UNIVERSITY OF LJUBLJANA
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UNDERGRADUATE THESIS

ESTIMATION OF THE OKUN'S LAW FOR SLOVENIA: VALIDITY AND STABILITY

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sl. – Slovene

AD – (sl. Agregatno povpraševanje); Aggregate Demand

AS – (sl. Agregatna ponudba); Aggregate Supply

IS – (sl. Investicije ter varčevanje); Investment-Savings

LM – (sl. Likvidnostne preference ter ponudba denarja); Liquidity Preference-Money Supply

LRAS – (sl. Dolgoročna krivulja ponudbe); Long Run Aggregate Supply

NAIRU – (sl. Stopnja brezposelnosti, ki ne pospešuje inflacije); Non-Accelerating Inflation Rate of Unemployment

NAWRU – (sl. Stopnja brezposelnosti, ki ne pospešuje rasti plač); Non-Accelerating Wage Rate of Unemployment

OC – (sl. Okunov koeficient); Okun's Coefficient

OL – (sl. Okunov zakon); Okun's Law

PS – (sl. Postavljanje cen); Price-Setting

SRAS – (sl. Kratkoročna krivulja ponudbe); Short Run Aggregate Supply

WS – (sl. Postavljanje plač); Wage-Setting

INTRODUCTION

In trying to achieve full employment, accurate measurements of potential output are of paramount importance. Namely, they provide a sense of direction, allowing stabilization policy to respond appropriately. One of the early works on closing the output gap was done by Arthur M. Okun (1962) who developed a quantitative expression capable of locating the economy's locus with respect to its potential. In addition, his paper inadvertently formalized the empirical relationship between output and unemployment later called the Okun's law (hereinafter: OL). In doing so, it seemed like this intuitive, yet profound framework could empower policymakers and academia to make better judgments about the state of the business cycle and the amount of government intervention necessary to bring the economy back into equilibrium. After all, the word »law« ought to imply stability and independence. Later, however, a plethora of research affirmed the scruple about it being a misnomer. Indeed, the OL exhibits large cross-country heterogeneity and time variance.

This thesis tackles the OL as one of the instruments used for assessing the dynamics between output and unemployment and therefore dedicates a large portion of the theoretical background to the understanding of macroeconomic fluctuations. These are explained primarily through the lens of Keynesian economics, culminating in the aggregate supply (hereinafter: AS) and aggregate demand (hereinafter: AD) framework. Afterward, the OL is presented in the form of three regression models, all of which were included in Okun (1962) along with the equation linking the trend output and unemployment variables. The effect measured in the OL is also disaggregated with the help of the production function approach following Prachowny (1993) and Schnabel (2002). Next, a literature review is conducted, emphasizing the properties of the OL and how are these reflected in seminal papers. Lastly, the dataset for Slovenia is specified, described, and used in regression analysis. Models are estimated with the OLS method and corrected with robust covariance estimators in the case of assumption violation.

In short, the purpose of this thesis is to evaluate the validity and stability of the OL for Slovenia. Surprisingly, this topic has been researched rather poorly. There are only a handful of similar studies, such as Pajk (2003) and possibly Dajcman (2018). Certainly, the OL estimation for Slovenia has been conducted in some other papers as well but as part of a much broader analysis (Bank of Slovenia, 2020, pp. 27-28; Barišić & Kovač, 2022; ECB, 2011; ECB, 2012; Kajzer, Hribernik, Perko & Selan, 2013, pp. 7-8). In this respect, the thesis might also prove valuable. To help with the determination of the OL for Slovenia, three hypotheses were formed. Firstly, we assumed the OL holds for Slovenia independently of the model used whereby the value of the regression coefficient could deviate from the value Okun obtained in his analysis. Secondly, there exists a dynamic relationship between the change in the unemployment rate and lagged output growth variables in Slovenia. Furthermore, the current change in the unemployment rate also follows its prior movements.

Thirdly, variable dynamics did statistically significantly change during the 2008-2013 double-dip recession.

1 A PRIMER ON MACROECONOMIC FLUCTUATIONS

The following overview will revolve around a structured approach to constructing the AS-AD model laid out in Mankiw (2010, p. 307) whereby the AS will be determined by the labor market equilibrium of the Wage-Setting (hereinafter: WS) and Price-Setting (hereinafter: PS) model and the Phillips curve while the AD curve will be derived from the Investment-Savings (hereinafter: IS) and Liquidity Preference-Money Supply (hereinafter: LM) relationship.

1.1 The Labor Market

Assuming the neoclassical framework of supply and demand under perfect competition (Samuelson & Nordhaus, 2010, p. 599), one could conclude that the labor market clears in equilibrium as voluntary or frictional unemployment arising from people's own volition to become unemployed to find a better, more suitable job or step in and out of the labor force is not detrimental to society's welfare. However, according to Blanchard, Amighini and Giavazzi (2017, p. 152), equilibrium unemployment is more likely to be involuntary or a combination of both as depicted in Karlin and Soskice (2014, p. 57). This can be shown by deriving the WS-PS model, arguably a better alternative to the standard supply-demand relation due to its unrealistic underlying assumptions. Here, the general case is such that the labor market does not clear, which means that some workers are willing to work at the prevailing wage but cannot find a job.

Wage determination in the WS-PS model follows the assumption of efficiency wages defined as the compensation linked to workers' productivity. In general, workers are paid above their reservation wage which denotes the point of indifference between working and being unemployed. Furthermore, the amount paid is also determined by the labor market conditions (the lower the unemployment rate, the higher the wage). The former is important because it induces labor to be more industrious and lowers the turnover rate whereas the latter contributes to workers' bargaining power along with the nature of one's job (e.g., replacement of high vis-à-vis low-skilled labor) (Blanchard, Amighini & Giavazzi, 2017, pp. 142-145). Both factors contribute to the upward-sloping WS curve drawn in Figure 1, which can be expressed by the following equation:

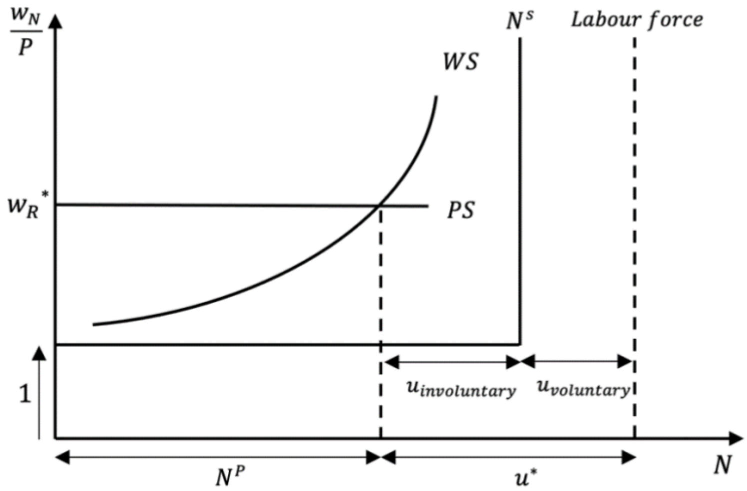
$$w = PF(u, z) \tag{1}$$

where P indicates the price level and $F(u, z)$ is a function of the unemployment rate (u) and a catch-all variable (z) that encompasses all the factors affecting the wage (w) ceteris paribus, such as business registration, minimum wage laws and unemployment insurance.

