

An Alternative Approach to Measuring Output Gap

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Abstract

This paper tries to identify inflationary pressures in Slovak economy by two methods. The first method uses concept of output gap considered as a main determinant of inflation dynamics. The traditional output gap is estimated by structural vector autoregressive (SVAR) technique. An emphasis of the paper is however placed on a new way of looking at inflation dynamics. An explicitly optimizing general equilibrium framework in the presence of nominal rigidities suggests marginal cost as an alternative measure of inflation. The second method, based on this framework, uses real unit labor cost in order to identify inflationary pressures in Slovak economy.

Keywords: output gap, inflation dynamics, real unit labor cost

JEL Classification: C32, E31, E32

Introduction

For assessment of the balance of the Slovak economy we shall use the concept of output gap. This concept is based on the assumption that for the economy characterized by the level of capital and labor force at certain time there is an optimal level of production called *potential output*. It is the highest level of production yet not giving rise to inflation pressure. An *output gap* is defined as a difference between actual output and potential output.

Economy is in (inner) balance if the output gap equals to zero, i.e. the total output (demand) is on the level of potential output. If the output exceeds the potential output, i.e. an output gap is positive, the economy becomes imbalanced and

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price pressure occurs. A contrary situation, i.e. negative output gap, represents an imbalanced state where production capacities of economy are insufficiently used in consequence of lower demand.

The concept of output gap is based on the assumption of inflexible or respectively on insufficiently flexible prices. Price rigidities result in slow elimination of imbalance or in its duration for certain time, hence, it is the Keynesian concept. It is impossible to define an output gap within neoclassical theory, i.e. in the environment of perfectly flexible prices, where any imbalance between demand and supply is immediately eliminated. Whereas certain price rigidity (prices of goods and services and cost of work) can be seen in each economy, the concept of output gap may be useful as an indicator of inner imbalance. Its application, however, involves certain problems. An output gap is defined in terms of a potential output while this variable cannot be directly observed. Therefore, output gap should be estimated by a suitable method on the basis of an appropriate model. There are many methods for output gap estimation, and it should be emphasized that sometimes the estimated outcomes differ substantially. Nevertheless this does not mean that such indicator is useless. Each estimate must be taken cautiously and supported by economic intuition.

1. Hodrick-Prescott Filter

Methods of output gap estimation may be classified in three groups. The first group consists exclusively of statistical approaches not based upon any economic theory. The most common method in this group is represented by the use of Hodrick-Prescott (HP) filter. Another group involves methods based on the estimation of production function. Such methods are the most illustrative as they draw from economic theory. Their deficiency consists in the fact that a hardly measurable variable, the amount of capital, must be used in calculation with regard to the estimate. The third group involves methods linking together statistical approaches and economic theory. In the following sections of this paper we shall use namely two methods out of this group. The first one is the structural VAR (SVAR) method and the other one is an approach based on optimizing a dynamic model of general equilibrium, the outcome of which leads to the evaluation of output gap on the basis of unit labor cost.

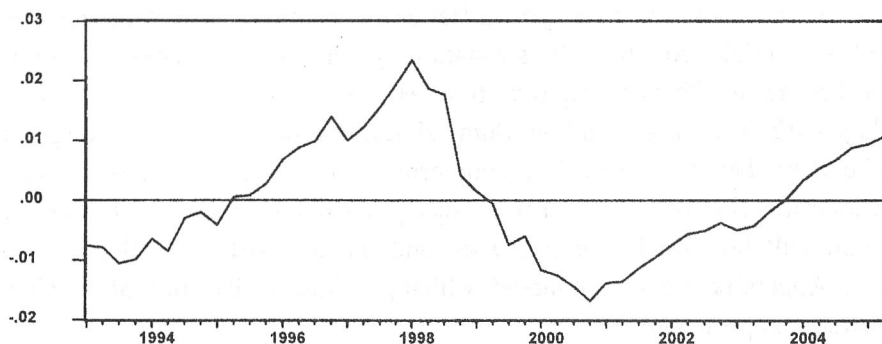
As the use of HP filter is very simple, let us first introduce a graph of output gap achieved by HP-filtrating the (time varying) trend from the actual level of real GDP (see Figure 1).

