whole economy goes with them over an infinite time horizon.

Each household, represented by a representative agent, consumes various goods, which are produced by a great spectrum of firms. He also accumulated capital and lends it to firms, the variety of consumption and investment to firms is then given by the amount of firms, which is indexed by $j \in [0,1]$. The representative agents maximize their utility on the following utility function:

$$U_t = E_t \sum_{t=0}^{\infty} u\left(C_{it,} L_{it}\right) \tag{3.1}$$

Where U_t is the utility at time *t*, E_t denotes rational expectations at time *t*, $u(.,.)$ is the classical utility function with $u' > 0$ and $u'' < 0$ properties, $C_{it,}$ being consumption of i-th agent at time *t* and L_{it} amount of labour exercised by i-th agent at time *t*. For the exact specification of the model, we choose the following utility function:

$$u\left(C_{it,} L_{it}\right) = \frac{\left[C_{it,}^{(1-\gamma)} \left(1 - L_{it}\right)^{\gamma}\right]^{(1-\frac{1}{\sigma})}}{\left(1 - \frac{1}{\sigma}\right)} \tag{3.2}$$

Which is a typical isoelastic utility function, where γ is the share of leisure in utility and σ is the elasticity of intertemporal substitution. It is worth noting that $\frac{1}{\sigma}$ is then the degree of risk aversion. The function is called isoelastic because it has constant elasticity of substitution. The agents optimize on these functions according to their budget constraint. The budget constraint for each of the *i* agents is given by their possible activities and is the following:

$$\frac{B_{it}}{P_t} + \frac{M_{it}}{P_t} + C_{it}\left(1 + \psi_t f\left(V_{it}\right)\right) + I_{it} = Z_{it} K_{it} + W_{it} L_{it} + \frac{M_{it-1}}{P_t} + R_{t-1}\frac{B_{it-1}}{P_t} + \int_0^1 \eta_i\left(j\right)\Omega_t\left(j\right)dj - T_{it} \tag{3.3}$$

On the left hand side are the possible expenditures of the agent and on the right hand side of the equation his possible incomes, all at time *t*. We shall start the explanation with the right hand side as it is simpler. The agent enters period *t* with his bonds purchased from previous period B_{it-1}, nominal money savings M_{it-1} and accumulated capital K_{it}. The bonds last one period and at their maturity, they pay back their nominal value plus an interest of r_t (when purchased at time *t*). Therefore $R_t = (1+r_t)$. Money savings is plain cash which he kept from previous period, he is motivated to keep an non-zero amount of cash due to transaction costs of consumption, which we will describe in greater detail later in the work. In the period *t*, he also works L_{it} amount of units of labour and gets paid wage W_{it} for each of the units. He also holds shares of the firms, these shares pay him a part of firms profit. The share the given agent has on the firms stock is denoted $\eta_i(j)$ and for simplicity and tracktability of the solution is assumed that each single agent does not influence the size of this share. This is certainly a simplifying assumption, but necessary in order to solve the model. The profit of firms is denoted by $\Omega_t(j)$. The agent also gets taxed, in this baseline model we assume the taxes to be lump-sum and are simply denoted as T_{it}. Finally, the agent does accumulate capital, he does it in accordance with the following expression, where δ is the rate of depreciation of capital and I is the investment to capital.

:

$$K_{it} = I_{it-1} - (1-\delta)K_{it-1} \qquad (3.4)$$

As far as the expenditures of agents go, B_{it} are bonds purchased at time *t* with properties described above. M_{it} are the nominal money savings the agent may deposit for the next period, free of interest. I is also important to notice that bonds *B* and nominal money savings *M* are the sum of those holdings over the whole economy, meaning for both the government and the agents alike. Here it is important to note that we have a sort of preference for liquidity, which is caused by the existence of transaction costs (financial frictions). Should these frictions not exist, there would be no reason for the agents to keep any nominal money holdings as these get no interest and are therefore inferior way of using money compared to accumulating capital or buying bonds. Balance on the capital market is reached automatically as there are no rigidities to capital sale and purchase. Because of this, it will always be the case that $R_t = Z_t$ for every *t*. C_{it} is the consumption and entails the whole spectrum of *j* goods produced by the firms, we will precisely specify consumption later on. For now we focus on one of the special features of our model, which is that consumption isn't automatic in the sense that there are transaction costs involved. $C_{it}\psi_t f(V_{it})$ is the amount of transaction costs paid for the consumption of C_{it}. The key to transaction costs is the money velocity V_{it}, which is defined by $V_{it} = \frac{P_t C_{it}}{M_{it}}$ and signifies the frequency at which the money is spent, or in other words what is the cost of getting the money necessary to accomplish a transaction of buying the consumption of C_{it}. For simplicity, we assume $f(V_{it}) = V_{it}$, however according to Sims (1994) any functional form of $f(.)$ that is convex ($f''(V_{it}) \geq 0_{it}$) is sufficient for the equilibrium to exist and us to be able to find it. ψ_t is the shock of money velocity, for it would be too simplistic to assume that there is no stochasticity involved in the money velocity. We define it in the simplest form, which is the following AR(1) process:

$$\log(\psi_t) = \rho_\psi \log(\psi_{t-1}) + (1-\rho_\psi)\log(\psi) + \varepsilon_{\psi t} \qquad (3.5)$$

Now we return to consumption. As we have said, it covers the whole spectrum of goods produced by firms, analytically speaking it means that:

$$C_{it} = \left[\int_0^1 c_t^i(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \qquad (3.6)$$

Here θ is the elasticity of substitution between each of the goods produced by the *j* firms, while $\theta > 1$. This equation is a constant elasticity of substitution (CES) aggregator, which is commonly used since Dixit and Stiglitz (1977). To briefly summarize the reasoning behind the equation, Dixit and Stiglitz (1977) assume that the market is made of a finite amount of firms, which each produces a unique output. The different ouputs are substitutable, but not homogenic. Hence each firm is a monopolist on its own product but still does compete with the other firms, so the model is called monopolistic competition. The market is subject to free entry, but every new firm will produce its own unique output and will chose to produce just that one (Baldwin et al. (2005)). For simplicity, it is assumed that the elasticity of substitution is same between each pair of goods. Price level is then defined in a similar way, but later when we define the behaviour of firms we will assume price setting rigidities, which we will explain later.

Households – first order conditions

In this part we will show the solution to the households problem in form of first order conditions. We will start by defining the Lagrangian:

$$\Im_t = E_t \sum_{k=0}^{\infty} \beta_{t+k} \left(\frac{\left(C_{it+k}^{(1-\gamma)} \left(1 - L_{it+k}\right)^{\gamma} \right)^{1-\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}} + \lambda_{t+k} \left(Z_{it+k} K_{it+k} + W_{it+k} L_{it+k} + \frac{M_{it+k-1}}{P_{t+k}} + \right. \right.$$

$$\left. \left. + R_{t-1} \frac{B_{it+k-1}}{P_{t+k}} + \int_0^1 \eta_i(j) \Omega_{t+k}(j) dj - T_{it+k} + (1-\delta) K_{it+k-1} - \frac{B_{it+k}}{P_{t+k}} + \frac{M_{it+k}}{P_{t+k}} - C_{it+k}\left(1 + \psi_{t+k} f\left(V_{it+k}\right)\right) - K_{it+k} \right) \right)$$

(3.10)

Now proceeding to the first order conditions. We will denote $N_{it} = 1 - L_{it}$ as leisure, we get:

$$\frac{\partial \Im_t}{\partial C_{it}} = \beta_t (1-\gamma) C_{it}^{(1-\gamma)\left(1-\frac{1}{\sigma}\right)-1} \left(N_{it}\right)^{\gamma\left(1-\frac{1}{\sigma}\right)} - \beta_t \lambda_t \left(1 + 2\psi_t V_{it}\right) = 0$$

$$(1-\gamma) C_{it}^{(1-\gamma)\left(1-\frac{1}{\sigma}\right)-1} \left(N_{it}\right)^{\gamma\left(1-\frac{1}{\sigma}\right)} = \lambda_t \left(1 + 2\psi_t V_{it}\right) \qquad (3.11)$$

$$\frac{\partial \Im_t}{\partial N_{it}} = \gamma C_{it}^{(1-\gamma)\left(1-\frac{1}{\sigma}\right)} \left(N_{it}\right)^{\gamma\left(1-\frac{1}{\sigma}\right)-1} - \lambda_t W_t = 0$$

$$\gamma C_{it}^{(1-\gamma)\left(1-\frac{1}{\sigma}\right)} \left(N_{it}\right)^{\gamma\left(1-\frac{1}{\sigma}\right)-1} = \lambda_t W_t \qquad (3.12)$$

$$\frac{\partial \Im_t}{\partial M_{it}} = -\left(1 - \psi_t V_{it}^2\right) \frac{\lambda_t}{P_t} + \beta E_t \frac{\lambda_{t+1}}{P_{t+1}} = 0$$

$$\beta E_t \frac{\lambda_{t+1}}{P_{t+1}} = \left(1 - \psi_t V_{it}^2\right) \frac{\lambda_t}{P_t} \qquad (3.13)$$

$$\frac{\partial \Im_t}{\partial B_{it}} = -\frac{\lambda_t}{P_t} + \beta R_t E_t \frac{\lambda_{t+1}}{P_{t+1}} = 0$$

$$\beta R_t E_t \frac{\lambda_{t+1}}{P_{t+1}} = \frac{\lambda_t}{P_t} \qquad (3.14)$$

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$$\frac{\partial \Im_t}{\partial K_{it}} = E_t \beta \lambda_{t+1} (1-\delta) + \lambda_t \left(Z_t - 1\right) = 0$$

$$E_t \beta \lambda_{t+1} (1-\delta) + \lambda_t Z_t = \lambda_t \qquad (3.15)$$

Equations (3.11) and (3.12) do, in combination, give the relationship between marginal utility of consumption and marginal disutility of labour. Equation (3.13) is the first order condition of the problem of money savings. Equation (3.14) is then the Euler equation of optimal bond allocation. From equations (3.13) and (3.14), we can derive the expression for money demand. Finally, equation (3.15) is the equation that presents the optimal allocation choice between present and future consumption.

Firms

In the previous part we defined the situation of households in our model. Now we will proceed to do the same for firms. We assume there to be a very large number of firms indexed $j \in [0,1]$. Each of these firms produces a unique output, which is a substitute to the output of other firms. Due to the large number of firms, no firm can influence the price of the output so they are all price takers. Each firm produces the output according to the following production function:

$$Y_{jt} = A_t K_{jt}^{\alpha} L_{jt}^{(1-\alpha)} \tag{3.16}$$

Where K_{jt} is the amount of capital stock and L_{jt} amount of labour employed in the production process. A_t is the technological shock to production, which is supposed to be common to all firms and follows the following AR(1) process:

$$\log(A_t) = \rho_A \log(A_{t-1}) + (1-\rho_A)\log(A) + \varepsilon_{At} \tag{3.17}$$

Where *A* represents the steady state value. As for the modelling of firms themselves, we use similar process as when modelling households. Again we assume that firms are on average rational, form rational expectations, exist over infinite time horizon and therefore be modelled through a representative firm. Moreover, we assume that market takes the form of Dixit-Stiglitz monopolistic concurrence with free entry, no fixed cost and free leave. What we assume differently from the standard monopolistic competition model is the price setting method. We assume that companies cannot simply change their prices free of costs any time they wish, but instead that in order to change their pricing, they need to pay a transaction cost *AC*. This cost pays a form of penalty and is measured as a share of output. The formal expression for these costs is the following:

$$AC_t^P(j) = \frac{\phi_P}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - \pi\right)^2 Y_t \tag{3.18}$$

Here ϕ_P is the parameter of the cost of price adjustment and π is the steady state inflation rate. The point to notice is that as the cost is measured in terms of total output, it will increase with the overall size of the economy and also change in the same direction as the potential shock since almost any type of shock will have an impact on the total amount of output Y. Now we shall proceed to the firms optimization problem.