As can be seen, the curve is located above the inverse L-shaped labor supply (N^S) because the effective wage must be higher than the reservation wage which amounts to the distance of line 1 (Karlin & Soskice, 2014, p. 44). Conceptually, it can be thought of as the sum of unemployment benefits and the disutility of turning up to work. Should the unemployment benefits rise (fall), the WS curve would shift upwards (downwards) because the wage must be higher (lower) to incentivize work to the same degree. Moreover, the portion of the N^S curve associated with the reservation wage is horizontal expressing the feature of indifference. On the other hand, the vertical part is a simplification based on balanced income and substitution effects accompanying rising wages. While the substitution effect suggests that N^s will rise because working becomes favorable in comparison to leisure, the income effect can explain a fall in N^s because the same amount of income can be earned from fewer hours of work (Karlin & Soskice, 2014, p. 45).

Apart from a positive substitution effect, labor participation rates also rise in response to higher wages, which further offsets the negative income effect of working fewer hours. Together, this produces an inelastic N^s that is in its extreme form drawn in Figure 1 but more likely resembles steep albeit not perfectly inelastic supply curves (Samuelson & Nordhaus, 2010, p. 251). The horizontal distance between the point on the WS curve and the vertical N^s in Figure 1 can be treated as involuntary unemployment and is key to the bargaining power of workers. When the unemployment rates are high (low), the cost of job loss is higher (lower) and the determined efficiency wages are lower (higher).

Figure 1: The WS-PS model



Adapted from Karlin & Soskice (2014).

Both the persistent existence of the involuntary unemployment and the position of the WS curve are related to the efficiency wages briefly mentioned at the start of this section. The term was first coined by Shapiro and Stiglitz (1984, pp. 433-444) who acknowledged that the labor market does not clear, which means wages do not fall to satisfy additional labor supply and are higher than assumed in the conventional neoclassical competitive paradigm. Under full employment, workers receiving the market wage are likely to be unproductive due to the absence of an effective punishing mechanism. If an employer detects shirking on the job, the worker is laid off but can immediately be rehired. To counter this, employers decide to pay more than the market wage which induces the employees to be more productive. This pushes up the costs of employment and decreases the demand for labor which results in unemployment. Consequently, even if all firms pay the same wages, a worker is discouraged to shirk because a layoff is not costless. In other words, unemployment serves as a worker-discipline device. The pool of unemployed also cannot bid for jobs by offering to work for lower wages because the employer knows it can lead to unproductive behavior (Yellen, 1984, p. 201), hence the presence of involuntary unemployment.

The second market force determining the equilibrium wage is the PS curve which reflects the decision-making of imperfectly competitive firms (Blanchard, Amighini & Giavazzi, 2017, p. 144). They set prices in relation to the incurred production costs whereby profitability is the single condition that ought to be satisfied. To simplify the model, we assume that the sole input used is labor and its productivity is constant. This can be written as $Y = AN$ (where A is the technological factor and equal to 1) implying that the cost of producing one more unit of output is the cost of employing one more worker at w. Furthermore, assuming imperfect competition, the prevailing P will not be equal to w but higher for $(1 + \mu)$ which constitutes a markup (Karlin & Soskice, 2014, pp. 58-59). Taking everything into consideration, the equilibrium w lies at the vertex of the WS and PS curves:

$$PF(u, z) = \frac{P}{(1 + \mu)} \tag{2}$$

where the left-hand side is the WS relation and the right-hand side is the PS relation. It is also important to emphasize that rational economic agents engaged in the process of wage-setting think in real terms since they entail the true utility of a received or paid-out wage (Blanchard, Amighini & Giavazzi, 2017, p. 145). From the worker's perspective, they are indifferent to the amount of money in their pocket but rather focus on its value. Similarly, firms are focused on wage costs in relation to the price of products they sell. Accordingly, the real wage (w_R) on the y-axis is assumed to be the nominal wage (w_N) divided by P. If the latter is expected to double, the former will follow suit to preserve the existing purchasing power. Namely, wages are not continuously adjusted but rather fixed by way of contractual agreements for at least a year based on the expected price level (P^e). Thus, we can rearrange the WS-PS equality in terms of w_N conditional on some expected price $P^e = P$, assuming a broader horizon (Blanchard, Amighini & Giavazzi, 2017, pp. 146-148):

$$F(u^*, z) = \frac{1}{(1 + \mu)} \tag{3}$$

In (3), we can see that the PS curve is indeed flat and its position depends solely on the value of the markup. Less market competition translates into higher prices which leads to lower real wages and higher unemployment. Importantly, (3) formalizes a medium to long-term equilibrium whereby the unemployment rate is equal to its natural rate (u^*) and the employment rate is at its potential (N^P). Needless to say, this does not hold in the short term because the economy is at the mercy of external forces described in the next section.

1.2 The Goods and Financial Market

1.2.1 The Theory of Production

To gauge the firm's productive capacity, one must inspect the quantity and quality of the production factors (also inputs) involved in the production process, the degree of technical knowledge possessed, and its application. Formally, the relation between the maximum output that can be produced given a certain number of inputs is called the production function (Samuelson & Nordhaus, 2010, pp. 107-108). Notwithstanding the indefinite amount of production functions corresponding to the firm's specific type of business activity, factor utilization, or technological advancement, their nature can still be visualized using the following equation:

$$Y = AF(K, N) \tag{4}$$

where Y is output created with the combination of the technological factor (A) and the production factors, generally categorized as employed labor (N) and capital (K) (e.g., machinery, buildings, and equipment). In addition, Charles W. Cobb and Paul H. Douglas (1928) have found that a specific form of production function closely replicates the input-output relationship of the whole manufacturing industry in the United States between 1899-1922. Specifically, the function of N and K is rewritten as a product of the two:

$$Y = AK^{\alpha}N^{1-\alpha} \tag{5}$$

where the sum of exponents of production factors is equal to 1 otherwise known as the condition of constant returns to scale. In the case of Cobb and Douglas (1928), $\alpha = 0.25$, which means that the input of capital represents a quarter of the industry's income while the rest is devoted to labor. Nowadays, however, empirical evidence suggests that $\alpha \approx 0.33$ (Blanchard, Amighini & Giavazzi, 2017, p. 235). In addition, if the logarithm of both sides is taken, we end up with the growth accounting equation whereby the exponents become output elasticities of both inputs:

$$lnY = lnA + \alpha lnK + (1 - \alpha)lnN \tag{6}$$

1.2.2 Derivation of the IS-LM model

Equipped with the knowledge of production, we now look at how its equilibrium level is determined in the goods market, the dynamics of which can be captured by the Keynesian cross, i.e. plotting aggregate demand against output. Put simply, aggregate demand (AD) is defined as the sum of consumption (C), investment (I), government expenditure (G), and net exports (NX). Additionally, these components can be broken down revealing their partial endogeneity:

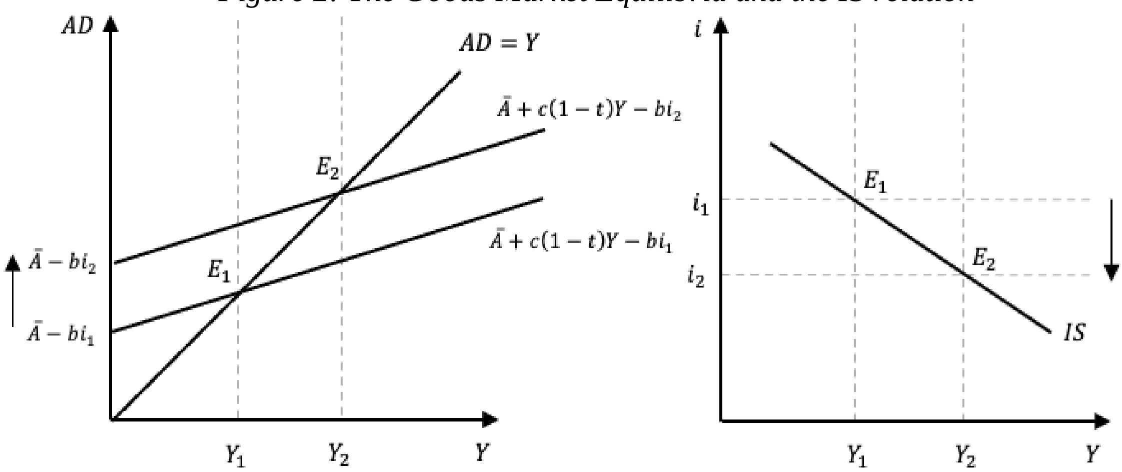
$$AD = C + I + G + NX = [\bar{C} + c\overline{TR} + c(1-t)Y] + (\bar{I} - bi) + \bar{G} + \overline{NX} \\ = \bar{A} + c(1-t)Y - bi \tag{7}$$