However simple the method used is, this graph provides basic information concerning the development of economic cycles of the Slovak economy. The

economy was rather overheated during the period of 1996 – 1998, and after restrictive measures of the Government it fell in recession. Whereas this is a purely formal statistical method, deeper economic analysis of the development of output gap is impossible. Another disadvantage of the application of HP filter is unreliability of the determination of output gap at the end of the monitored period. This is exactly the period, which is the most important for the monetary policy decision taking.

Figure 1

Output Gap Achieved Through HP Filter



2. SVAR Method for Output Gap Wstimation¹

It is rather widely accepted that a single positive (negative) productivity shock would increase (decrease) GDP value in all subsequent periods, i.e. the impact of shocks on GDP has a long-run effect. It is also well-known that GDP growth rate is affected by such shock only for a short term. In terms of statistical theory this means that GDP variable is a first-order integrated process and its growth rate is a stationary process. It is known from the statistical theory that such (nonstationary) variables may be decomposed into a (stochastic) trend and a cyclic component – fluctuations. The trend may then be identified with a potential output, and fluctuations with output gap. Provided that only one type of shocks exists (one-dimensional case), such shocks may be identified by an appropriate statistical method and used for the estimation of output gap. At the same time, shocks may be confronted with economic reality.

However, in the case of GDP the aforesaid assumption of one type of shocks appears to be too simplifying. If we accept a presumption that GDP is exposed to

¹ This section draws from Blanchard and Quah (1989).

more than one type of shocks, then in order to identify such shocks we have to monitor their effect on several economic variables (multidimensional case). Furthermore, in order to identify them, we have to adopt other (structural) presumptions, derived from economic theory, of effects of shocks considered on individual variables. In paragraphs below we will discuss in more details a two-dimensional case. Let us admit that two types of mutually non-correlated shocks affect GDP. For their identification we should consider, apart from GDP, another economic variable, which is going to be employment.² The exact reason of this choice is determined by the theory; let us state only basic facts about this choice at this point. As already mentioned, GDP is a (nonstationary) integrated first-order variable (let us designate it y) and its first difference Δy , which represents GDP growth, is stationary; employment (let us designate it l) is a stationary variable. Whereas GDP growth³ Δy is a stationary variable the shocks affecting it are of a short-term effect ceasing over time. However, this does not apply to the variable y – the level of production. Some shocks affecting it are of a long-term effect, i.e. they change its level for a long term. And we will use namely this fact for the identification of shocks. The shocks permanently affecting the level of production will be called *supply shocks*, and the rest will be called *demand shocks*. In Appendix A a simple model, which provides justification of the above identification, is presented.

The demand and supply shocks are abstractions – unobservable, and therefore they should be estimated. First, we shall estimate a reduced form of stationary vector $(\Delta y - \overline{\Delta y}, l - \bar{l})$ by VAR method. Based on the assumptions adopted – mutually miscorrelated demand and supply shocks and their different long-term impact on the level of production – a transformation matrix may be defined with the help of which we shall transform the residuals achieved by VAR method into structural residuals representing in fact demand and supply shocks.⁴

Each supply shock (impulse) has a permanent effect on the level of production. A typical supply impulse is an unexpected change in productivity (see the model in Appendix A), but it can be an unexpected change of any output factor – labor force, capital. Supply impulses increase (decrease in the case of negative impulses) the potential of economy. In our case, they change the potential growth rate. By accumulation of such effects we get the growth of potential output.

Through such method, and we would like to underline this fact, we estimate the growth of potential output (and accordingly, the shape of an output gap curve),

² We have certain discretion in the choice of this variable.

³ We work with GDP logarithm, therefore the difference corresponds to the growth rate.