Firms – optimization

In this part we will calculate the profit maximizing algorithm for the firms. Due to the previously introduced price setting rigidities in equation (3.18), the problem of the profit maximization is of dynamic nature. Any firm therefore maximizes its profit as a stream of future profits discounted by its discount factor. The firm profit maximization problem is the following:

$$\max_{K_t(j),L_t(j)} E_0\left(\sum_{t=0}^{\infty}\beta_t^f\left(P_t(j)Y_{jt}-W_tL_{jt}-P_tR_tK_{jt}-P_tAC_t^P(j)\right)\right) \quad (3.19)$$

As we have said, the β_t^f is the complex stochastic discount factor for all the contingent claims of the companies. In order to keep the model simple, we will simply treat it as a parameter without any more exact estimation. This maximization is then subject to demand, recalling:

$$\frac{Y_{t+k||t}}{C_{it}}=\left[\frac{P_t^*}{P_t}\right]^{-\theta} \quad (3.20)$$

After calculating with (3.20) and (3.18), we can calculate the first order conditions of the firms. The first order condition with respect to K_{jt} is the following:

$$\frac{R_t}{P_t}=\alpha\left(\frac{Y_{jt}}{K_{jt}}\right)\left(\frac{P_t(j)}{P_t}\right)\left(1-\frac{1}{\Xi_t(j)}\right) \quad (3.21)$$

And with respect to is the following:

$$\frac{W_t}{P_t}=(1-\alpha)\left(\frac{Y_{jt}}{L_{jt}}\right)\left(\frac{P_t(j)}{P_t}\right)\left(1-\frac{1}{\Xi_t(j)}\right) \quad (3.22)$$

Where $\Xi_t(j)$ is the output demand elasticity, defined by the following expression:

$$\frac{1}{\Xi_t(j)} = \frac{1}{\theta}\left(1-\phi_p(\pi_t-\pi)\pi_t\frac{Y_t}{Y_{jt}}+E_t\left(\phi_p(\pi_{t+1}-\pi)\frac{P_{t+1}}{P_t(j)}\pi_{t+1}\frac{Y_{t+1}}{Y_{jt}}\right)\right) \quad (3.23)$$

This equation measures the gross markup price over the marginal costs. Should $\phi_p = 0$, we get the standard constant Dixit-Stiglitz markup of $\frac{\theta}{\theta-1}$, which comes out directly from the monopolistic competition market setup. Should also $\theta \to \infty$, then the markup would be equal to 1. As the markup price is intertemporal, it contains the effects of both technology and demand shocks, which makes it one of the shock transmission channels of the model.

Monetary policy

In our model, we also assume the existence of a central bank who does monetary policy. We will assume that the central bank executes rather simple policy rule so that the model doesn't get unnecessarily complicated, the rule we will take as benchmark is the following:

$$R_t = \phi_\pi \pi_t + \phi_y Y_t + \mu_t^M \quad (3.23)$$

If we were to follow reality as closely as possible, all the variables would have a bar above them to differentiate them from others as these are specific to the central bank. For the simplicity of the model, we will however consider the central bank to have the benefit of access to full information, meaning it will always act upon the true realization of the variables. R_t is the nominal interest rate in period *t* as measured and used by the central bank as its main instrument, π_t is the gross inflation rate, Y_t is the real output and finally μ_t^M is the monetary policy shock. Coefficients ϕ_π, ϕ_y are the central banks response parameters to shock in inflation and output. This setup follows Taylor (1993), who calibrated this rule for US economy and found it to be working sufficiently well. A possible modification to the rule is that the central bank doesn't consider present inflation, but instead the estimate of future inflation. That would make sense should central bank possess extra information about the future inflation compared to the rest of the subjects in the economy. In our setup, however, the expected inflation would be the same for central bank as for everyone else, so the change in considered inflation would only result in an according change of the applied coefficient. As for the monetary policy shock, it is assumed to be exogenous and to take the following shape:

$$\log\left(\mu_t^M\right) = \rho_\mu \log\left(\mu_{t-1}^M\right) + \left(1-\rho_\mu\right)\log(\mu) + \varepsilon_{\mu t} \quad (3.24)$$

Where $\varepsilon_{\mu t}$ has iid $N(0,\sigma_{\mu}^{2})$ distribution. This assumption makes the central bank policy significantly more persistent (Further and Moore (1995)), which is in compliance with empirical observations as central banks seldom exercise large policy jumps.

Fiscal policy

In the benchmark model we cannot discard some basic setup of fiscal policy. Even in the simplest definition of fiscal policy, we need to define a budget constraint and an algorithm of government expenditure. The budget constraint is essential for the solution of the model to exist, for without it the government could borrow money endlessly and thus have infinitely large expenditures. We define the budget constraint as following:

$$\frac{B_t}{P_t}+\frac{M_t}{P_t}=\left(1+i_{t-1}\right)\frac{B_{t-1}}{P_t}+\frac{M_{t-1}}{P_t}+G_t-T_t \qquad (3.25)$$

Where i_{t-1} is the nominal interest rate at period *t – 1*. As for the government expenditure and its financing itself, we will assume its simplest and completely random form of an AR(1) process:

$$\log\left(G_t\right)=\rho_G\log\left(G_{t-1}\right)+\left(1-\rho_G\right)\log\left(G\right)+\varepsilon_{Gt} \qquad (3.26)$$

and

$$\log\left(T_t\right)=\rho_T\log\left(T_{t-1}\right)+\left(1-\rho_T\right)\log\left(T\right)+\varepsilon_{Tt} \qquad (3.26b)$$

respectively.

Where $\varepsilon_{Gt},\varepsilon_{Tt}$ has iid $N\left(0,\sigma_G^2\right)$ and $N\left(0,\sigma_T^2\right)$ distribution respectivelly. A necessary remark here is that even in this simplest setting fiscal policy is not neutral. The transmission channel goes through the budget constraint of the households and thus the effect of government expenditures spills into the rest of the model.

With this, we have the model fully specified. Now in order to solve it, we first need to calibrate the deep parameters of the model, which we will do in the following sub-chapter.

Calibration

In this part of the thesis, we will perform the calibration of the deep parameters for the case of Czech Republic. This is a relatively crucial part, because, indeed, these deep parameters link the model to the reality of Czech Republic. Our model has large amount of parameters, so we summarize them in the following table:

Table 2 – Benchmark model calibration

	Calibration										
Parameter	α	β	γ	δ	σ	η	θ	ϕ_p	ϕ_y	ϕ_π	$\rho_{a,g,t,\psi,\mu}$
Value	0.49	0.95	0.64	0.012	7.661	0.1	10	70	0.22	1.14	0.9

The basic assumption is that the parameters are related to human nature, that they shouldn't change over time and should definitely be policy invariant. Now starting with the actual calibration, first of all is the share of capital in production α. This classic parameter is well estimated by Hlédik (2003) at the value of 0.49. The discount factor, β, is often not completely estimated and just put into 0.95-0.99 interval. We will take set the parameter to 0.95 as it may be closest to reality given the fact that our topic is primarily oriented on fiscal policy and voters tend to be rather short-visioned in their wishes. The share of leisure in utility can be calculated from the steady state values of equations (3.11) and (3.12), in our given specification it is 0.64. For the rate of depreciation, we take the calculated estimate of Hlédik (2003), which is 0.012. Since the calibration is done quarterly, that makes yearly depreciation of about 4.8 %. As for the elasticity of intertemporal substitution, we will refer to Tonner at al. (2010), who estimates the given parameter at 7.66. The parameter for the share of each agent in companies η has a very wide range of observations. For the best consistency of our model, we pick 0.1 by Marzo (2004) who estimated a model quite similar to ours. θ is the elasticity of substitution across goods. Since the whole oligopolistic market setup is quite artificial, the parameter easy to estimate. We use the classic estimate of 10 by Rotemberg and Woodford (1999), but this is more of a working hypothesis. The parameter of price adjustment rigidity ϕ_p is by far the most difficult parameter to estimate. We will use the estimation of Keen and Wong (2003), who cap it between 58.25 and 96.15. That is not a very precise interval, but they also make an interval estimate for Ireland which is between 72 and 78. For the Czech Republic as a less developed country we will pick 70, as we assume the adjustment time needed is rather smaller in less developed economies due to lesser extent of regulations. For the monetary policy parameters ϕ_y and ϕ_π, we will go directly to the source – Czech Central National Bank. One of its working papers by Tonner et al. (2010) estimates these parameters at 0.2233 and 1.14 respectively. Finally, the AR(1) process persistence parameters $\rho_{a,g,t,\psi,\mu}$. Since they are all a completely artificial construct, there is no real estimation available. We will therefore simply set them to 0.9 since the model is both not very sensitive to them and the chosen value is rather standard in the literature. We have now all model parameters estimated so we can proceed to defining the steady state of the economy.

Steady state

In this part of this chapter we will describe the steady state of our mode. First of all, we will assume a crucial simplifying assumption that *j* is symmetrical to i, meaning $X_t(j) = X_t$ and $x_t^i(j) = x_t \; \forall i, j \in [0,1]$. The most important simplification from this assumption is that all consumers and firms have identical set of behavioural relationships, allowing us to completely ignore relative price distributions between firms. That keeps the model relatively simple and tracktable. Now in order to represent the model in the steady state form, we will present all the main relationships of the economy. But before that, we will assume a social planners point of view, which allows us to collide government and household budget constraints, making it significantly easier to demonstrate the model in a succinct version. By collapsing the budget constraints (3.3) and (3.25), after applying the steady state condition we obtain, $C_t(1+\psi V) + I_t + G_t = Y_t\left(1 - \frac{\phi}{2}(\pi_t - \pi)^2\right)$ by applying the steady state condition we get:

$$C(1+\psi V) + I + G = Y \tag{3.27}$$

Which is indeed the most classical budget constraint equation, just it is enhanced by the existence of the transaction costs. Now defining the rest of the model, we start with the first order conditions of the households problem. Collapsing together equations (3.11) and (3.12), while applying the steady state condition we obtain:

$$\frac{(1-\gamma)}{\gamma(1+2\psi V)} W = \frac{C}{N} \tag{3.28}$$

Which is the core relationship of consumption and leisure. From the equation (3.13) we obtain the specification of the steady state discount factor:

$$V = \frac{1-\beta}{\psi} \tag{3.29}$$

Equation (3.15) then gives us the relationship of rental rate of capital Z and the real rate of return:

$$Z = \beta - 1 + \delta \tag{3.30}$$

On the side of the firms, but applying of the steady state to the first order conditions we obtain the relationships for the price level:

$$\frac{R}{P} = \alpha\left(\frac{Y}{K}\right)(1-\theta)$$

(3.31)

$$\frac{W}{P} = (1-\alpha)\left(\frac{Y}{L}\right)(1-\theta)$$

(3.32)

And finally from the Taylor rule of monetary policy (3.23) we obtain the relationship for the interest rate:

$$R = \phi_\pi \pi + \phi_y Y \tag{3.33}$$

Here it is important to notice that $\mu = 0$ as there is no reason for it to be otherwise. Now, we take the steady state values of π, P and N as parameters and we can see our steady state has 7 variables defined through 7 equations. That makes our model exactly specified and we can proceed to the solution itself.

Solution method

The solution itself is based on Schur decomposition method, which was in the care of real business cycle models proposed by Sims (2000). The basis of the method is to decompose the model into the following form:

$$\Gamma_0 \tilde{z}_t = \Gamma_1 \tilde{z}_{t-1} + \Gamma_2 \varepsilon_t + \Gamma_3 \left(\tilde{z}_t - E_{t-1}\left(\tilde{z}_t\right)\right)\Gamma_{0-3} \tag{41}$$

In this form $\tilde{z}_t$ is the vector of all variables, both exogenous and endogenous, $\tilde{z}_{t-1}$ is the vector of the very same variables but lagged by one time period, ε_t is the vector of all exogenous errors in the model (technology, fiscal policy, transfers..etc) and the last polynomial on the right hand side is the error of expectations. All variables in the vector $\tilde{z}_t$ are expressed in their percentage deviation from steady state, meaning

$\tilde{z}_t = \ln Z_t - \ln Z$ where Z is the vector of all variables in their steady states. The transaction errors vector is the one through which shocks are implemented into the model as a shock is a sudden change to one of the exogenous variables. We will differentiate two types of shock – temporal and permanent. Finally the polynomial at the far end of the right hand side contains the very errors of standard rational expectations, which we assume the agents make. Matrices Γ_{0-3} are non-linear functions of model`s parameters. We assume these parameters to be deep, meaning they do not change significantly over time and certainly not due to a policy change, be it fiscal or monetary. This way the model avoids the famous Lucas critique (Lucas 1974). The solution of this form is then calculated through MATLAB and thus numerically simulated. On the simulation, the most important factor are the impulse response functions, which let us study how does the model adjust after being shocked through one or multiple exogenous variables.