By expanding (7), we acknowledge that C is a three-part concept including autonomous consumption ($\bar{C}$), government transfers ($\overline{TR}$), and disposable income $(1-t)Y$ consumption while I is in part a function of the interest rate (i). The term $\bar{A}$ denotes all the variables that are unaffected by either the level of income (Y) or i (Dornbusch, Fischer & Startz, 2011, pp. 219-226). In (7), they carry a bar notation characteristic of exogenous variables. On the other hand, as already indicated in the previous subsection, output is synonymous with income since production factors K and N are compensated to produce a certain amount of output. Indeed, in the mainstream macroeconomic literature, Y is a symbol for both. Eventually, the income received is used by way of consumption, savings (S), or taxation (T). If we assume the equilibrium condition with a balanced government budget, meaning $G = T$, and leave out the foreign sector, a simple IS relation can be obtained:

$$AD = Y \Rightarrow (C + I + G = C + S + T) \Rightarrow I = S \tag{8}$$

Nevertheless, the goods market is seldom in equilibrium. At other times, aggregate demand can exceed or fall short of output whereby the difference is made up by changes in inventories. If the economy is located left of the equilibrium E_1 in Figure 2, $AD > Y$ (or $I > S$) and inventories are depleted. Simultaneously, firms will also increase their production orders for the next period increasing the output as a whole. The opposite happens when $AD < Y$ (or $I < S$). Accumulation of inventories will lead to a decrease in production orders and consequently output. Alternatively, unplanned dis(investment) relative to aggregate demand can be thought of as a signal preceding the change in production levels (Fonseca, n.d.).

Figure 2: The Goods Market Equilibria and the IS relation



Adapted from Dornbusch, Fischer & Startz (2011).

Afterward, a spiral effect called the Kahn-Keynesian multiplier takes place gradually moving the goods market back into equilibrium. For instance, as new production orders follow the now higher demand associated with the equilibrium E_2 in Figure 2, the income of production factors rises leading to an additional increase in demand which further stimulates production. This process repeats until the economy has moved from Y_1 to Y_2 (Fonseca, n.d.).

As depicted in Figure 2, connecting all the equilibria of the goods market allows us to draw the IS relation. To do this, we make use of i whose change partially alters the value of I. Furthermore, plotting it against Y presents us with two possible sets of moves. Should the increase in AD be the result of the change in i, the economy will move along the IS curve from i_1 to i_2 (see Figure 2). However, if the increase in AD results from the change in $\bar{A}$, the whole IS curve will shift to the right, which means a higher level of income will correspond to the same level of interest (Dornbusch, Fischer & Startz, 2011, pp. 226-232).

Still, where does the value of i come from? According to Keynes, »the rate of interest at any time, being the reward for parting with liquidity, is a measure of the unwillingness of those who possess money to part with their liquid control over it... It is the price which equilibrates the desire to hold wealth in the form of cash with the available quantity of cash.« (Keynes, 1936, p. 167, as cited in Fonseca, n.d.). In practice, this means people hold a portfolio of assets adjusted to their liquidity preference. We can imagine a simple model in which our portfolio contains only two assets – money and bonds. The former does not yield interest since it is the most liquid but the latter do. Hence, the demand for money (M^D) or liquidity (L) can be summarized by the following equation:

$$M^D = PL(i, Y) \Rightarrow \frac{M^D}{P} = L(i, Y) \tag{9}$$

where L is negatively correlated with i (bonds become progressively attractive) while higher Y and P typically lead to more spending exhibiting a positive correlation (Krugman & Obstfeld, 2003, pp. 361-364). The originator of money is usually a region's monetary authority, commonly known as the central bank. Depending on the scope of measurement, there are several different types of money supply, such as the monetary base, the first (M1), and the second (M2) money aggregate (The Federal Reserve, 2015). To avoid confusion, we will assume a universal exogenously determined nominal base of money supply (M^S) divided by P to acquire the real money supply (M_R^S) and concurrently equilibrium in the money market:

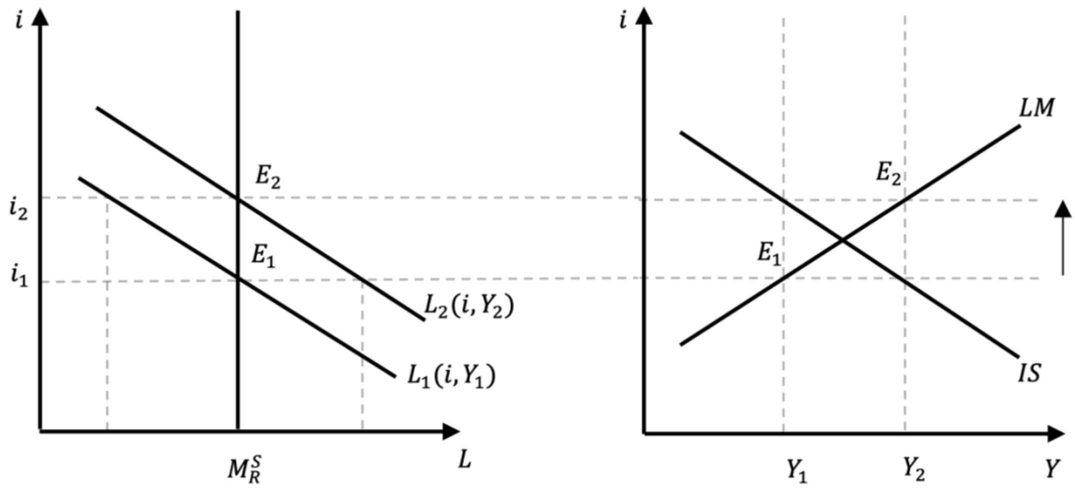
$$M^S = M^D \Rightarrow \frac{M^S}{P} = M_R^S = L(i, Y) \tag{10}$$

Apart from (10), the money market dynamics can also be explained by a portfolio stock constraint composed of both the money market and bond market (Krugman & Obstfeld, 2003, pp. 361-364):

$$(M^D - M^S) + (B^D - B^S) = 0 \quad (11)$$

Looking at the left graph of Figure 3, i_2 is above the E_1 equilibrium interest rate i_1. Here, $M^D < M^S$ and the demand for bonds (B^D) is larger than supply (B^S) to satisfy (11) which means individuals hold more money than they desire, given i_2. To decrease their money balances, they are willing to lend money to others by purchasing bonds. However, because many more people offer to lend it than to borrow it at i_2, competition, to attract borrowers, lowers the prevailing interest rate to i_1 where $M^D = M^S$ and $B^D = B^S$. On the contrary, the reverse will happen if i_1 is below the E_2 equilibrium interest rate i_2. Besides moving along the real money demand curve, a shift can also appear, should Y change. For example, a move from E_1 to E_2 results from an increase in output from Y_1 to Y_2, more explicitly captured with the LM relation in the IS-LM model (see the right graph in Figure 3). Furthermore, shifts in the latter are possible as well, owing to the change in M_R^S. An increase in M_R^S (shift to the right) leads to a likewise shift of the LM relation and an overall lower interest rate at the same level of output Y_2 (Fonseca, n.d.; Krugman & Obstfeld, 2003, pp. 364-365).