⁴ The method is described in Appendix B.

not its absolute level.⁵ Therefore, with its help we cannot decide whether an output gap in the period concerned is positive or negative. One of the ways to overcome this problem consists in adoption of the assumption that the output gap for the whole monitored period equals zero in average. Such assumption, however, shall not be met for the economies being long-term under their potential. Another way of anchoring paths for the potential is additional information concerning the size of output gap at a certain moment.

Each demand shock (impulse) has only temporary impact on the level of production, and accumulation of effects caused by demand impulses represents output fluctuations around potential level. Typical demand impulses are unexpected changes in fiscal or monetary policy.

Description of Data

We made use of quarterly time series of the level of production measured by real GDP in 1995 constant prices and employment rate according to statistical reporting for the period of 1993:1 – 2005:2 (Statistical Office of the Slovak Republic: Macroeconomic indices of quarterly national accounts). Both time series are seasonally adjusted. In applying VAR method we used a logarithm of the level of production for the variable y , and logarithm of employment centered around its average for the variable l . Accordingly, the graph in Figure 2a shows percentage of Q-O-Q growth rate of real GDP, and the graph in Figure 2b shows percentage variance of employment from its average.

Figure 2a
GDP Growth – Δy

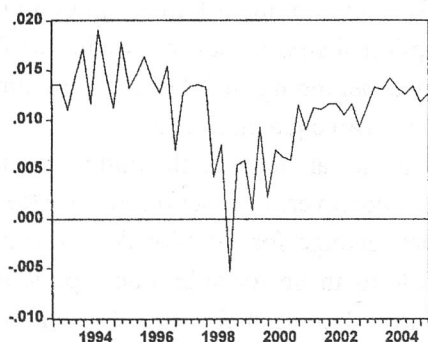
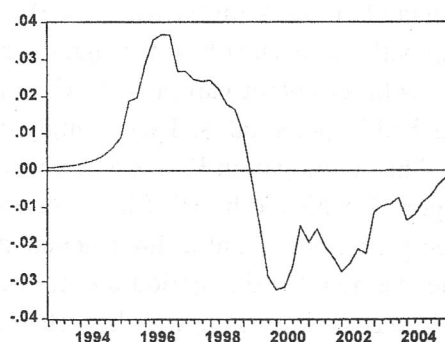


Figure 2b
Employment Rate – l



Dynamic effects of supply and demand shocks on the level of production and employment are shown in Figures 3a, 3b, respectively.

⁵ In fact all available methods for output gap estimation suffer from this deficiency.

Figure 3a
Output Response to Supply
(Blue) and Demand Shock

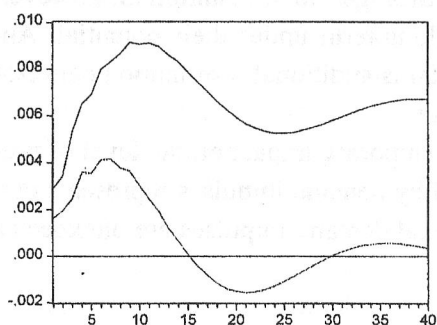
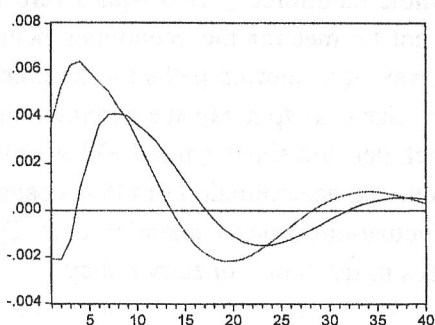


Figure 3b
Employment Rate Response to Supply
(Blue) and Demand Shock



The output responds to a positive supply shock by increasing its level reaching its top in approximately 2 years, and afterwards it slowly falls and becomes stabilized on a new higher level. The employment responds to a positive supply shock first by a sudden decrease, which shall change into growth in a year reaching its top in approximately 1.5 year, and afterwards it slowly falls towards its initial level. The course of the response of the output to a positive demand shock is similar as in the case of a supply shock, however, with approximately half amplitude and with the difference that the level of production returns to its initial level. The employment responds to a demand shock by immediate increase and afterwards slowly falling to its initial level.