Log linearization

In this part we transform the model to the log linearized version, which is exactly the version MATLAB needs to apply Schur decomposition and display the resulting numerical simulation. We will present the log-linearized form of the model in a form-logical order, that is to say we split the equations into the types depending on whether they contain exogenous, endogenous or no error and display them in an order from the simplest equations of the model to the most complicated one. Afterwards, we will reorder the equations of model into the logic solution form and display the model in the form directly before we use MATLAB to solve it. Notation wise, we will denote the log-linearized variables as $\tilde{x}_t = \ln X_t - \ln X$, where X is the given variable in its steady state.

First of all, we log-linearize all the exogenous processes as these are the simplest, to be concrete they are equations (3.5), (3.17), (3.24), (3.26) and (3.26b) and their log-linearized form is the following (in order of listing):

$$\tilde{\psi}_{t+1} = \rho_\psi \tilde{\psi}_t + \varepsilon_{\psi t} \tag{3.34}$$

$$\tilde{a}_{t+1} = \rho_a \tilde{a}_t + \varepsilon_{at} \tag{3.35}$$

$$\tilde{\mu}_{t+1} = \rho_\mu \tilde{\mu}_t + \varepsilon_{\mu t} \tag{3.36}$$

$$\tilde{g}_{t+1} = \rho_g \tilde{g}_t + \varepsilon_{gt} \tag{3.37}$$

$$\tilde{t}_{t+1} = \rho_T \tilde{t}_t + \varepsilon_{Tt} \tag{3.38}$$

Where $\varepsilon_{\psi t}$, ε_{at} , $\varepsilon_{\mu t}$ and ε_{gt} are all i.i.d. ~ $N(0,\sigma^2)$ random noises. These are all the equations in the model that contain the exogenous shock, which is accounted for by the Γ_2 matrix in the solution form equation (41). Now we proceed to the equations that contain all variables of the same period, these are the equations without endogenous or exogenous error. First and foremost equation of this type is the production function (3.16), which has a straightforward log-linearized form of:

$$\tilde{y}_t = \tilde{a}_t + \alpha \tilde{k}_t + (1-\alpha)\tilde{l}_t \quad (3.39)$$

then we continue with the relationship of consumption *C* and leisure *N*, collapsing equations (3.11) and (3.12) into each other yields:

$$n_t w_t (1-\gamma) = \gamma c_t (1+2\psi_t v_t)$$

Which in log-linearized form looks as follows:

$$(1-\gamma)(\tilde{n}_t + \tilde{w}_t) = \gamma\left((1+4c\psi v)\tilde{c}_t + 2c\psi v(\tilde{p}_t - \tilde{m}_t)\right) \quad (3.40)$$

We continue with the money demand function, first we derive it from the equations (3.13) and (3.14):

$$\frac{m_t}{p_t c_t} = \psi_t^{\frac{1}{2}} \left(\frac{r_t - 1}{r_t}\right)^{\frac{1}{2}}$$

Which we log-linearize into:

$$\tilde{m}_t - \tilde{p}_t - 3\tilde{c}_t = \varsigma \frac{1}{2}\left((R-1)^{\frac{1}{2}} - \frac{1}{\varsigma}\right)\tilde{r}_t \quad (3.41)$$

Moving forward, next equation without any sort of error is the monetary policy algorithm (3.23), the log-linearization is straightforward and, given $\mu = 0$, yields:

$$\tilde{r}_t = \phi_\pi \frac{\pi}{R}\tilde{\pi}_t + \phi_y \frac{Y}{R}\tilde{y}_t \quad (3.42)$$

As we have moved to inflation, we need its specification in its log-linearized form, which is:

$$\tilde{\pi}_{t+1} = \tilde{p}_{t+1} - \tilde{p}_t \quad (3.43)$$

And finally, the last equation which doesn't contain any sort of error is the general budget constraint. We shall not take a social planners stance and solve both for the government and households separately. Given the nature of our model, the social planners solution could significantly differ from the decentralized solution. First of all, budget constraint (3.3) with plugged in profit function of (3.25) is, after moving forward for one period, the following:

$$\frac{B_{t+1}}{P_t}+\frac{M_{t+1}}{P_t}+K_{t+1}=R_tK_t-(1-\delta)K_t+W_tL_t+\frac{M_t}{P_t}+R_t\frac{B_t}{P_t}+\eta\left(P_t(j)Y_t-W_tL_t-P_tR_tK_t-P_tAC_t^P(j)\right)-T_t-+C_t\left(1+\psi_t f(V_t)\right)$$

Now, log-linearizing gives:

$$\frac{B}{P}\left(\tilde{b}_{t+1}-\tilde{p}_t\right)+\frac{M}{P}\left(\tilde{m}_{t+1}-\tilde{p}_t\right)+K\tilde{k}_{t+1}=RK\left(\tilde{r}_t+\tilde{k}_t\right)+WL\left(\tilde{w}_t+\tilde{l}_t\right)+\frac{M}{P}\left(\tilde{m}_t-\tilde{p}_t\right)+\frac{BR}{P}\left(\tilde{b}_t+\tilde{r}_t-\tilde{p}_t\right)+\eta PY\left(\tilde{p}_t+\tilde{y}_t\right)-$$
$$-\eta WL\left(\tilde{w}_t+\tilde{l}_t\right)-\eta PY\left(1-\frac{\phi_p}{2}\left(2\pi-2\pi^2\right)\right)\left(\tilde{p}_t+\tilde{y}_t+\tilde{\pi}_t\right)+PRK\left(\tilde{p}_t+\tilde{r}_t+\tilde{k}_t\right)-T\tilde{t}_t-C\tilde{c}_t+\frac{\psi PC}{M}\left(\tilde{\psi}_t+\tilde{p}_t+2\tilde{c}_t-\tilde{m}_t\right)$$

which after reorganization finally yields:

$$\frac{B}{P}\tilde{b}_{t+1}+\frac{M}{P}\tilde{m}_{t+1}+K\tilde{k}_{t+1}=\left(RK-\delta+1+PRK\right)\tilde{k}_t+(1-\eta)WL\left(\tilde{w}_t+\tilde{l}_t\right)+\left(\frac{M}{P}-\frac{\psi PC}{M}\right)\tilde{m}_t+$$
$$+\left(\frac{BR}{P}+RK+PRK\right)\tilde{r}_t+\frac{BR}{P}\tilde{b}_t+\eta PY\left(1-\eta PY\left(1-\frac{\phi_p}{2}\left(2\pi-2\pi^2\right)\right)\right)\tilde{y}_t-\eta PY\left(1-\frac{\phi_p}{2}\left(2\pi-2\pi^2\right)\right)\tilde{\pi}_t+$$
$$+PRK\left(\tilde{p}_t\right)-T\tilde{t}_t-\left(C-2\frac{\psi PC}{M}\right)\tilde{c}_t+\left(\frac{\psi PC}{M}\tilde{\psi}_t-\frac{BR}{P}+\frac{B}{P}+\eta PY-\eta PY\left(1-\frac{\phi_p}{2}\left(2\pi-2\pi^2\right)\right)\right)\tilde{p}_t \tag{3.44}$$

Now for the government resource constraint, we move it forward and plug in $R_t=\frac{i_t}{P_t}$

:

$$\frac{B_{t+1}}{P_t}+\frac{M_{t+1}}{P_t}=\left(1+P_tR_t\right)\frac{B_t}{P_t}+\frac{M_t}{P_t}+G_t-T_t$$

And finally log-linearize it:

$$\frac{B}{P}\tilde{b}_{t+1}+\frac{M}{P}\tilde{m}_{t+1}=\left(\frac{B}{P}+BR\right)\tilde{b}_t+BR\tilde{r}_t+\frac{M}{P}\tilde{m}_t+G\tilde{g}_t-T\tilde{t}_t \tag{3.46}$$

This finishes up the equations with no error. We will proceed to the equations which contain expectations of future variables and thus an endogenous error. We start with the first order conditions of firms, their log-linearized forms are the following:

$$\tilde{r}_t-\tilde{p}_t=\alpha(1-\frac{1}{\theta}\phi_p\left(3\pi-2\pi^2\right))\tilde{y}_t-\alpha\tilde{k}_t+\frac{1}{\theta}\Big(1-\left(\phi_p\left(2\pi-\pi^2\right)+\phi_p\left(3\pi-2\pi^2\right)\right)\tilde{\pi}_t+E_t\left(\phi_p\left(3\pi-2\pi^2\right)\tilde{y}_{t+1}\right)\Big) \tag{3.47}$$

And

$$\tilde{w}_t-\tilde{p}_t=\left(1-\alpha\right)(1-\frac{1}{\theta}\phi_p\left(3\pi-2\pi^2\right))\tilde{y}_t-\left(1-\alpha\right)\tilde{l}_t+\frac{1}{\theta}\Big(1-\left(\phi_p\left(2\pi-\pi^2\right)+\phi_p\left(3\pi-2\pi^2\right)\right)\tilde{\pi}_t+E_t\left(\phi_p\left(3\pi-2\pi^2\right)\tilde{y}_{t+1}\right)\Big) \tag{3.48}$$

And finally, we log-linearize the Euler equation of the households optimization problem, denoting $U_t=C_t^{(1-\gamma)\left(1-\frac{1}{\sigma}\right)}\left(N_{it}\right)^{\gamma\left(1-\frac{1}{\sigma}\right)}$ we have:

$$E_t\beta\left(1-\gamma\right)\frac{U_{t+1}}{C_{t+1}}\frac{\left(1-\delta\right)}{\left(1+2\psi_{t+1}V_{t+1}\right)}=\left(1-Z_t\right)\frac{U_t}{C_t}\frac{\left(1-\gamma\right)}{\left(1+2\psi_tV_t\right)}$$

Which we log-linearize into the following form, denoting $q_1=\left(1-\gamma\right)\left(1-\frac{1}{\sigma}\right)$, $q_2=\gamma\left(1-\frac{1}{\sigma}\right)$:

$$\begin{aligned}&\left(1+4\psi V\right)\tilde{c}_t+\left(1+2\psi V\right)q_1\tilde{c}_{t+1}+\left(1+2\psi V\right)q_2\tilde{n}_{t+1}+2\psi V\left(\tilde{\psi}_t+\tilde{p}_t-\tilde{m}_t\right)=\\&=\left(1+4\psi V-R\right)\tilde{c}_{t+1}+\left(1+2\psi V-R\right)q_1\tilde{c}_t+\left(1+2\psi V-R\right)q_2\tilde{n}_t+\left(2\psi V-R\right)\left(\tilde{\psi}_{t+1}+\tilde{p}_{t+1}-\tilde{m}_{t+1}\right)-R\tilde{r}_t\end{aligned}$$

Now we rearrange the equation to finally reach:

$$\begin{aligned}&\left(\left(1+2\psi V\right)q_1-\left(1+4\psi V-R\right)\right)\tilde{c}_{t+1}+\left(1+2\psi V\right)q_2\tilde{n}_{t+1}+\left(Z-2\psi V\right)\left(\tilde{\psi}_{t+1}+\tilde{p}_{t+1}-\tilde{m}_{t+1}\right)=\\&=\left(\left(1+2\psi V-R\right)q-1-4\psi V\right)\tilde{c}_t+\left(1+2\psi V-R\right)q_2\tilde{n}_t-2\psi V\left(\tilde{\psi}_t+\tilde{p}_t-\tilde{m}_t\right)-R\tilde{r}_t\end{aligned} \tag{3.49}$$