Figure 3: The Money Market Equilibria and the IS-LM model



Adapted from Dornbusch, Fischer & Startz *(2011).*

1.3 Cyclicality and Equilibrium

1.3.1 Constructing the AS-AD framework

The AD curve has already been mentioned in the previous section catalyzing changes in the goods market and IS-LM framework while keeping P fixed. Here, the derivation is turned on its head assuming only varying P coupled with fixed $\bar{A}$ and M^S. The associated transmission mechanism is the following: a higher P lowers M_R^S (moving it to the left), which props up i in the money market shifting the LM curve to the left. The resulting equilibrium is higher in the IS-LM model or lower in the goods market, both signifying a decrease in AD and subsequently Y (refer to Figure 2, Figure 3 and Figure 4) (Dornbusch, Fischer & Startz, 2011, pp. 241-242).

On the other hand, formalizing the AS curve necessitates a more nuanced approach. To start, there is a trade-off between u and the change in money wages (also wage inflation) (π_w) called the Phillips curve which can be written as:

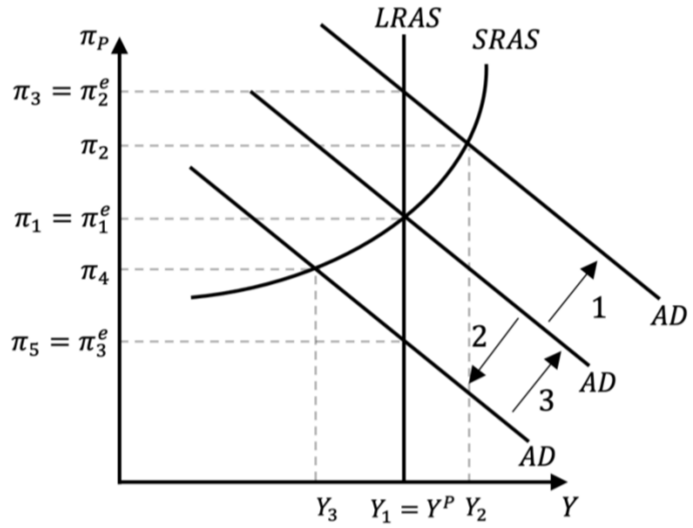
$$\frac{W_{t+1}-W_t}{W_t} = \pi_w = -\alpha(u - u^*) \quad (12)$$

where α measures the responsiveness of wages to unemployment and u^* denotes the natural rate of unemployment in the context of (12) synonymous with the non-accelerating wage rate of unemployment (hereinafter: NAWRU). It follows that when $u < u^*$ ($u > u^*$) money wages increase (decrease) or $\pi_w > 0$ ($\pi_w < 0$). Although this was the initial form of the equation proposed by A. W. Phillips, two important modifications were later introduced. Firstly, π_w was replaced by price inflation (π_P), and secondly, P^e or its change (π_P^e) was included (see Equation 13). Hence, the term non-accelerating inflation rate of unemployment (hereinafter: NAIRU) is often used in place of NAWRU. Furthermore, it was also pointed out that equating $P^e = P$ is reasonable for broader horizons as expectations are unlikely to be systematically wrong for a long period of time. Namely, the unemployment rate converges to its non-inflation accelerating level in the medium and long term ($\pi_P = \pi_P^e$ and $u = u^*$) (Dornbusch, Fischer & Startz, 2011, pp. 120-125).

$$\pi_w = -\alpha(u - u^*) \Rightarrow \pi_P = \pi_P^e - \alpha(u - u^*) \quad (13)$$

Albeit (13) provides a good insight into the characteristics of AS, it is still short of Y which is central to the AS-AD framework (see Figure 4).

Figure 4: The Dynamic AS-AD model



Adapted from Dornbusch, Fischer & Startz (2011).

Accordingly, we take advantage of the OL, i.e., the inverse relation between the unemployment and output gaps (see Equation 14), to derive the AS curve mathematically (see Equation 15).

$$(Y - Y^P) = -\beta(u - u^*) \quad (14)$$

$$\pi_P = \pi_P^e + \frac{\alpha}{\beta}(Y - Y^P) \quad (15)$$

In (15), we can see that the AS curve is upward-sloping ($\frac{\alpha}{\beta}$) and has an intercept of π_P^e. Still, the linear relationship does not effectively capture the price dynamics proposed by Keynesian or Classical economists. Due to nominal rigidity, the AS curve is close to flat in the short run since the change in output is hardly followed by the change in price ($\frac{\alpha}{\beta} \approx 0$). Moreover, the flatness is associated with an output level below potential whereas, in times of overheating, the curve is unconventionally steep. On the contrary, the curve is vertical in the long run as current inflation equals inflation expectations $\pi_P = \pi_P^e$ and $Y = Y^P$ where Y^P is the potential level of output. Thus, the AS-AD framework is composed of three curves, the short run aggregate supply (hereinafter: SRAS), the long run aggregate supply (hereinafter: LRAS), and the AD (see Figure 4) (Dornbusch, Fischer & Startz, 2011, pp. 97-141).

1.3.2 Dynamics and Unemployment

The dynamics between unemployment and output are most conveniently studied starting from the long run equilibrium, which is graphically depicted by the intersection of the LRAS, SRAS, and AD in Figure 4. At this point, $Y_1 = Y^P$, whereby the economy is achieving maximum production capacity without the overuse of resources or production factors. This also implies no inflationary pressures since $\pi_1 = \pi_1^e$ (Cecchetti & Schoenholtz, 2017, pp. 583-603). Over time, the potential output level is likely to increase due to supply-side factors, such as technological advancements and an enlarged pool of production factors. A decrease, however, is also possible as suggested by the hysteresis hypothesis which gained traction during the Great Recession. For example, a persistent drop in demand may discourage firms from undertaking investment decisions and stalling innovation whilst workers might stop searching for jobs leading to a gradual erosion of their skills (Andersson, Szörfi, Tóth & Zorell, 2018). In addition, the latter is a major cause of structural unemployment, a component of the NAIRU.

Similar to output, the current unemployment matches with the NAIRU in the long run (see Equation 13). Moreover, its structure can be inferred from the WS-PS model. Since it holds that the labor market does not clear in equilibrium, both involuntary and voluntary or frictional unemployment are present. In this case, involuntary is characterized solely by structural unemployment as cyclical is by definition related to the deviation from its long-run potential trend. As mentioned, structural shifts may ensue from an extended period of unemployment caused by cyclical unemployment spillovers which slowly translate into a reduction in human capital (Punnoose & Wong, 2018). Meanwhile, frictional unemployment is ever-present but quite short-term in nature. Combining the two, we can conclude that the value of NAIRU can change in response to shifts in the potential output.

Yet, most of the time, an economy is not at its long run equilibrium with respect to output or unemployment. Namely, unexpected events generally referred to as demand or supply shocks, can push current output (unemployment) away from potential creating what is called an output (unemployment) gap. To illustrate this, we will make use of demand shocks but note that supply shocks are of equal relevance, even more so when discussing stagflationary environments.