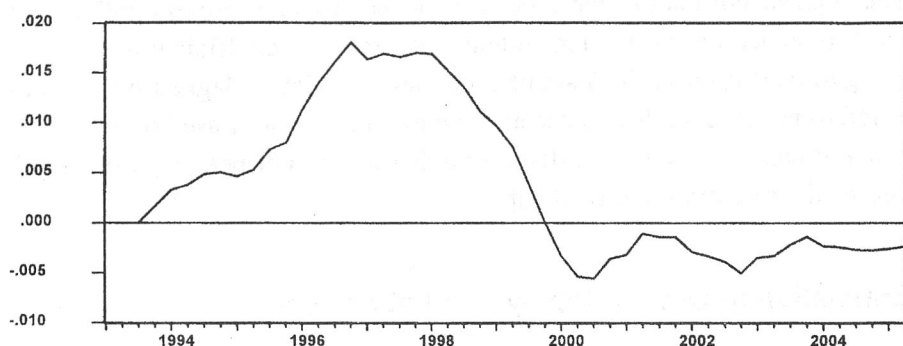
Potential output is achieved by accumulating the effects of supply shocks and an output gap by accumulating the effects of demand shocks, (or by deducting potential output from the actual one). The aforesaid problem of anchoring output gap path has been solved through the assumption shared by several studies dealing with an output gap in Slovakia⁶ that at the beginning of 1994 the economy reached its potential, and accordingly the output gap equaled to zero.

The output gap in Figure 4 seems to have a similar shape as the output gap in Figure 1 achieved by HP filter. We point out, however, to essential differences. The year 1993 meant a fundamental structural change for the Slovak economy, and the data for this period are not as reliable as those for subsequent periods. Whereas the gap achieved through HP filtration has been for the whole monitored period zero in average (this follows from the construction of HP filter), the year 1993 affects the development of gap to the same extent as other years. The gap estimated by SVAR method partly eliminates the effect of the year 1993 and

⁶ See, e.g. Updated convergence programme of Slovakia for the years 2004 to 2010 and also the study ING – Slovak output gap.

makes more account of later periods. We can see even a more significant difference at the end of the monitored period. The estimate by HP method is less reliable just at the end of the monitored period, and therefore data on gap achieved by SVAR method are more reliable, which is free of similarly biased estimates.

Figure 4
SVAR Output Gap



In consequence of expansionary fiscal policy during the period of 1994 – 1998 the economy occurred in substantial inner and external imbalances which resulted in high 11% inflation rate and high 10% deficit in current account in 1999. The new Government had to adopt restrictive measures, including deregulation of administrated prices, which resulted in decreased domestic demand. This caused that output gap reached low negative figures during the year 1999. After stabilization of the economy, an inflow of foreign investment started, which improved export potential of economy, and in particular due to increased foreign demand the production gap began to close. Gradually, domestic demand also recovered which then contributed to accelerated GDP growth. In spite of that, the gap is still negative at the middle of 2005 (–0.5%), which is caused by accelerated growth of potential output (see Table 1).

Table 1
Growth of Potential Output

		2000	2001	2002	2003	2004
GDP growth	% per year	2.1	3.7	4.4	4.4	5.5
Potential output	% per year	3.5	3.7	4.1	4.0	5.1

Is an estimated gap really a good measurement of expected inflation?

In order to answer this question, we tried to estimate a model in which, apart from past inflation, also an output gap is included. The inflation within the model was defined as a quarterly change of CPI logarithm: $\Delta \log(CPI)$. When selecting

a suitable model we tried to identify the relation among current inflation, inflation of past periods and output gap where all coefficients are statistically significant and residuals behave in a standard way. The following model met such criteria best (t-statistics values are in square brackets):

$$\text{infl}_t = 0.23 \cdot y_gap_{t-6} + 0.37 \cdot \text{infl}_{t-4} + 0.01$$

$$\begin{matrix} [1,37] & & [2,08] & & [2,46] \end{matrix}$$

The highest correlation have been achieved between current inflation and output gap lagged by six quarters although the relevant coefficient is not statistically significant even at 10% significance level. Inflation lagged by 4 quarters appeared to be statistically significant for current inflation. Based on such simple approach it can be stated that inflation prediction has not been significantly improved by the inclusion of output gap.