To summarize, out whole model is fully described by the following set of linear differential equations:

$$\tilde{y}_t = \tilde{a}_t + \alpha\tilde{k}_t + (1-\alpha)\tilde{l}_t$$

$$\frac{B}{P}\tilde{b}_{t+1} + \frac{M}{P}\tilde{m}_{t+1} + K\tilde{k}_{t+1} = (RK - \delta + 1 + PRK)\tilde{k}_t + (1-\eta)WL(\tilde{w}_t + \tilde{l}_t) + \left(\frac{M}{P} - \frac{\psi PC}{M}\right)\tilde{m}_t +$$
$$+\left(\frac{BR}{P} + RK + PRK\right)\tilde{r}_t + \frac{BR}{P}\tilde{b}_t + \eta PY\left(\left(-\frac{\phi_p}{2}\left(3\pi - 2\pi^2\right)\right)\right)\tilde{y}_t - \eta PY\left(1 - \frac{\phi_p}{2}\left(3\pi - 2\pi^2\right)\right)\tilde{\pi}_t +$$
$$+PRK(\tilde{p}_t) - T\tilde{t}_t - \left(C - 2\frac{\psi PC}{M}\right)\tilde{c}_t + \frac{\psi PC}{M}\tilde{\psi}_t + \left(-\frac{BR}{P} + \frac{B}{P} + \eta PY - \eta PY\left(1 - \frac{\phi_p}{2}\left(3\pi - 2\pi^2\right)\right)\right)\tilde{p}_t$$

$$\frac{B}{P}\tilde{b}_{t+1} + \frac{M}{P}\tilde{m}_{t+1} = \left(\frac{B}{P} + BR\right)\tilde{b}_t + BR\tilde{r}_t + \frac{M}{P}\tilde{m}_t + G\tilde{g}_t - T\tilde{t}_t$$

$$(1-\gamma)(\tilde{n}_t + \tilde{w}_t) = \gamma\left((1 + 4c\psi v)\tilde{c}_t + 2c\psi v(\tilde{p}_t - \tilde{m}_t)\right)$$

$$\tilde{m}_t - \tilde{p}_t - 3\tilde{c}_t = \frac{1}{2}\left((R-1)^{\frac{1}{2}} - 1\right)\tilde{r}_t$$

$$\tilde{r}_t = \phi_\pi \frac{\pi}{R}\tilde{\pi}_t + \phi_y \frac{Y}{R}\tilde{y}_t$$

$$\tilde{\pi}_{t+1} = \tilde{p}_{t+1} - \tilde{p}_t$$

$$\tilde{r}_t - \tilde{p}_t = \alpha(1 - \frac{1}{\theta}\phi_p\left(3\pi - 2\pi^2\right))\tilde{y}_t - \alpha\tilde{k}_t + \alpha\frac{1}{\theta}\left(\left(\phi_p\left(3\pi - 2\pi^2\right)\right)\tilde{\pi}_t + E_t\left(\phi_p\left(3\pi - 2\pi^2\right)\tilde{y}_{t+1}\right)\right)$$

$$\tilde{w}_t - \tilde{p}_t = (1-\alpha)(1 - \frac{1}{\theta}\phi_p\left(3\pi - 2\pi^2\right))\tilde{y}_t - (1-\alpha)\tilde{l}_t + (1-\alpha)\frac{1}{\theta}\left(\left(\phi_p\left(3\pi - 2\pi^2\right)\right)\tilde{\pi}_t + E_t\left(\phi_p\left(3\pi - 2\pi^2\right)\tilde{y}_{t+1}\right)\right)$$

$$\tilde{a}_{t+1} = \rho_a\tilde{a}_t + \varepsilon_{at}$$

$$\tilde{\psi}_{t+1} = \rho_\psi\tilde{\psi}_t + \varepsilon_{\psi t}$$

$$\tilde{\mu}_{t+1} = \rho_\mu\tilde{\mu}_t + \varepsilon_{\mu t}$$

$$\tilde{g}_{t+1} = \rho_g\tilde{g}_t + \varepsilon_{gt}$$

$$\tilde{t}_{t+1} = \rho_T\tilde{t}_t + \varepsilon_{Tt}$$

$$\left(\left(1+2\psi V\right)q_1-\left(1+4\psi V-R\right)\right)\tilde{c}_{t+1}+\left(1+2\psi V\right)q_2\tilde{n}_{t+1}+\left(R-2\psi V\right)\left(\tilde{\psi}_{t+1}+\tilde{p}_{t+1}-\tilde{m}_{t+1}\right)=$$
$$=\left(\left(1+2\psi V-R\right)q_1-1-4\psi V\right)\tilde{c}_t+\left(1+2\psi V-R\right)q_2\tilde{n}_t-2\psi V\left(\tilde{\psi}_t+\tilde{p}_t-\tilde{m}_t\right)-R\tilde{r}_t$$

Which can be put into matrix form as shown in the solution method sub-chapter:

$$\begin{pmatrix}
1 & -\alpha & 0 & 0 & \alpha-1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & K & \frac{B}{P} & \frac{M}{P} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \frac{B}{P} & \frac{M}{P} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2c\psi v\gamma & 1-\gamma & -2c\psi v\gamma & 0 & 0 & 1-\gamma & 0 & 0 & 0 & 0 & 0 & -\gamma\left(1+4c\psi v\right) \\
0 & 0 & 0 & 1 & 0 & -1 & 0 & -\frac{1}{2}\left(\left(R-1\right)^{\frac{1}{2}}-1\right) & 0 & 0 & 0 & 0 & 0 & 0 & -3 \\
-\phi_y\frac{Y}{R} & 0 & 0 & 0 & 0 & 0 & -\phi_\pi\frac{\pi}{R} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\alpha\frac{\phi_p}{\theta}\left(3\pi-2\pi^2\right) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\left(1-\alpha\right)\frac{\phi_p}{\theta}\left(3\pi-2\pi^2\right) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & -\left(R-2\psi V\right) & \left(1+2\psi V\right)q_2 & \left(R-2\psi V\right) & 0 & 0 & 0 & 0 & \left(R-2\psi V\right) & 0 & 0 & 0 & q_3
\end{pmatrix}
\begin{pmatrix}
\tilde{y}_{t+1} \\ \tilde{k}_{t+1} \\ \tilde{b}_{t+1} \\ \tilde{m}_{t+1} \\ \tilde{l}_{t+1} \\ \tilde{p}_{t+1} \\ \tilde{\pi}_{t+1} \\ \tilde{r}_{t+1} \\ \tilde{w}_{t+1} \\ \tilde{a}_{t+1} \\ \tilde{\psi}_{t+1} \\ \tilde{\mu}_{t+1} \\ \tilde{g}_{t+1} \\ \tilde{t}_{t+1} \\ \tilde{c}_{t+1}
\end{pmatrix}$$

$$=$$

$$\begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
q_4 & q_5 & \frac{BR}{P} & \frac{M}{P}-\frac{\psi PC}{M} & \left(1-\eta\right)WL & q_6 & -q_7 & q_{10} & \left(1-\eta\right)WL & 0 & \frac{\psi PC}{M} & 0 & 0 & -T & -\left(C-2\frac{\psi PC}{M}\right) \\
0 & 0 & \frac{B}{P}+BR & \frac{M}{P} & 0 & 0 & 0 & BR & 0 & 0 & 0 & 0 & G & -T & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\alpha-q_8 & -\alpha & 0 & 0 & 0 & 1 & q_8 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\alpha-\frac{q_8-\alpha q_8}{\alpha} & 0 & 0 & 0 & \alpha-1 & 1 & \frac{q_8-\alpha q_8}{\alpha} & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_A & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\psi & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\mu & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_G & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_T & 0 \\
0 & 0 & 0 & 2\psi V & \left(1+2\psi V-R\right)q_2 & -2\psi V & 0 & -R & 0 & 0 & -2\psi V & 0 & 0 & 0 & q_9
\end{pmatrix}
\begin{pmatrix}
\tilde{y}_t \\ \tilde{k}_t \\ \tilde{b}_t \\ \tilde{m}_t \\ \tilde{l}_t \\ \tilde{p}_t \\ \tilde{\pi}_t \\ \tilde{r}_t \\ \tilde{w}_t \\ \tilde{a}_t \\ \tilde{\psi}_t \\ \tilde{\mu}_t \\ \tilde{g}_t \\ \tilde{t}_t \\ \tilde{c}_t
\end{pmatrix}$$

$$+$$

$$\begin{pmatrix}0\\0\\0\\0\\0\\0\\0\\0\\0\\1\\1\\1\\1\\1\\0\end{pmatrix}\xi \quad + \quad \begin{pmatrix}0\\0\\0\\0\\0\\0\\0\\1\\1\\0\\0\\0\\0\\0\\1\end{pmatrix}\Psi$$

Where:

$$q_1 = (1-\gamma)\left(1-\frac{1}{\sigma}\right)$$

$$q_2 = \gamma\left(1-\frac{1}{\sigma}\right)$$

$$q_3 = \left((1+2\psi V)q_1 - (1+4\psi V - R)\right)$$

$$q_4 = \eta PY\left(-\frac{\phi_p}{2}\left(3\pi - 2\pi^2\right)\right)$$

$$q_5 = \left(RK + (1-\delta)K - \eta PRK\right)$$

$$q_6 = \left(-\frac{BR}{P} + \frac{B}{P} + q_4\right)$$

$$q_7 = \eta PY - q_4$$

$$q_8 = \left(\alpha\frac{1}{\theta}\phi_p\left(3\pi - 2\pi^2\right)\right)$$

$$q_9 = \left((1+2\psi V - Z)q_1 - 1 - 4\psi V\right)$$

$$q_{10} = \left(\frac{BR}{P} + RK + PRK \right)$$

This is the full specification of the model. We will now see how does the model adjust to a shock to technology. We will, in this and all the future cases use one period 1 % positive shock to technology. The transmission mechanism is then demonstrated by the impulse response functions.