Upon closer inspection of Figure 4, there are two possible movements in the short run. Whether the AD curve shifts outwards (line 1), output increases from Y_1 to Y_2 along with inflation (from π_1 to π_2). Since $Y_2 > Y_1$, the output gap is said to be positive (or expansionary). Of course, this is not a stable equilibrium. With $\pi_1^e < \pi_2$, inflation expectations will increase and move the SRAS upwards. This process unfolds until $\pi_3 = \pi_2^e$ and Y_2 declines back to its potential $Y_1 = Y^P$. In other words, we end up with higher equilibrium inflation and the original output level (Cecchetti & Schoenholtz, 2017, pp. 583-603). An overheating economy is normally accompanied by levels of unemployment below the NAIRU. Still, there is not much leeway for businesses to employ new workers. At this point, the assumption of constant productivity should be abandoned, since constrained production capacity is associated with a rapid increase in unit costs due to the use of idle, older equipment, overtime work, and frequent bottlenecks (analogous to diminishing marginal returns) (Lipsey & Harbury, 1992, p. 393).

Higher marginal costs in turn lead to higher output prices. In the medium run, once worker contracts are up for renewal and bargaining power is high due to prevailing tight labor market conditions, nominal wages are finally adjusted to reflect the change in inflation expectations arising from higher prices. This can induce a self-sustaining process called the wage-price spiral contributing to a reduction in real money stock or purchasing power in the long run, i.e., demand decreases in aggregate. Because price stability is in question, restrictive disinflationary monetary policy is conducted as soon as inflationary pressures begin to form in hopes of curbing expectations before they set in. In this case, the biggest risk is overshooting in the other direction pushing the economy into a recession (Goodwin et al., 2022).

Now, suppose that the AD curve shifts inwards (line 2) and output decreases from Y_1 to Y_3. This is synonymous with a negative (or recessionary) output gap which brings about a fall in inflation ($\pi_4 < \pi_1$) and a rise in cyclical unemployment exacerbated by downward wage stickiness. Namely, it takes time for wages to start falling in line with the demand for labor. This produces a rate of unemployment that would not be present in the case of perfectly flexible wages (Haltom, 2013). However, as Okun (1962) points out, the change is not instant. Firstly, slack economic activity is characterized by on-the-job underemployment reflected in depressed levels of manhour productivity and fewer working hours (the opposite holds for expansions). Although firms lay off workers, they do so reluctantly. Hence, employment may not be variable for several reasons (Okun, 1962):

1. Contractual agreements include guaranteed annual wages, supplementary unemployment compensation, right to severance pay, etc., as well as a fixed term of employment.
2. Technological factors, whereby the division of labor and degree of specialization is such that even if output falls below normal, certain job roles, such as specialists, sales personnel, and supervisors, are indispensable for business continuity.
3. Transaction costs associated with layoffs and rehiring processes.
4. The acquired skills of some employees are invaluable to the firm and outweigh the costs of their underemployment.
5. Morale factors surrounding layoffs.

Accordingly, one could conclude that in milder recessions, productivity will act as a cushion for employment. Of course, the status quo does not last forever. If a recession is prolonged, employment numbers will fall drastically creating a large pool of cyclically unemployed that can in small part, as alluded to earlier, move on to become structurally unemployed (Okun, 1962). In dealing with a downturn, two approaches are possible. Either the government takes an active role through expansionary fiscal and monetary policy or leaves the market to its innate medium run correcting mechanism. The former shifts the AD curve outwards (line 3) in an optimal case bringing the economy back to its potential. However, as with disinflationary policies, the risk of overstimulation is present. Nevertheless, this can be an effective way to lower cyclical unemployment and increase output. Since there is unused capacity in the economy and nominal rigidity is present, an increase in demand produces only a slight or no price increase but a considerable jump in output (Lipsey & Harbury, 1992, p. 393).

If a more passive approach is taken, disinflationary pressures will appear since $\pi_4 < \pi_1^e$. Workers and unions will eventually agree to slower wage growth, which allows firms to reduce the speed of price increases. When demand starts to increase, new workers will be employed at lower wages according to their bargaining power (Goodwin et al., 2022). In the worst-case scenario, disinflation can also turn into deflation, an absolute decrease in price levels. In the medium run, SRAS shifts downwards until the conditions $\pi_5 = \pi_3^e$ and $Y_1 = Y^P$ are satisfied in the long run (Cecchetti & Schoenholtz, 2017, pp. 583-603). This downward process of readjustment, however, is usually slower than its counterpart (Lipsey & Harbury, 1992, p. 396). Deep recessions can even lower potential productive capacity (shifting the LRAS curve inwards) by increasing the NAIRU or reducing firm entry (Benati & Lubik, 2022, p. 5).

2 OKUN'S LAW: DESCRIPTION AND EXTENSIONS

In his paper, Okun proposed three different models that were necessary for constructing an equation capable of measuring potential output based on the current unemployment rate. In this chapter, these are put forward together with his estimates. Furthermore, this framework is extended by introducing a production function approach that disaggregates the value of the Okun's coefficient (hereinafter: OC) bringing it in line with the common values of production factors' output elasticities.

2.1 Proposed models and Extensions

2.1.1 First Differences model

The first method of relating output to the unemployment rate is the model of first differences whereby quarterly changes in the unemployment rate (Δu) expressed in percentage points were regressed on quarterly percentage changes in real GNP ($rGNP$). The equation was fitted to quarterly observations from 1947Q2 to 1960Q4 for the United States (see Equation 16) (Okun, 1962).

$$\Delta u_t = b_1 + b_2 rGNP_t \tag{16}$$

According to Okun's estimates $b_1 = 0.3$ while $b_2 = -0.3$. The regression coefficient b_2 implies that, on average, a percentage point increase in real GNP growth will yield a 0.3 percentage point decrease in the change of the unemployment rate. We could also calculate the real GNP growth rate consistent with a stable unemployment rate which is the ratio b_1/b_2 (Christl, Köppl-Turyna & Kucsera, 2017, p. 100). Here, it is equal to one percent. Okun also inverted the value of the regression coefficient b_2 to obtain the change in real GNP growth due to a percentage point increase in the change of the unemployment rate, which means $\frac{1}{-0,3} \approx -3,33$. However, this does not adhere to econometric theory and was later disputed in an article by Plosser and Schwert (1979, pp. 179-180). What Okun wished to do is take the function $y = bx$ and invert it to get a new relationship between x and y; $x = \frac{1}{b}y$. This is incorrect and would only be true if the correlation coefficient between the two amounted to ± 1. It is imperative to measure the expected movement in real GNP growth conditional on some observed movement in the change of the unemployment rate.

2.1.2 Trial Gaps model

To better understand the next technique, it is important to note that, at the time in the United States, the unemployment rate associated with the potential output was believed to be stationary at 4 percent. With this assumption, one was able to build a relationship that would help with discerning the corresponding trend growth of potential output (Okun, 1962).

$$u_t = b_1 + b_2 OG_t \tag{17}$$

In (17), the unemployment rate (u) is regressed on the output gap (OG). Because one of its components, the potential output, is unmeasurable, it was presupposed using certain exponential paths. The candidate was picked based on two criteria: 1) the model retained a high goodness of fit and 2) the regression constant b_1 (or the natural rate of unemployment u^* if $OG = 0$) was close to 4 percent. In the end, the gap was derived from a 3.5 percent potential GNP growth trend line through actual real GNP in the middle of 1955 whereby observations from 1953Q1 to 1960Q4 were used. The estimated regression constant $b_1 = 3.72$ was relatively close to the 4 percent ideal while the coefficient $b_2 = 0.36$, which implies a 0.36 percentage point increase in the unemployment rate when the output gap increases by a percentage point on average (Okun, 1962). The version at hand is similar to the differences model. However, it also emphasizes that the trend or potential growth might not be similar throughout the observed time horizon (Chamberlin, 2011).