3. Estimation of Output Gap by Unit Labor Cost

The definition of an output gap from the previous section is based on a demonstrative, however, not theoretically sufficiently defined concept of potential output. Furthermore, it appears that it fails to reflect enough the level of economic activity in the sense that it would predict future level of inflation. In this section we shall describe a model that should eliminate the above deficiencies. It is an optimizing general equilibrium dynamic model with price rigidities described in Galí (2003).

The model includes households and firms. Households maximize their lifetime utility function containing consumption and leisure. A decision between immediate consumption and consumption in the future, i.e. savings, is subject to budget constraints. A decision whether to work or enjoy free time depends on the amount of real wage. Firms produce a differentiated product by production technology with exogenously developing productivity. They maximize their profit through determining prices, which cover production costs and margin. The main equations of the model are listed in Appendix C.

Mechanism of Price Setting

In the environment of flexible prices, i.e. when firms reevaluate optimal prices of their products and labor each period, the resulting equilibrium represents the most effective allocation of resources within economy and equals to the equilibrium introduced in neoclassical model described in a seminal work by Kydland and Prescott (1982). The relevant equilibrium value of production level, which corresponds to optimal prices, represents a potential output of the economy concerned.

As we have already mentioned, this model is set in the environment of rigid prices whose mechanism of determination is described in Calvo (1983). Some firms change prices of their products within a given time period while others leave prices unchanged for several subsequent time periods. This method of price setting reflects better the reality as product prices are usually agreed under contracts for several forthcoming time periods. Similarly, wage is also a result of negotiations between employees and employers and determined for at least one year in advance. With such mechanism of price setting the anticipated future costs have to be foreseen by firms in advance for several time periods. Certainly, the costs anticipated are not consistent with actual costs incurred, in consequence of which the prices are not optimal and economy deflects from its equilibrium. The relevant deflection from equilibrium (potential) level of production will be called an output gap. Such deflection acquires negative value if prices are overestimated (higher than optimum) in average and positive value if prices are underestimated. *The concept of output gap is here theoretically exactly defined as a difference between actual level of production (not necessarily corresponding to optimal prices) and potential level of production (corresponding to optimal prices). Inflation dynamics is of a strongly forward-looking character.*

Although the concept of potential output is exactly defined, we again encounter the problem of determining its value. If the above model is calibrated, the equilibrium values of variables involved in it can be calculated. But it is not a typical solution. This type of models (small dynamic models based on micro-economic foundations) serve for qualitative analysis of economic processes but not for their quantitative description. Under certain conditions, however, to be listed below, the model provides an observable variable, which can be used for the estimation of output gap.

The actual output is closely related to the real marginal cost, which is defined as real cost of production of additional unit of goods and service. In consequence of limited resources (material, labor force, land) the real marginal cost increases with increased production (see e.g. Rotemberg and Woodford (1999)). Under the assumptions of competitive labor market, equilibrium on the market of goods and services and exogenous productivity of labor, the marginal cost will be an increasing function of actual output as an exclusive endogenous variable, while the other variables present in the equation are exogenous (equation (22) in Appendix C). This results in an output gap, expressed as percentage variation of actual level of production from the potential (equilibrium) level, proportionate to the percentage variation of *real marginal cost* from its equilibrium level.