Impulse response functions

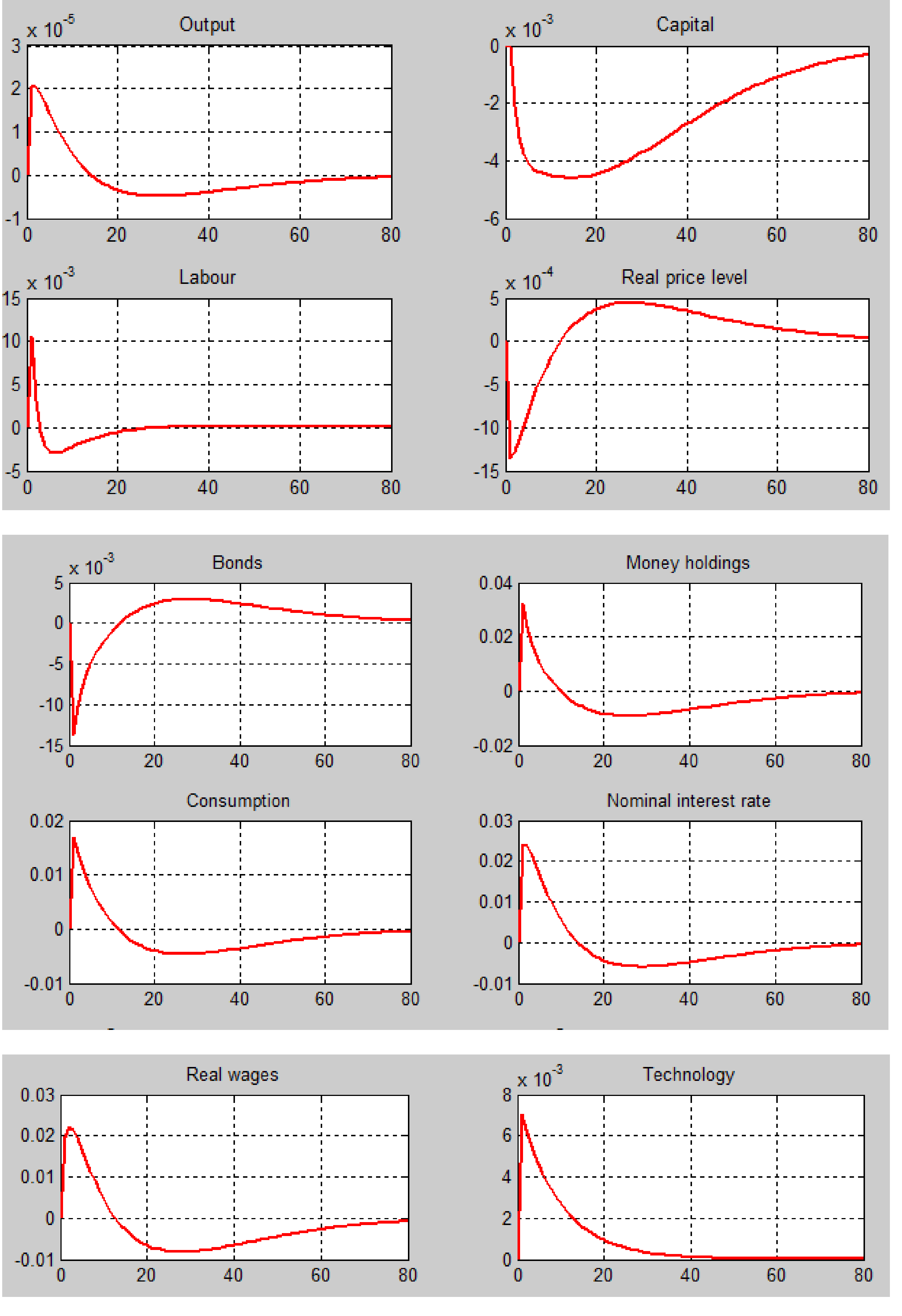


Figure 4 – Benchmark model impulse response functions

We applied a temporary positive one period shock to the technology. We will now describe and explain the adjustments to shock of all the variables. The length of the interval is 80 periods, which due to quarterly nature of the model is 20 years. That is a long period, but as we have multiple rigidities included in the model it is just about the time it takes for the full adjustment. Since output is directly driven by the technology, it immediately increases with the shock to technology and remains above steady state for approximately 16 periods (quarters). However, after the initial boom is followed by a slight recession. Here we see the business cycle itself – even the positive shock leads to a short below steady state period. The reason for this phenomenon is that the increase in productivity leads to decrease in accumulation of capital, which after the productivity shock fades becomes too scarce. That is followed by a drop in agent´s utility, because now it is necessary to replenish the capital at the expense of consumptions and monetary holdings. Note that we use the word recession for the period with negative output gap. This definition is different from usual definition of recession that is based on quarter to quarter output dynamics. The term boom is used similarly.

This, in our model, is caused by the existence of the discount factor and the chosen utility function. Agents receive much more utility during the large productivity shock, therefore they can achieve a very large consumption increase should they work harder and spend the new extra money on goods before prices adjust. Prices adjust slower due to the introduced price rigidities, that is why the real price level decreases first, because nominal prices cannot change immediately while nominal wages increase. Wages increase because the employers produce more output and they have more money to compete for the workers so they increase the nominal wage. Thanks to the slow price adjustment, the real wage increases as well. Since the agents want to consume more, they need to hold more cash money due to the transactions costs introduced in our model. That pushes out bonds and more importantly, capital accumulation. Decrease in bonds and capital accumulation, largely caused by the time preference of agents is what starts the actual cycle to happen.

After 4 quarters, the prices start to adjust so the real wage starts decreasing. Therefore, workers opt out to get some extra leisure in favour of consumption. That is the reason why labour reaches the minimum much faster than other variables as the *work more – consume a lot more* is better than *work less – consume more* behaviour only by a small margin and quickly switches when the productivity shock starts fading. The utility gain is still high and he agents do not know that the productivity shock will fade away, so the agents are unknowingly sacrificing the future utility for it. The initial drop in bonds and capital actually caused the interest rate to increase as when households offer less capital, the interest rate increases and opposite way, when firms don’t want to use as much capital, interest rate decreases. Therefore in these periods it is interesting for the agents to buy bonds instead of holding just cash for consumption. Since capital depreciates, it is still less interesting than the bonds for these periods so the level of capital is further decreasing/staying low.

This process leads to a small recession after 16 quarters. At this point the technology shock has almost faded. The agents now have to pay for the previously high consumption and leisure that caused significant decline in capital accumulation, so now there is lower than steady state amount of capital while labour has already returned to the steady state.. The prices have adjusted as well, so basically now there is higher price level and low saturation by capital so the real wage has decreased. The interest rate has dropped due the increase in demand for bonds in the second period and the way out of the recession is through making up for the missing capital, despite the lower interest rate on it. That way the agents work the same and consume less, while using the remaining money on bonds and capital accumulation. This painful period leads to a full recovery to the steady state. It is important to notice that the initial spike up in the output and consumption were much higher than the drop in this last period, so the productivity shock did lead to a significant utility gains.

This discussion concludes the results of the baseline model, we will now analyse the impulse responses of the enriched models to see which fiscal policy rule fits the best for the model calibrated on the Czech Republic.

Enriched models

Acyclical

By Barro (1979), government expenditures follow the following function:

$$G_{t+1} = B_{t+1} + T_{t+1} - R_t B_t$$

Basically, the government expenditures are equal to how many bonds government issues + how much does it collect on taxes minus what it pays on the interest rate. Log-linearizing it yields:

$$G\tilde{g}_{t+1} = B\tilde{b}_{t+1} + T\tilde{t}_{t+1} - RB\left(\tilde{r}_t + \tilde{b}_t\right) \tag{4.1}$$

For the tax collection, the government optimizes at time *t* the collection costs *Z*, defined in this way:

$$Z_t = \sum_{t=1}^{\infty} \frac{\tau_t f\left(\tau_t / Y_t\right)}{\left(1+r\right)^t}$$

The optimization is reached when $\frac{\partial Z_t}{\partial \tau_t}$ is the same for all *t*, for simplicity we will take it as being constant. The FOC is then:

$$\frac{\partial Z_t}{\partial \tau_t} = \frac{\partial f\left(\tau_t / Y_t\right)}{\partial \tau_t} \frac{1}{R_t} = \varsigma$$

Where ς is constant for all *t*. Now, we will assume a functional form for $f\left(\tau_t / Y_t\right)$ to be the following:

This function fulfils the requirements of being increasing and convex for all *t*.

So the solution to the FOC is:

$$\frac{\partial Z_t}{\partial \tau_t} = \frac{\partial f\left(\tau_t / Y_t\right)}{\partial \tau_t} \frac{1}{R_t} = \frac{2}{Y_t}\left(1+\frac{\tau_t}{Y_t}\right)\frac{1}{R_t} = \varsigma$$

Which solving for taxes becomes:

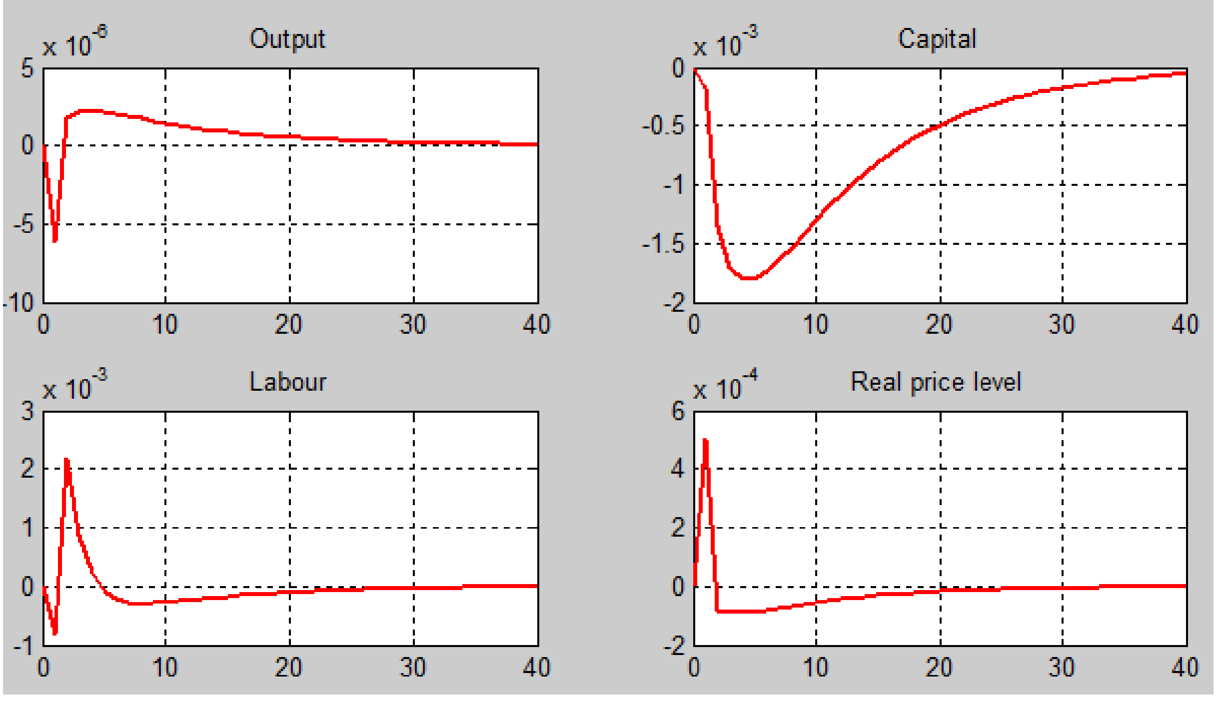
$$\tau_t = Y_t - \frac{\varsigma Y_t^2 R_t}{2}$$

Now finally, log-linearizing this equation and switching to the notation of the original model yields:

$$T\tilde{t}_t = Y\tilde{y}_t - \frac{\varsigma YR}{2}\left(2\tilde{y}_t + \tilde{r}_t\right) = \left(2Y - \varsigma YR\right)\tilde{y}_t - \frac{\varsigma YR}{2}\tilde{r} \qquad (4.2)$$

Now, we enrich the original model by equation (4.1) and (4.2) instead of simple AR(1) relationships for G and T and solve through MATLAB.