Additionally, the gap model can be modified to address both the fluctuations in potential output and unemployment. As economists now typically believe that the latter varies over time, contemporary studies on the OL typically estimate the gap version by subtracting the constant from both sides yielding (18) (Knotek, 2007, pp. 94-95). Since both potential terms in the model are unobservable and have to be measured, the results highly depend on the methodology used (Ball, Leigh & Loungani, 2013; Lee, 2000).

$$(u_t - u_t^*) = b_2 OG_t \tag{18}$$

2.1.3 Elasticity model and Potential Output Trend

In their paper, Porras-Arena and Martín-Román (2022) claim (16) and (18) have been the most used methods for researching the OL, and we can surely attest to that based on the literature review. Although the elasticity model (see Equation 19) seems different, it is similar to the previous two if potential GNP, employment, and unemployment are held constant. Consequently, all the models in Okun's paper also yielded comparable results (Belmonte & Polo, 2004, as cited in Porras-Arena & Martín-Román, 2022). In essence, it is mathematically equivalent to the gap model. However, it does not require the calculation of potential output or the assumption of its trend growth (Kaufman, 1988, as cited in Pajk, 2003, p. 34). Yet, the derivation is longer and more sophisticated in its underlying assumptions (see Appendix 2).

$$lnN_t = b_1 + b_2 lnGNP_t - b_3 t \tag{19}$$

In Okun's case, the model was fitted to the period 1947Q1-1960Q4 and its subperiods, yielding the values of b_2 between 0.35 and 0.40. On average, this suggests a 0.35-0.40 percentage increase in N should GNP increase by one percent. Similarly, r calculated from b_3 also differed, albeit in the range of 3.5 and 4.5 percent (Okun, 1962).

Using the weighted average of all the inversed values of b_2 equal to 0.032, Okun was able to construct a relationship determining the current level of GNP^P solely with the knowledge of GNP and u, which are both observable variables, and the assumption that $u^* = 4$ (see Equation 20).

$$GNP^P = GNP(1 + 0.032(u - 4)) \tag{20}$$

Notwithstanding the ingenuity of his approach, it is worth remembering that the relationship is faulty due to the use of inverse values. As explained, (16), (17), and (19) would have to be rearranged and refitted to the observed data. Still, (20) indicates a 3.2 percent negative output gap if $u = 5$. Furthermore, the relation only holds for the observed period and is not meant to be extrapolated.

2.2 Decomposition of Effects

Nowadays, interpretations of the OC frequently imply "ceteris paribus", leaving out the effects of other factors which might influence the change in output, such as the labor force participation rate, manhour productivity, and the duration of an average workweek (Prachowny, 1993, p. 332). On the contrary, Okun (1962) pointed out that the models used were a simplification whereby the unemployment rate was only a proxy for the aforementioned variables. Therefore, he interpreted the coefficients as "mutas mutandis". To disaggregate the effects, Prachowny (1993, as cited in Schnabel, 2002) utilized a linearized Cobb-Douglas production function with constant returns to scale and natural logarithms of all the included variables (denoted with small letters):

$$y = a + \alpha(k + c) + (1 - \alpha)(\gamma n + \delta h) \tag{21}$$

where (21) differs from (6) in the capital utilization rate (c). Furthermore, the input of labor (l) is broken down into the employment rate (n) and the average number of hours worked (h) with their respective contributions γ and δ. The same relationship can also be written for potential output (y^P), only with all the inputs at their long run equilibrium levels:

$$y^P = a^P + \alpha(k^P + c^P) + (1 - \alpha)(\gamma n^P + \delta h^P) \tag{22}$$

Assuming $u = s - n$ logarithmically where u is the unemployment rate and s the labor supply, $a = a^P$and $k = k^P$, we can subtract (22) from (21) to get:

$$\begin{aligned}(y - y^P) = \alpha(c - c^P) + (1 - \alpha)\gamma(s - s^P) - (1 - \alpha)\gamma(u - u^P) \\ + (1 - \alpha)\delta(h - h^P)\end{aligned} \tag{23}$$

As mentioned in subsection 1.2.1, historical estimates of labor output elasticity $(1 - \alpha)$ move between 0.67-0.75, i.e., around a quarter of the value of the OC. If $\gamma = \delta = 1$ and the upper bound of output elasticity is applied, a percentage point decrease in the unemployment rate would have to be accompanied by at least a 3 percent increase in average hours worked or in labor supply. This would translate into a 3 percent increase in y relative to y^P. The same effect would also be achieved should the capital utilization rate increase by 9 percent (Schnabel, 2002, p. 3). Again, the 3 percent unemployment coefficient has to be treated with care since it is only an approximation of the inverses of b_2 in (16), (17), and (19). Nevertheless, we can conclude that the value of the latter is surely affected by the aforementioned non-included variables. Furthermore, adopting the restriction $\gamma = \delta = 1$, the estimated $(1 - \alpha)$ in Prachowny (1993) was equal to 0.673. This is almost on par with the lower value of the marginal contribution of labor to output assumed nowadays.

3 LITERATURE REVIEW: CROSS-COUNTRY VARIATION AND STRUCTURAL STABILITY

Retrospectively, Okun was correct to warn against extrapolating his newly found estimates. As subsequent research pointed out, although the relationship itself is very robust, considering other regions or adjusting the sample period might have a noticeable impact on the value of the coefficients. Thus, the role of this chapter is to examine the set of factors that might affect the magnitude of the OC and provide examples sourced from the relevant literature subsequently.

3.1 Determinants of the OC

In general, stricter employment protection legislation should make it more difficult to fire workers in a downturn and hire them during recovery. This should lead to a lower elasticity of unemployment with respect to the changes in output. For example, employers in a country with stricter employment protection legislation will rather make use of the internal margins of adjustment (e.g., reduction in working hours and productivity) as opposed to the external ones (e.g., layoffs). Both, however, act as alternatives to cutting wages which is an unpopular policy option because it can harm workers' morale and productivity (Cazes, Verick & Al Hussami, 2013). Thus, downward rigidity entails adjustments elsewhere. Furthermore, the IMF (2010) lists three other main aspects of the labor market's institutional framework that might contribute to the heterogeneity of the OC:

1. Unemployment benefits – the effects are theoretically ambiguous in the sense that they work procyclically with respect to job losses in a recessionary period. However, they limit employment gains in the recovery phase due to the higher wage expectations.
2. Temporary employment contracts – the higher the use in the economy, the higher the responsiveness of unemployment to the changes in output. Namely, these provide less employment protection in comparison to regular contracts.
3. Decentralized wage systems – mitigating job losses through easier downward adjustment of wages. On the other hand, centralized collective bargaining systems are likely to contribute to inflexibility and higher unemployment.

Taking everything into account, we can conclude that structural reforms of the labor market can have an impact on the relationship between unemployment and output. By extension, this may even point to its variation over time. In connection with this, episodic factors, such as crises, especially financial, sectoral shocks, and discretionary government policies are also relevant. Accompanied by a credit crunch, the first force highly leveraged firms into deleveraging while also lowering net worth and increasing uncertainty, which might lead to a slower recovery in the end. Similarly, sectoral shocks can exacerbate the conditional impact of output loss on the unemployment rate, especially for low-productivity sectors. To counterbalance these effects, the government normally plays a key role. Depending on the scope of intervention, this can also lead to a deviation from the expected change in the unemployment rate (IMF, 2010). Researchers study these time-variant properties of the OC by searching for possible structural breaks in three ways:

1. Dividing the time series into two periods whereby the break is normally (although not always) attributed to the advents of domestic or global economic crises. For example, while the older literature inspected the effects of oil shocks (Moosa, 1997), the last decade revolved around the shifts in the dynamics due to the Great Recession (Cazes, Verick & Al Hussami, 2013; Ball, Leigh & Loungani, 2013; Margirier, 2018).
2. Using rolling regression which estimates the OC using moving subsamples (or windows) of the time series with a predetermined length (Knotek, 2007; Owyang & Sekhposyan, 2012).
3. Employing econometric tests for structural breaks at an unknown date in the time series (Lee, 2000).