Real marginal cost is also an unobservable variable. Under the conditions referred to in the previous paragraph the real marginal cost is proportionate to

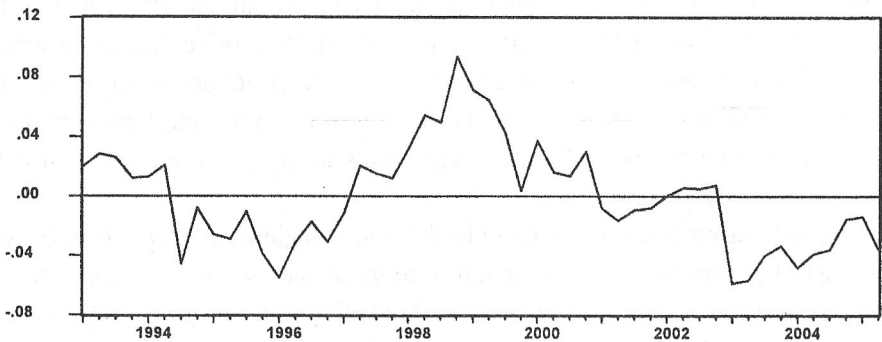
the real unit labor cost (equation (23) in Appendix C). If we link the findings of the two previous paragraphs, then the output gap will be proportionate to the observable variable, namely percentage variance of the *real unit labor cost* from its (constant) long-term average $rulc = \log(RULC) - \log(\overline{RULC})$.

Real unit labor cost – RULC is defined as a proportion of compensation per employee and his/her productivity in current prices.

$$RULC = \frac{\frac{\text{Compensation of Employees}}{\text{Employees}}}{\frac{\text{GDP in current prices}}{\text{Employment}}}$$

We made use of seasonally adjusted quarterly time series for the period of 1995:1⁷ – 2005:2 acquired from the database of the Statistical Office of the Slovak Republic: Macroeconomic indices of quarterly national accounts. In Figure 5 a graph of percentage variance of real unit labor cost from its average – *rulc* is shown.

Figure 5
Percentage Variance of Real Unit Labour Cost from its Average



Note that the values of the output gap are proportionate but not equal to the values of RULC variances plotted in Figure 5.

As regards quality, the output gaps estimated by both methods are quite similar since 1998 when output gap reached its largest positive level. Then it sharply dropped by the year 2000. According to SVAR method output gap in 2000 reached slightly negative value that has been maintained ever since. An output gap

⁷ For the reason of unavailable data (employees, compensation) we have chosen the year 1995 instead of 1993 as the beginning of the period.

identified by RULC method oscillated around zero in 2000 – 2002 it slightly opened reaching its lowest level at the beginning of 2003 when it began to close up. At the middle of 2005 it was still negative.

Is an output gap estimated with the help of RULC a better measure of future inflation than a gap estimated with the help of SVAR? On the basis of the same criteria as those used in SVAR method we have estimated the following model:

$$\text{infl}_t = 0.29 \cdot y_rulc_{t-3} + 0.44 \cdot \text{infl}_{t-4} + 0.03$$

$$\begin{matrix} [2, 53] & & [2, 68] & & [2, 32] \end{matrix}$$

Both coefficients are statistically significant on 1% level of significance. The highest value of correlation has been reached between the current inflation and *rulc* lagged by three quarters.⁸ The shift between current inflation and output gap has decreased from 6 (in the case of SVAR) to 3 quarters (RULC), which indicates a shift in the formation of inflation expectations towards the present time. Similarly as in SVAR method, the inflation lagged by 4 quarters has appeared to be statistically significant for the current inflation.

4. Estimation of the Development of Output Gap for Next Years

On the basis of anticipated development of variables by which the real unit labor cost is defined, we can estimate their development, and thus also the future development of output gap. Real unit cost is determined mainly by the development of nominal wages and GDP in current prices. According to the Monetary Programme of the NBS until 2008 and medium-term prognosis of the National Bank of Slovakia (NBS) of April 2005 the productivity of labor (from the nominal GDP) will grow faster than wages (by 1% in average), which will result in the reduction of (real) unit labor cost. A turnover is anticipated in 2007 when unit labor cost should start to grow. Thus, an output gap will remain negative during this period and until 2007 it should even increase by 1% per year. Such development would contribute to disinflation, which is welcome for monetary policy as regards the fulfilment of Maastricht criteria for inflation.