Impulse response functions



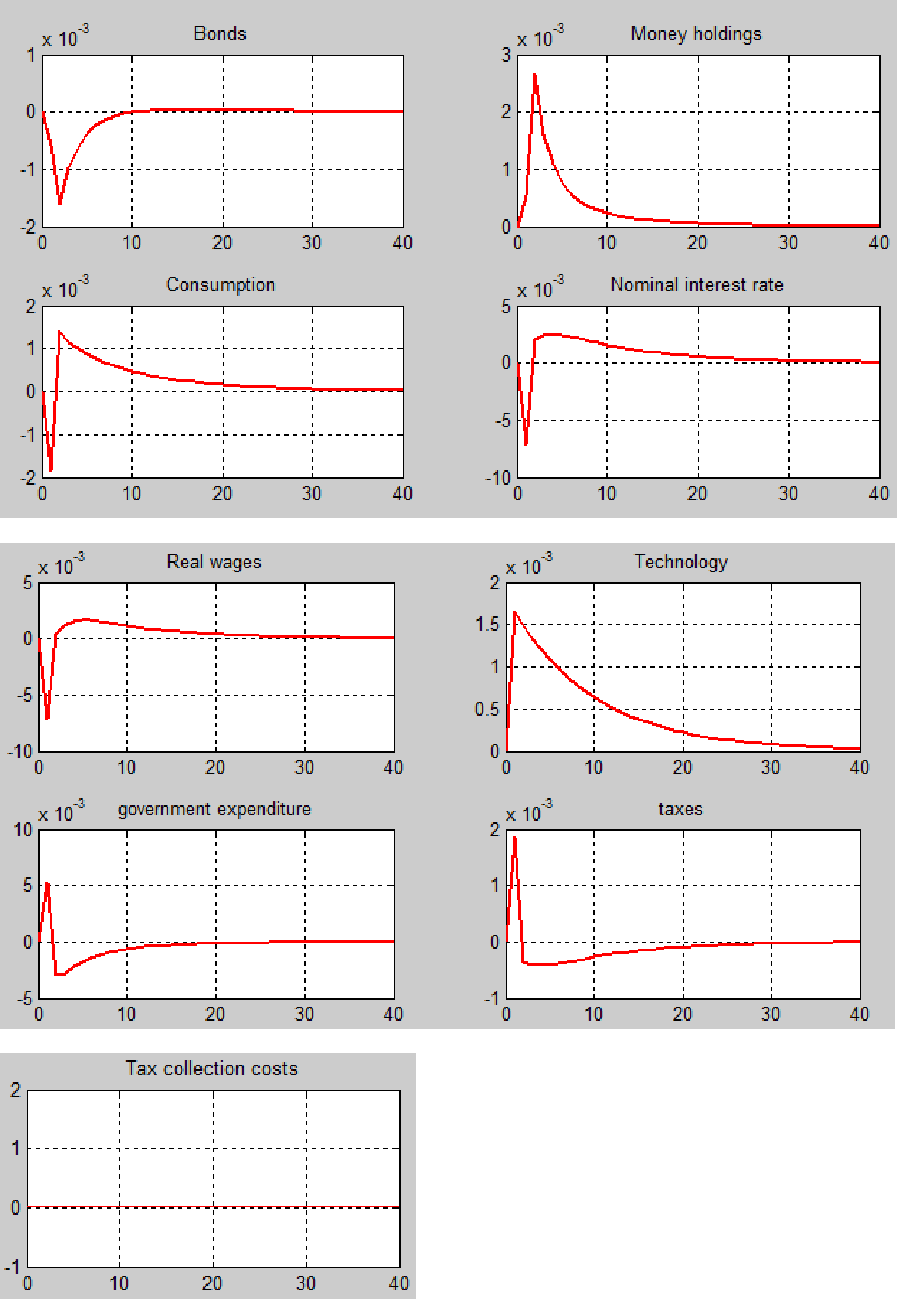


Figure 5 – Acyclical model impulse response functions

This specification proved not to be suitable for the chosen model. The results of the model are counter intuitive and not plausible. The government spending goes rampart together with taxes to pay for it. This crowds out any output increase since the government spending is modelled as unproductive and the taxes take away the extra resources introduced by production technology shock. Since the bond market is flooded with cheap bonds, their prices drop and this forces the interest rate to decrease and, as a result, the money holdings do increase despite the consumption drop since neither capital nor bonds are interesting for purchasing. This is possible due to real interest rate being negative on bonds for a short period. As the government is able to sell low amount of bonds, it needs to adjust the spending and taxes. Decrease in taxes allows the output to finally increase above the steady state level and the amount of bonds decreases, which allows the interest rate to increase as well. Finally the capital accumulation starts to recovery and money holdings decrease. Agents use the money saved from the previous period to buy the extra consumption they can achieve due to working more and not getting everything taken by the taxes. Going from this second period onward, the adjustments are quite similar to the benchmark model. The government, however, achieved its target – tax collection costs remained exactly at the steady state value. Unfortunately, the agents would not really appreciate it because they paid for it by having to postpone the consumption at the start of the adjustment process.

Overall, this model does not really make much economic sense as the government does keep the tax collection costs the same, but completely disregards the utility of agents so it does it at the cost of output and consumption. Therefore this model of government expenditure is not useful in DSGE settings. The simple description of fiscal policy is not plausible, since the utility of all agents is significantly lowered by inferior fiscal policy. True government would not, or at least should not, behave according to this fiscal policy rule.

Pro-cyclical fiscal policy – version 1

We start with Talvi and Vegh (2005). According to them, the government expenditure can be expressed as the following:

$$G_t = \bar{G} + f\left(PS_t\right)$$

Where $\bar{G}$ is an autonomous part of government expenditure and $PS_t = T_t - G_t$. Originally the model assumed a stream of endowment for the government, for simplicity we leave that out. The conditions for $f\left(PS_t\right)$ are:

$$f'\left(PS_t\right) > 0$$

$$f''\left(PS_t\right) > 0$$

In order to solve the model, we will assume that $f\left(PS_t\right) = PS_t^2$ and apply a condition that $T_t > G_t$. Plugging all the equations together, we get:

$$G_t = \bar{G} + \left(T_t - G_t\right)^2 = \bar{G} + T_t - 2T_tG_t + G_t^2$$

This quadratic equation defines the government expenditure. This equation does not have to be solved since the model is defined in log-linearized form, so after log-linearizing we get:

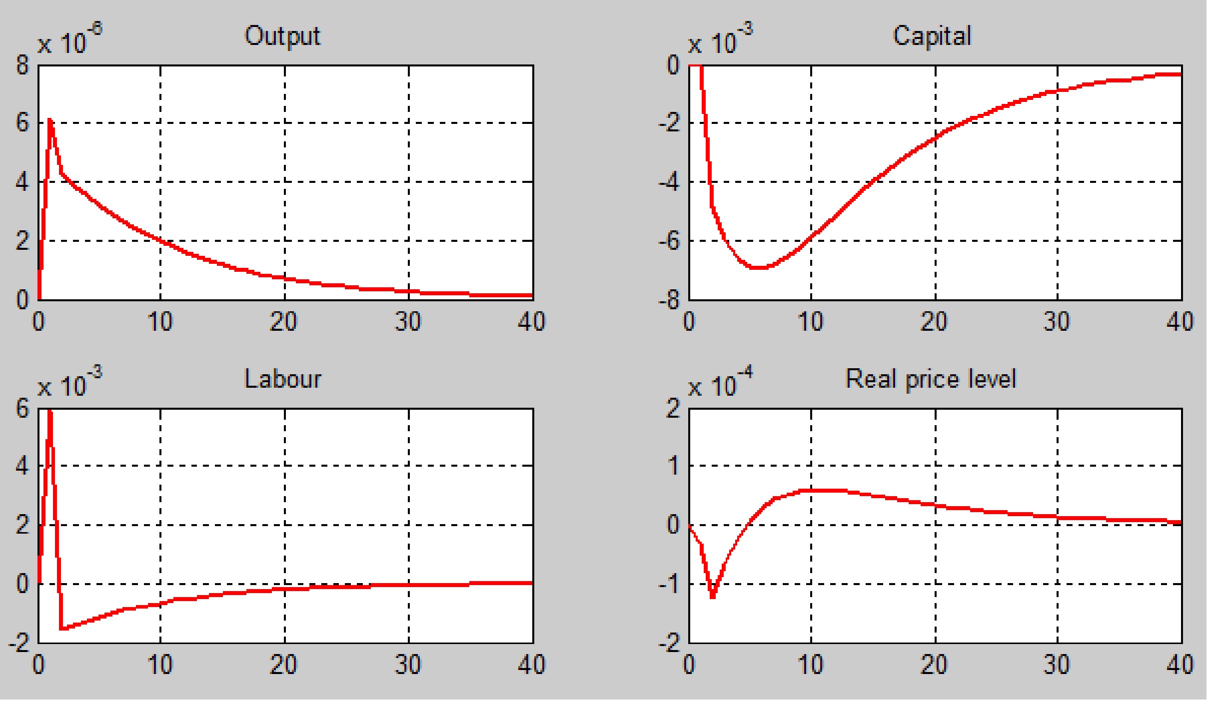
$$(-G + 2TG)\tilde{g}_t = \left(T - 2TG\right)\tilde{t}_t$$

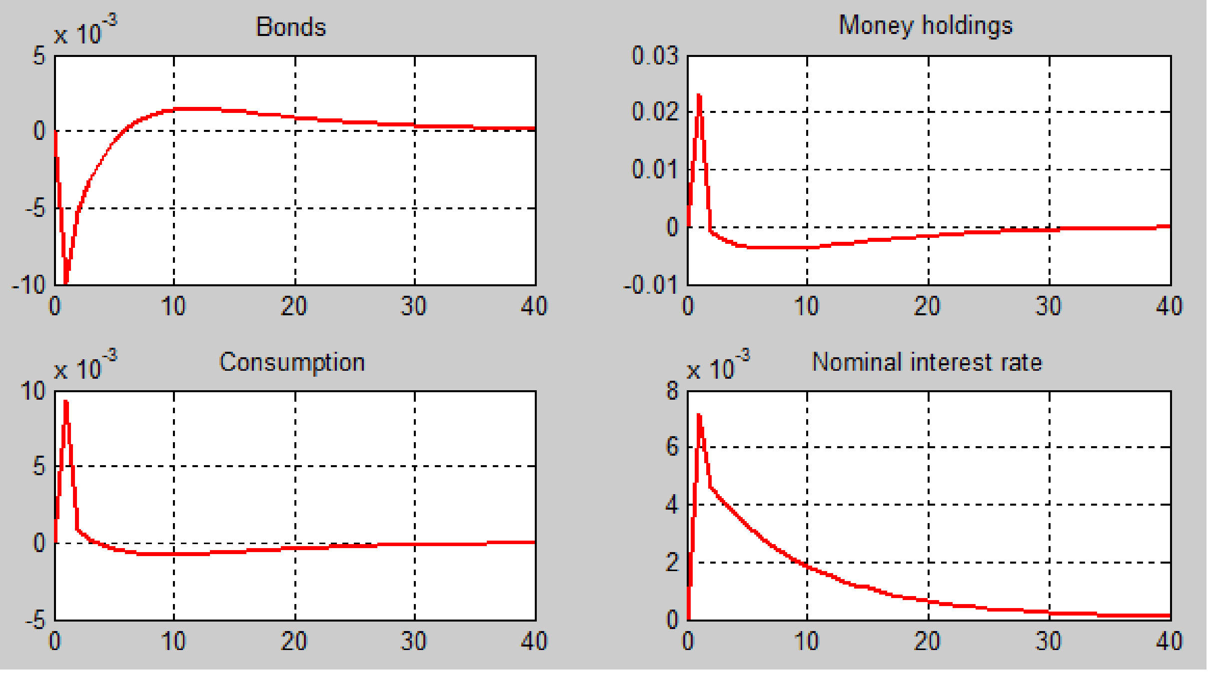
$$\tilde{g}_t = \frac{T\left(1-2G\right)}{G(2T-1)}\tilde{t}_t \qquad (4.3)$$

Now this algorithm is actually quite double edged, because T < 0.5 under most calibrations, but G can easily be smaller than 0.5 as well, in which case the multiplier of taxes would be negative and that should not be the case.

Tax adjustment is unspecified by the paper, so we will continue using the AR(1) process specification.