Albeit a break is frequently not recognized, studies show that the OL has not been a stable relationship. Moreover, it is also sensitive to the state of the business cycle. Some would even call it asymmetrical. In addition, the dynamics between unemployment and output may also shift. Indeed, even Okun (1962) hypothesized that "decisions on hiring labor for next quarter are strengthened by a high level of current output". Famously, this was formalized by Knotek (2007):

$$\Delta u_t = b_1 + b_2 rGDP_t + b_3 rGDP_{t-1} + b_4 rGDP_{t-2} + b_5 \Delta u_{t-1} + b_6 \Delta u_{t-2} \qquad (24)$$

In essence, the dynamic model is an extension of the first differences model whereby two lags of output growth and the change in the unemployment rate were included. While the reason for lagged output growth was stressed, past changes in the unemployment rate help with eliminating possible serial correlation in the error terms (Christl, Köppl-Turyna & Kucsera, 2017) and reflect the importance of rigidities and inertia in the labor market in leading to a gradual adjustment in the unemployment rate to output movements (Chamberlin, 2011).

3.2 Relevant Literature and Findings

An impactful paper by Paldam (1987) showed that apart from its robustness for all countries, the fall in the change of the unemployment rate is stretched across two years as a product of output growth in the first year. Furthermore, he concluded that countries with lower unemployment rates tended to have lower OC, which means a set decrease in the change of the unemployment rate requires higher output growth. Lastly, the OL applies particularly well to the United States whereby the lagged variable coefficients are relatively small. Likewise, from his estimations for six industrialized countries, Kaufman (1988) concluded that, overall, the response of employment to output growth is much quicker in North America in comparison to Europe or Japan (the lowest OC in the sample). In addition, North American countries and the UK have significantly larger employment elasticities in comparison to the latter two. He argues that this might be the result of stricter employment protection legislation. Albeit this does not follow from his estimates of the working hours' elasticity of output, above-average coefficients are indeed found for Germany and Sweden. On the topic of time variance, the estimates indicated two breaks at approximately the time of both oil price shocks in 1973 and 1979. Regarding North America and Japan, Moosa (1997) agreed with Kaufman (1988). A structural break relating to the first oil shock was attributed to three out of seven countries in the sample.

A decade later, Knotek (2007) further affirmed the time-variant property of the OC by using rolling regression on United States data from 1948 to 2007. The paper found a sudden decrease in the OC in 1984, a clear upward trend in the 1960s and 1970s, and a downward trend in the 1980s (see also Meyer & Tasci, 2012). Apart from searching for structural breaks in the OC, the author also questioned whether the term »jobless recoveries« holds any merit. In particular, the 1990-91 and 2001 recessions were associated with a slower unemployment decline despite output growth. As estimations suggest, this was due to the change in the dynamics of the OC. Specifically, the largest decline in the change of the unemployment rate was associated with output growth one quarter in the past.

On the other hand, Ball, Leigh and Loungani (2013) have found no evidence to support this premise. Accordingly, jobless recoveries are the result of below-normal output growth after recent recessions. Since sizable output gaps stretch farther into recovery, the decrease in the unemployment rate is also slower. The paper also opposes the existence of a correlation between the strictness of employment protection legislation and the size of the country's OC implied by IMF (2010). Still, cross-country heterogeneity and time variation were again confirmed. Another influential paper was prepared by Cazes, Verick and Al Hussami (2013) which looked at the shifts in the OC of different countries after the Great Recession in relation to the degree of internal or external adjustment. For example, while the United States and Spain saw a spike in the OC value due to a large fall in employment followed by a significant rise in productivity and working hours, the opposite happened in Germany and Japan.

4 DATA, METHODOLOGY AND EMPIRICAL RESULTS

4.1 Data

The subsequent data required for the regression analysis was gathered from the SORS (2022a), SORS (2022b), Eurostat (2022) and received from the Institute of Macroeconomic Analysis and Development (personal communication, November 16, 2022):

1. Gross Domestic Product (GDP) – constant prices, reference year 2010 (million EUR)
    a. 1995-2019, annual data
    b. 1999Q1-2019Q4, seasonally and calendar adjusted, quarterly data
2. ILO Unemployment Rate (u) – in percent
    a. 1995-2019, annual data
    b. 1999Q1-2019Q4, seasonally adjusted, quarterly data
3. Potential Gross Domestic Product (GDP^P) – constant prices, reference year 2010 (million EUR), 1995-2019, annual data
4. Non-Accelerating Wage Rate of Unemployment ($NAWRU$) – in percent, based on ILO Unemployment Rate, 1995-2019, annual data

As proposed by Foroni and Furlanetto (2022) to avoid distortions in the results due to the COVID-19 pandemic, the sample evaluation stops in 2019. Furthermore, to make use of the models proposed by Okun (1962) and Knotek (2007), changes in the unemployment rate (Δu) and output growth rates ($rGDP$) had to be calculated along with the unemployment (UG) and output (OG) gaps, utilizing (25) and (26).

$$\Delta u = u_t - u_{t-1} \qquad \text{and} \qquad rGDP = \left(\frac{GDP_t}{GDP_{t-1}}\right) * 100 - 100 \qquad (25)$$

$$UG = u_t - NAWRU \qquad \text{and} \qquad OG = \frac{(GDP_t - GDP_t^P)}{GDP_t} * 100 \qquad (26)$$

As shown in Table 1, the average annual potential and actual gross domestic product values are fairly close. Although the former is higher as intuitively expected (EUR 33,548 million), the latter has a higher standard deviation (EUR 5,842 million). The lowest and highest values of both correspond to years at the start and end of the observed period respectively whereby the output gap was negative in 1995 and positive in 2019. On the other hand, the average quarterly gross domestic product amounts to EUR 8,779 million while its highest value of EUR 11,050 million corresponds to 2019Q4. As regards the unemployment rate, the average of annual values is higher than the quarterly mean by 0.12 percentage points. The minimum annual unemployment rate was also higher than the quarterly rate (4.40 percent). On the contrary, its maximum value was lower (10.10 percent). In comparison to both, the NAWRU has a lower mean (6.06 percent) while also exhibiting a substantially smaller degree of variation (0.24 percent). Thus, its maximum value is equal to only 6.53 percent.