Some well-known facts, however, do not support such development. Yearly employment growth in the first quarter was much higher (even by 2.3 p.p.) than in the past years and higher than anticipated by Monetary Program of NBS for the year 2005. Wage growth was also much faster although single factors have

⁸ In papers analysing US data (see Galí and Gertler (1999)) and EMU data (see Galí, Gertler and López-Salido (2001)) the highest correlation has been reached between the current inflation and current *rulc*.

probably played their role. Although other facts, in particular really expected development of unemployment, suggest that unit labor cost will not grow significantly, it will not decrease significantly, either. It would stem from this that a negative output gap (estimated by RULC method) should not grow but it should gradually close up.

Conclusion

In SVAR method an output gap is defined in an intuitive way as a difference between actual and potential outputs, and estimated by accumulation of short-term shocks deflecting economy from potential (equilibrium) state. The estimated gap indicates that since 2000 the economy has been slightly below its potential.

In RULC method an output gap is defined as a difference between the output of economy in actual setting of prices and the output in optimal setting of prices. In general, in consequence of low price flexibility actual prices differ from optimal prices. A gap estimated by such method also indicates unused reserves in economy since 2003 up to now.

Appendix A

Underlying model of SVAR method

$$y_t = m_t - p_t + \alpha \cdot a_t \quad (1)$$

$$y_t = l_t + a_t \quad (2)$$

$$p_t = w_t - a_t \quad (3)$$

$$w_t = w / \left\{ E_{t-1} l_t = \bar{l} \right\} \quad (4)$$

The variables y , l , a , p , w , m denote the logarithm of output, employment, productivity, price level, nominal wage and money stock, respectively.

Equation (1) states that aggregate demand is a function of real money balance and productivity. Notice, that productivity affects demand directly.

Equation (2) is the production function, which relates output, employment and productivity and assumes a constant returns-to-scale technology.

Equation (3) describes price-setting behavior and gives the price level as a function of the nominal wage and of productivity.

Equation (4) characterizes wage-setting behavior: the wage is chosen one period in advance and is set so as to achieve expected full employment. Hence wages are rigid and this rigidity is transmitted to price rigidity through equation (3).

Exogenous variables a and m evolve according to the following equations:

$$a_t = a_{t-1} + \theta_t^S \quad (5)$$

$$m_t = m_{t-1} + \theta_t^D \quad (6)$$

where θ^S and θ^D are the serially uncorrelated and pairwise orthogonal demand and supply disturbances. Let's also assume they are normalized.

$$E\left(\begin{bmatrix} \theta^S \\ \theta^D \end{bmatrix} \cdot \begin{bmatrix} \theta^S, \theta^D \end{bmatrix}\right) = I_2 \quad \text{and} \quad E\left(\theta_t^k \cdot \theta_{t+i}^k\right) = 0, \quad i \neq 0, \quad k = S, D \quad (7)$$

System of equations (1) – (6) can be rearrange written in the following form:

$$\begin{bmatrix} \Delta y_t - \overline{\Delta y} \\ l_t - \bar{l} \end{bmatrix} = \begin{pmatrix} (1 + \alpha) - \alpha L, & 1 - L \\ \alpha & , & 1 \end{pmatrix} \cdot \begin{bmatrix} \theta_t^S \\ \theta_t^D \end{bmatrix} \quad \text{or} \quad x_t = A(L) \cdot \theta_t \quad (8)$$

Appendix B

SVAR Method

Structural shocks θ^S and θ^D are not observable hence the equation (8) can't be estimated directly. In order to identify it, the vector autoregressive reduced form of the model is first estimated and then expressed in its VMA form:

$$x_t = B(L) \cdot x_{t-1} + \varepsilon_t \quad \text{where} \quad \varepsilon_t = \begin{bmatrix} \varepsilon_t^S \\ \varepsilon_t^D \end{bmatrix} \quad (9)$$

where $B(0) = I$ by construction. Let a covariance matrix of the reduced form residuals is called:

$$\Sigma = E\left(\begin{bmatrix} \varepsilon^S \\ \varepsilon^D \end{bmatrix} \cdot \begin{bmatrix} \varepsilon^S, \varepsilon^D \end{bmatrix}\right) \quad (10)$$

As the shocks are mutually correlated, it is not possible to identify impacts of supply and demand shocks on Δy and l separately.