Impulse response functions





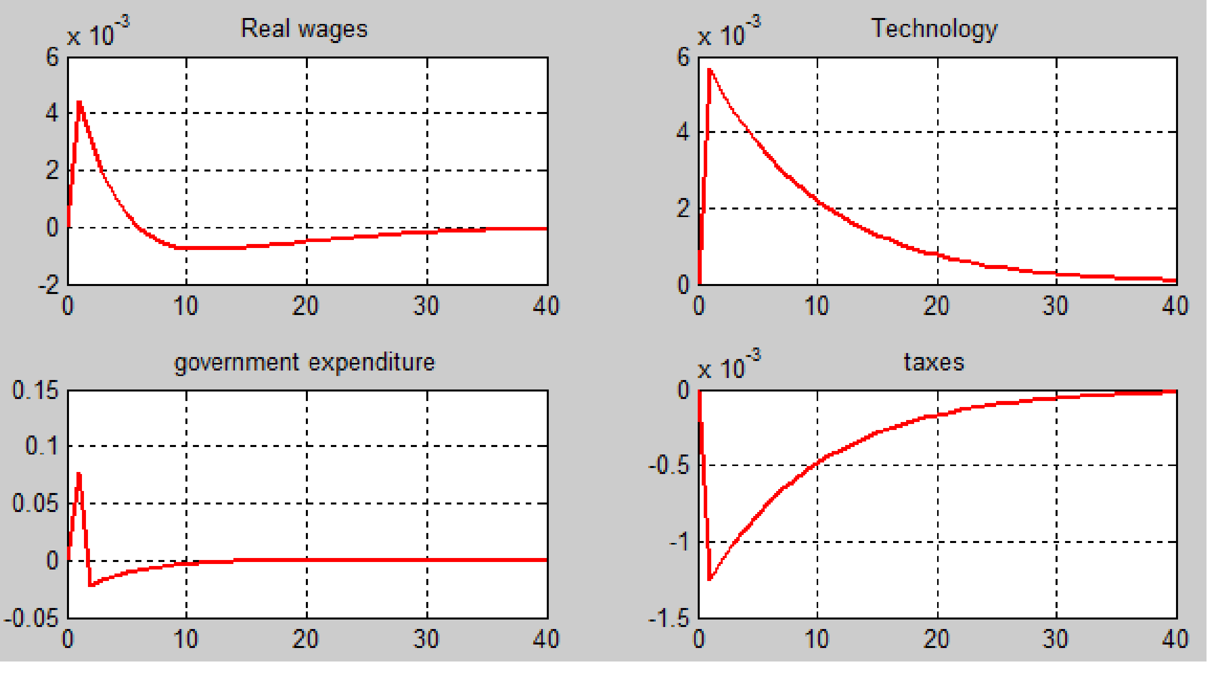


Figure 6 – Pro-cyclical model 1 impulse response functions

The results of this pro-cyclical model are very intriguing. The first period is the same as in the baseline model, except that government hugely increases its expenditures and decreases taxes. That drives the output even higher, but crowds out a significant amount of consumption and capital accumulation (in the baseline model, the consumption peak was about 0.175, now it is about 0.009. Conversely, the drop in capital accumulation is almost doubled which makes the second part of the cycle to arrive much faster. Since there is persistence in taxes, the government cannot adjust them right after the output starts to fall, it needs to decrease its expenditures because otherwise they would be unfeasible due to high interest rates. Interest rates shoot up high in the benchmark model and in this model due to the lack of interest in bonds, but in the current case they also stay high, because the switch in preferences from consumption to leisure is much smaller than in the baseline model and thus the output gap remains positive so the central bank doesn´t decrease the interest rate quickly. Overall, the cycle is faster and smoother both in the boom and in the recession so ironically, the pro-cyclical policy driven by the voracity effect leads to a business cycle smoothening. It is important to notice here, that this is achieved through a relatively strict government budget constraint (it cannot accumulate significant debt) and highly persistent taxes so the initial drop to tax rate stays for an extended period of time. The non-existence of a tax rule that is modelled specifically for this government expenditure setting is the greatest limitation of this approach.

Pro-cyclical model – 2

By Alesina et al. (2008). They assume the government expenditure to be defined as:

$$G_t + Q_t + B_t = T_t + \beta B_{t+1}$$

Where $Q_t = \bar{q} + \rho_q Y_t$ is the maximum political rent while ρ_q is the ability of the interest groups to steal output. Plugging together yields:

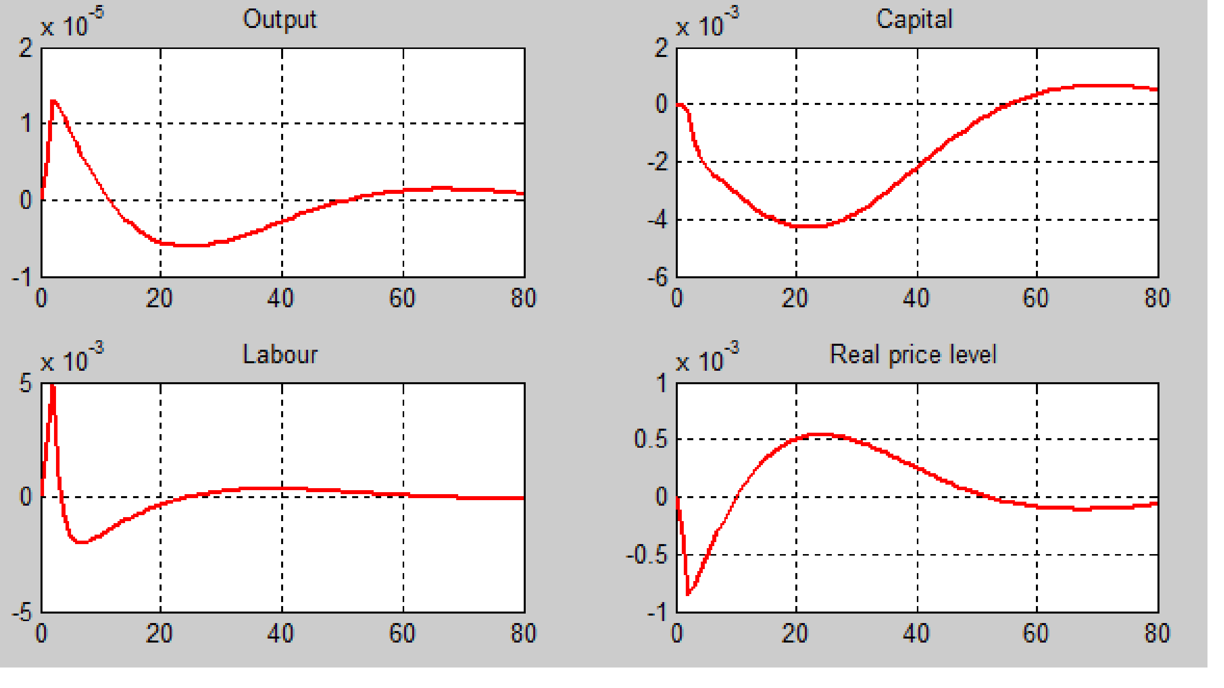
$$G_t + B_t = T_t + \beta B_{t+1} - \bar{q} - \rho Y_t$$

After log-linearization we get:

$$\beta B\tilde{b}_{t+1} = G\tilde{g}_t + B\tilde{b}_t - T\tilde{t}_t + \rho Y\tilde{y}_t \quad (4.4)$$

Again tax rates are unspecified, so we assume AR(1) process. Now we plug it into the baseline model and obtain the impulse response functions

Impulse response functions



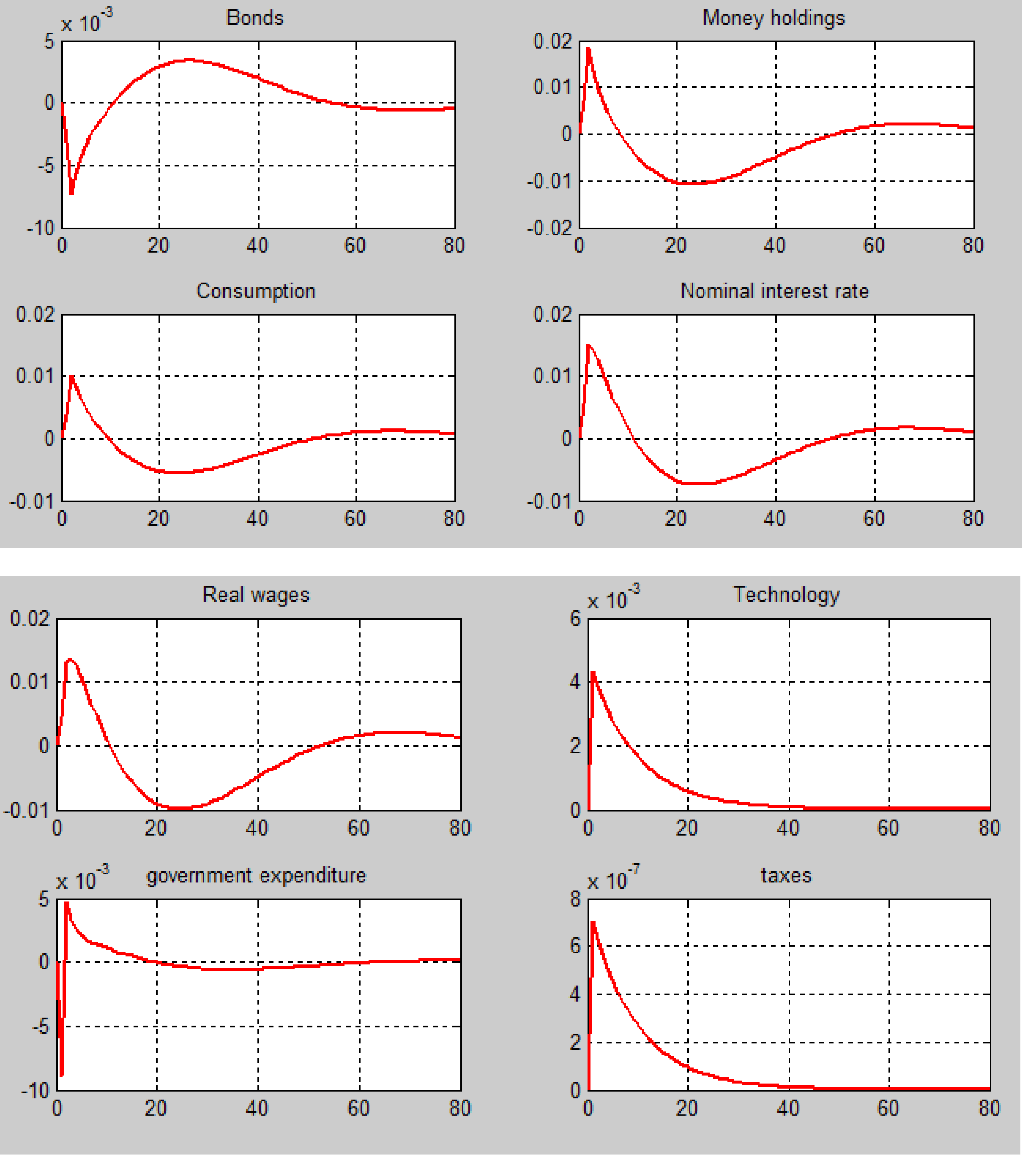


Figure 7 – Pro-cyclical model 2 impulse response functions

The second version of the pro-cyclical model works much more as expected compared to the first one. The government waits out the first period as the output increase does not happen yet and government accumulates money until the output booms up on the second period. Together with the output, the government increases the expenditures and then mirrors the behaviour of the output when in boom period. In the period of recession, however, the government does not need to spend that much because it has saved resources from the first period – at first it held them in money holdings, then switched to the bonds all much alike the households. As for the rest of the model, the government greatly enhance the cyclic behaviour as most series look like a roller coaster ride with two above steady state and one below steady state period, all from a single temporary shock. Overall this government expenditure rule does achieve in the model what it was expected to, but, much like the previous model, it is limited by not having a specific tax setting rule included.