Equation (9) can be expressed in vector moving average representation form:

$$x_t = C(L) \cdot \varepsilon_t \quad \text{where} \quad C(L) = (I - L \cdot B(L))^{-1} \quad (11)$$

Equating (8) and (11) and keeping in mind that in the reduced form $C(0) = I$ it is easy to verify that the following relation holds:

$$\varepsilon_t = A(0) \cdot \theta_t \quad (12)$$

This equation shows that knowledge of $A(0)$ is the key to recover the structural shocks from the residuals of the reduced form.

Substitution of (12) into (10) leads to:

$$\Sigma = E \left(A(0) \cdot \theta_t' \cdot \theta_t' \cdot A(0)' \right) = A(0) \cdot A(0)' \quad (13)$$

Relation (13) represents only three independent equations, as the matrix $\Sigma_{2 \times 2}$ is symmetrical.

Combining (12) and (11) and comparing with (8) we have:

$$A(L) = C(L) \cdot A(0) \quad (14)$$

The fourth remaining equation is received by substituting 1 for L in (14). As the coefficient $A_{12}(1)$ is equal to 0 we have:

$$0 = A_{12}(1) = C_{11}(1) \cdot A_{12}(0) + C_{12}(1) \cdot A_{22}(0) \quad (15)$$

The matrix $A(1)$ represents long-run effect of structural shocks θ_t on vector x_t ; $A_{12}(1) = 0$ means that demand shocks have no long-run effect on the level of output.

Once the structural shocks are identified it is possible to decompose the output growth rate into its components.

Growth rate of potential output is the accumulation of supply shocks:

$$\Delta y_t^{POT} = \overline{\Delta y} + A_{11}(L) \cdot \theta_t^S \quad (16)$$

and output gap is the accumulation of demand shocks:

$$\Delta y_t^{GAP} = A_{12}(L) \cdot \theta_t^D \quad (17)$$

Appendix C

Underlying Model of RULC Method

Under the assumption of a perfectly competitive labor market, the supply of hours must satisfy:

$$w_t - p_t = \sigma \cdot c_t + \varphi \cdot l_t \quad (18)$$

where c_t is aggregate consumption.

In equilibrium all firms face a common *real* marginal cost, which is given by:

$$mc_t = w_t - p_t - a_t + v \quad (19)$$

with v representing a constant employment subsidy rate.

The clearing of all goods markets implies:

$$y_t = c_t + g_t \quad (20)$$

where g_t is an exogenous (log) government consumption.

Cobb-Douglas production function is of the form:

$$l_t = y_t + a_t \quad (21)$$

Combining (18) – (21) we obtain an expression for the equilibrium real marginal cost in terms of aggregate output and productivity:

$$mc_t = (\sigma + \varphi) y_t - (1 + \varphi) a_t - \sigma \cdot g_t - v \quad (22)$$

As a_t and g_t are both exogenous, real marginal cost is an increasing function of output – the only endogenous variable on the right side of (22).

Expression (22), obtained theoretically, represents empirically confirmed fact (e.g. Rotemberg and Woodford, 1999) that real marginal cost moves with output; that is, it is a procyclical variable.

Real marginal cost is a ratio of the real wage rate and the marginal product of labor. Given the Cobb-Douglas production technology and labor market competitiveness, real marginal cost is:

$$MC_t = \frac{\frac{W_t}{P_t}}{\frac{\delta Y_t}{\delta L_t}} = \frac{W_t \cdot L_t}{P_t \cdot Y_t}, \quad \text{and} \quad mc_t = \log(MC_t) \quad (23)$$

The right hand side of (23) is real unit labor cost.

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