Counter-cyclical model

Following Coate et al. (2010) the optimal tax setting is the following:

$$\frac{1-\tau_\theta(b)}{1-\tau_\theta(b)(1+\varepsilon)} \le \alpha_{\theta H}\frac{1-\tau_H(x(b))}{1-\tau_H(x(b))(1+\varepsilon)} + \alpha_{\theta L}\frac{1-\tau_L(x(b))}{1-\tau_L(x(b))(1+\varepsilon)}$$

Now, in order to simplify we assign:

$$\omega_H = \alpha_{\theta H}\frac{1-\tau_H(x(b))}{1-\tau_H(x(b))(1+\varepsilon)}$$

$$\omega_L = \alpha_{\theta L}\frac{1-\tau_L(x(b))}{1-\tau_L(x(b))(1+\varepsilon)}$$

Now, using $\tau_\theta(x(b)) = T_t$ we obtain:

$$1-T_t = \omega_H + \omega_L - (1+\varepsilon)(\omega_H + \omega_L)T_t$$

Which simplifies into:

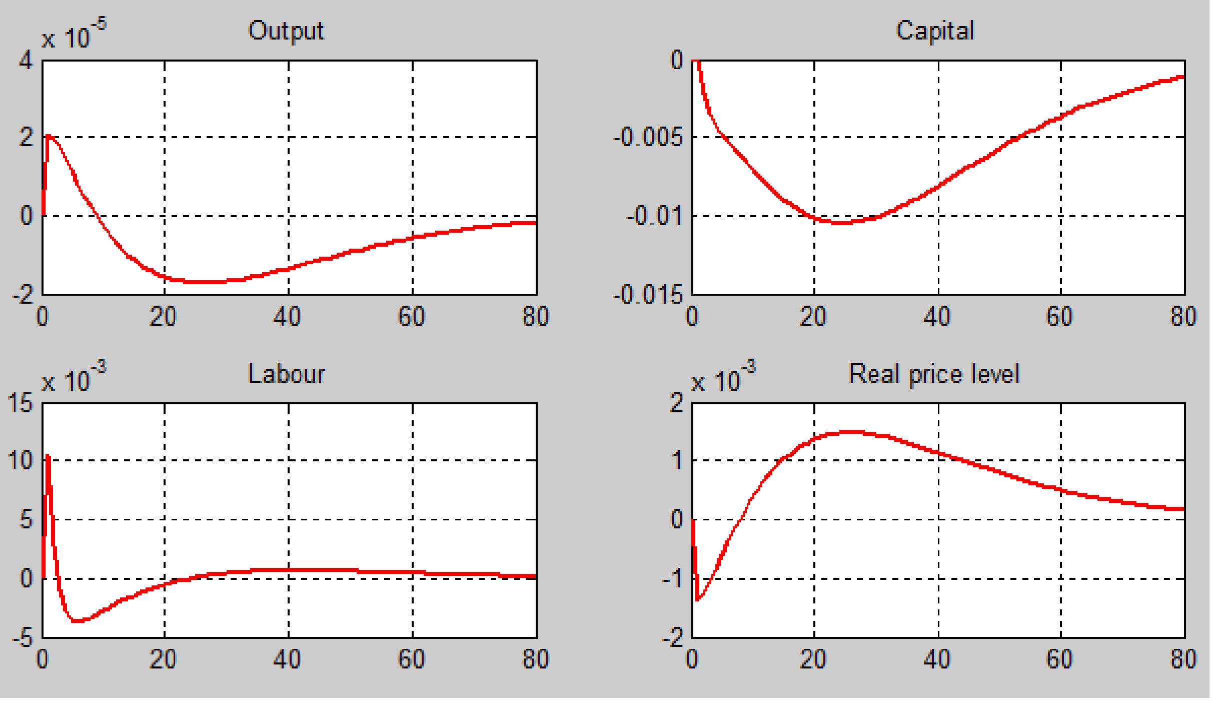
$$T_t = \frac{\omega_H + \omega_L - 1}{((1+\varepsilon)(\omega_H + \omega_L) - 1)}$$

Unfortunately, this doesn’t work in DSGE framework by design – it requires tax bounds for bust and boom periods and some expectations function for the probability of the next period being either bust or boom. But the model has no past, so the bounds would have to be somehow calibrated or taken from the first period. However, in the first period they would be the same which breaks the model as the government would optimize on senseless parameters. In the other case, if the bounds were to be calibrated then taxes would be constant. Similarly, the probability function for the next period being boom or bust makes no sense in the given model because we assume perfect foresight. Therefore, we assume the government knows what the next period is going to be. In order to change that, we could need to assume a sequence of random shocks, which would break the rest of the analysis as there would be no periods left to observe the adjustment process. Therefore, this version is unsuitable for DSGE framework by design.

Dichotomous spending model

Finally, we apply the dichotomous spending model of government expenditure to the baseline model. All computations are not shown for this complicated model for the sake of the brevity. To summarize, we split capital in all equations, except of the firms maximization problem, into private and government capital. Then we adjust the government expenditures to mirror the split into autonomous government expenditures and the accumulation of government capital. Since transfers are already included in the lump sum taxes, we will not model them in this case as it would make the model too complicated without clear benefit.

Impulse response function



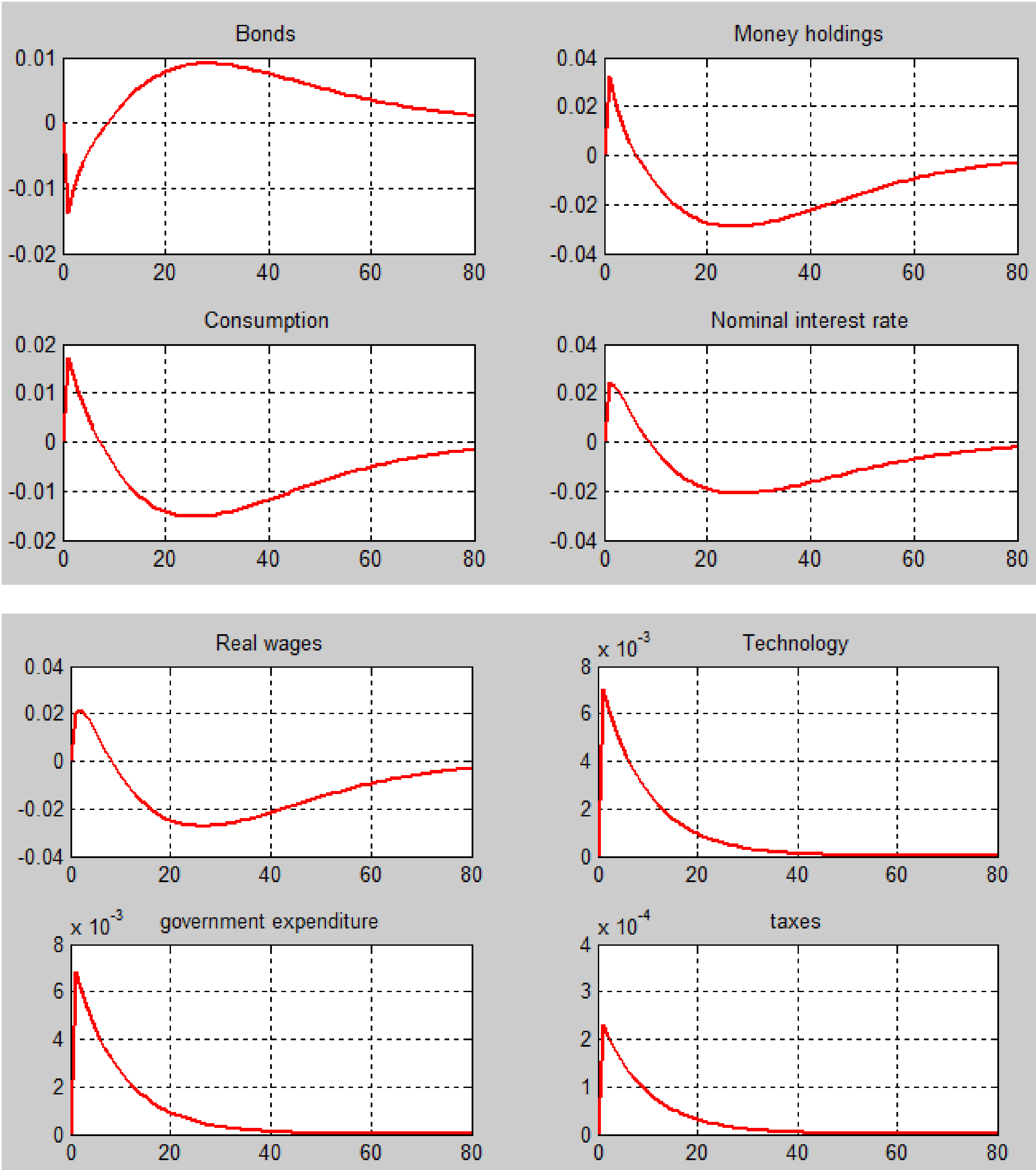


Figure 8 – Dichotomous spending model impulse response functions

The last model provides results similar to what was expected. The government makes opportunity out of the technology shock and increases its autonomous spending accordingly. It also increases the government capital accumulation, but much less than the autonomous spending. Since the only part of government expenditure being regarded as productive are the capital investments, the increase in autonomous spending causes much deeper future recession as it crowds out the private capital accumulation. As the productivity shock starts to fade, the lack of private capital turns the economy into a lengthy recession. In this model the government is virtually a malicious force, which takes away resources from the economy and gives back only a small part. While this hypothesis is seemingly disturbing, it could also be quite realistic as, especially in the case of Czech Republic, the government´s ability to efficiently allocate resources is dismal at best.

Conclusion

We compared multiple fiscal policy rules in a DSGE modelling framework calibrated for Czech Republic. For this goal, we selected the most suitable for the case of Czech Republic. In particular, we picked the acyclical fiscal policy setting of Barro (1979), which claims that government executes expenditures and sets taxes to keep tax collection costs constant. For the pro-cyclical spending models, we chose Alesina et al. (2008) and Talvi and Vegh (2005). Alesina et al. (2008) attribute the pro-cyclicality to the influence of interest groups, which are able to steal resources from the government through corruption. Since agents do not possess full information, they take the observed state of the economy as a main indicator and then rationally demand more spending during good periods. Talvi and Vegh (2005) explain virtually the same behaviour through voracity effect. It says that the interest groups, usually due to weak institutions, are able to steal any surplus of the government budget. As a result, the most rational response of the government is not to accumulate any surplus and simply spend the revenues during booms as they come. The dichotomous spending model of Baxter (1993), which we recreated into the DSGE framework assumes that government has two types of spending. The first one is unproductive autonomous government spending representing political spending. The second one is productive government investment into its own capital. This model gives government the ability to waste resources, which very non-economical but very realistic.

Then we created a benchmark model, which had both government expenditure and taxation set as an exogenous AR(1) process. For the model itself, we used the classic CES utility function and introduced transaction costs to consumption to keep both bonds and money deposits as viable options for savings of households. Considering firms, we assumed the firms face a cost to price adjustment. Finally, monetary policy was set according to a classic Taylor rule. We completely solved the benchmark model utilizing the calibration of Czech Republic and used it as a tool for comparison of the picked fiscal policy rules.

The comparison was done through analysing impulse response functions of temporary positive shock to technology of each specific model. As the main results, the acyclical fiscal policy rule of Barro (1979) proved to be completely dysfunctional in the given framework as the government´s efforts to keep tax collection costs constants undermines the positive effects of the shock on all other variables. The dichotomous government spending model of Baxter (1993) assigned the government too negative role to be deemed as trustable. In fact, the governments autonomous spending increasing at the start of the boom caused a much lower boom and greater recession in output after the shock. That left the two pro-cyclical fiscal policy models as the best choices. However, the models showed a remarkable difference in their outcomes.

The model of Talvi and Vegh (2005), which is based on voracity effect – an observation that a government is unable to generate surpluses because they would be stolen by the interest groups. It turned out that model produced a shock smoothing results. The reason is the strict government constraint and the inability to adjust taxes. The government increases spending at the first boom, but then it needs to decrease them in order to stay solvent since it decreased the taxes at first and now cannot quickly rise them due to rigidities. That leads to the much faster adjustment than in the exogenous fiscal policy case, while the output does not dip into the recession at all thanks to lower taxes and lower government spending. That gives an interesting message, because it implies that the less freedom of spending the government has, the better for the economy.

The model of Alesina et al. (2008) gives the most standard result from among the used models and is the most plausible one. The pro-cyclical fiscal policy takes an interesting 1st period fiscal spending decrease to become classically pro-cyclical starting from period 2. The results are mostly expectable since this setup greatly increases the volatility of all variables during the business cycle and makes it last longer. The government expenditure is again not fully pro-cyclical, because the rigidities take place in tax setting. The plausibility of the model might therefore be greatly enhanced through an introduction of a proper tax setting rule.

The fact that both pro-cyclical rules of fiscal policy are the most plausible ones is no coincidence. In fact, the government of Czech Republic has been observed to be very pro-cyclical in the past years. The model assumes an existence of interest groups that can steal part of the government´s income without the voters being able to fully observe it. This description actually describes well the situation in Czech Republic, For the future research, the analysis should be both deepened and implemented for other countries. The deepening is especially necessary for the pro-cyclical policies, which despite having the best economic fit, could be further improved by precise modelling of tax setting policy rules. Furthermore, the performance of the respective models should be compared to real data in terms of volatility and co-movement.

Finally, the model displays great sensitivity to change in parameters, so a sensitivity analysis to parameter change could be a great point of interest for any future research.

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Appendix A: Content of Enclosed DVD

There is a DVD enclosed to this thesis which contains MatLab source codes.

- Folder 1: Source codes