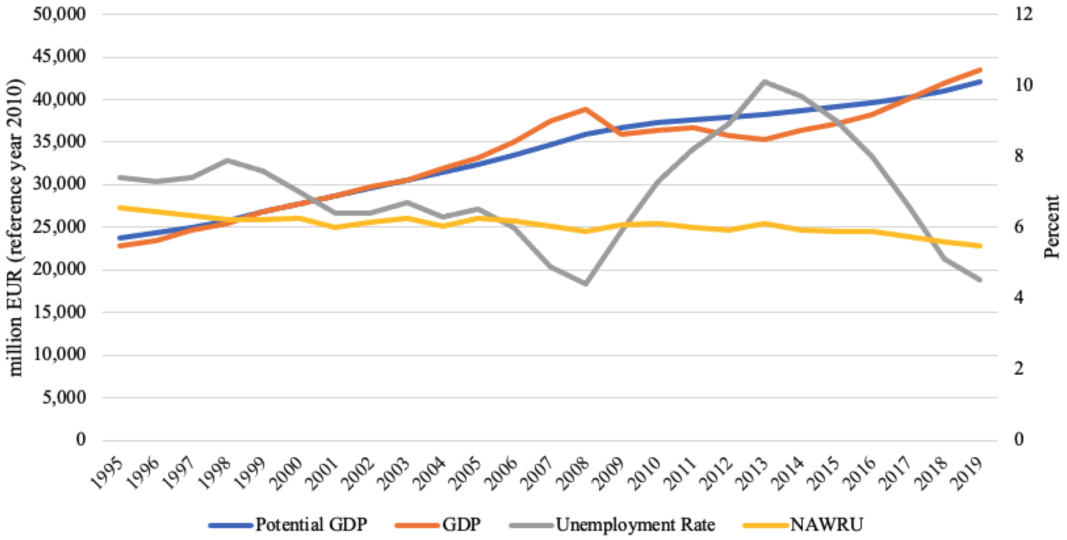
Table 1: Descriptive Statistics

Variable	Mean	St dev	Min	Max
Gross Domestic Product, annual	33,347	5,842	22,750	43,388
Gross Domestic Product, quarterly	8,779	1,118	6,542	11,050
ILO Unemployment Rate, annual	7.02	1.49	4.40	10.10
ILO Unemployment Rate, quarterly	6.90	1.68	4.00	11.10
Potential Gross Domestic Product	33,548	5,779	23,716	42,072
Non-Accelerating Wage Rate of Unemployment	6.06	0.24	5.49	6.53

Adapted from Eurostat (2022); Institute of Macroeconomic Analysis and Development (personal communication, November 16, 2022); SORS (2022a); SORS (2022b); own work.

Moving on to identifying possible patterns in our data, we can see a clear upward trend in the output variables over the observed period (see Figure 5). Indeed, GDP increased by 90.7 percent overall. A clear exception to the rule was the period 2008-2013 when Slovenia experienced a double dip or W-shaped recession. During those years, GDP fell from EUR 38,811 million to EUR 35,342 million. Of course, this also impacted its trend or potential value. Although it did not decrease, the compound annual growth rate fell from 3.21 percent during the pre-crisis years to 1.45 percent during the crisis and post-crisis periods.

Figure 5: Gross Domestic Product and Unemployment Rate with Trend Variables

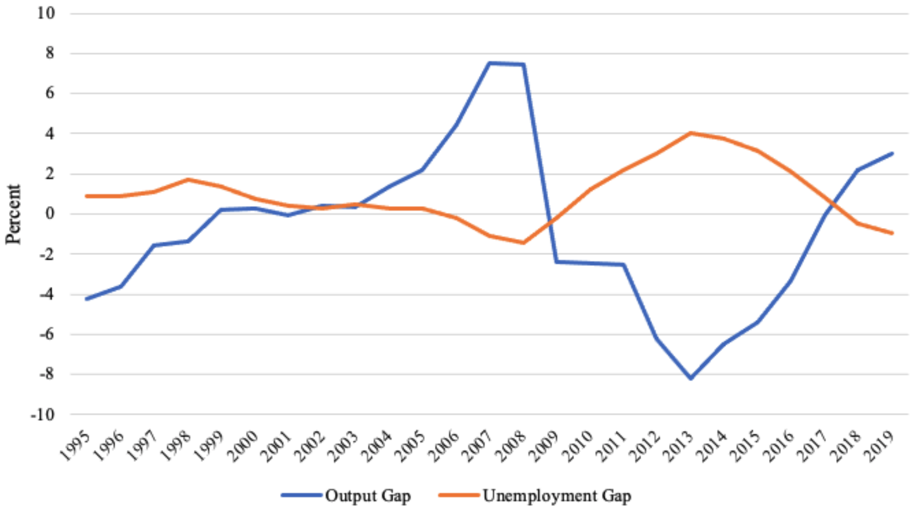


Note: Potential GDP and GDP values correspond to the left y-axis whereas Unemployment Rate and NAWRU values correspond to the right y-axis.

Adapted from Institute of Macroeconomic Analysis and Development (personal communication, November 16, 2022); SORS (2022a); own work.

As the OL predicts, the unemployment rate had broadly moved in line with output, albeit in the opposite direction. This relationship becomes evident after the unemployment rate started to decrease in 1999 continuing the downward trend until 2008 (from 7.9 percent to 4.4 percent). Afterward, it had risen precipitously in the crisis period and subsequently peaked at 10.1 percent in 2013. Then, it started falling again, reaching 4.5 percent at the end of the observed period. Contrary to potential output, NAWRU slightly decreased (from 6.5 percent to 5.5 percent) but stayed relatively stable during the observed period, even during the crisis years. The output-unemployment dynamic becomes even more apparent in Figure 6. Generally, it holds that positive output gaps are complemented by a reduction in positive unemployment gaps or even negative unemployment gaps like during the 2006-2008 and 2018-2019 periods and vice-versa. The unemployment gap also seems to be less responsive to expansionary periods than slumps. As expected, the largest positive output gap (7.54 percent) corresponds to the year before the start of the double-dip recession in Slovenia, and the largest negative output gap (8.17 percent) to the year preceding the recovery in 2014. The reverse also holds for the unemployment gap although it reached its low in 2008 (-1.47 percent).

Figure 6: Relationship between the Output Gap and Unemployment Gap



Adapted from Institute of Macroeconomic Analysis and Development (personal communication, November 16, 2022); SORS (2022a); own work.

4.2 Regression models and Interpretation

Due to the lack of data for GDP^P and $NAWRU$ values, solely annual data-based estimations will be provided for the gap models of the OL. Furthermore, the dynamic model with dummy variables will be measured using only quarterly data. More importantly, when considering annual data, changes in the unemployment rate and output growth rates will be calculated as shown in (25) while for quarterly data, changes in the unemployment rate will imply fourth differences and output growth rates the growth from the same period of the previous year. This follows the approach adopted by ECB (2011), ECB (2012) and Anderton, Aranki, Bonthuis and Jarvis (2014) because it yields a substantially better fit. Still, estimations based on first differences and quarterly output growth rates will be provided in Appendix 3. Unless indicated differently, p-values in the parentheses correspond to robust standard errors computed with the Newey-West estimator while robust F-statistics are computed using the Wald test.

Starting with the differences model, we first regress the change in the unemployment rate on output growth using both annual and quarterly data. For annual data, $b_2 = -0.20$ and is statistically significant, which means a percentage point increase in GDP growth will on average result in a decrease of approximately 0.20 percentage points in the change of the unemployment rate. Output growth corresponding to a zero change in the unemployment rate is equal to $\frac{0.43}{0.2} = 2.15$ percent. Furthermore, we can say that the variability in output growth explains 51.7 percent of the variability in the change of the unemployment rate while the estimated residual standard error is equal to 0.591 percentage points. For quarterly data, b_1 is lower, the estimated residual standard error is equal to 0.755 percentage points, and the model has a worse fit. The presence of heteroskedasticity was tested using the Breusch-Pagan test whereby we cannot reject the null hypothesis for both. On the contrary, both models suffered from some degree of autocorrelation which was tested using the Breusch-Godfrey test for AR(1) and AR(4), respectively.

Table 2: Results of the OLS method for the Differences model

$\Delta u_t = b_1 + b_2 rGDP_t$							
Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1995 - 2019	0.43 (0.006)	−0.20 (0.000)	0.517 (0.495)	0.591	44.16 (0.000)	0.012 (0.912)	5.321 (0.021)
1999Q1 - 2019Q4	0.36 (0.001)	−0.20 (0.000)	0.455 (0.448)	0.755	31.79 (0.000)	3.132 (0.071)	41.0 (0.000)

Source: own work.

Reversing the relationship, $b_2 = -2.60$ and is statistically significant, which means a percentage point increase in the change of the unemployment rate will on average lead to a decrease of 2.60 percentage points in GDP growth. Notice how the OC is significantly smaller than the value predicted by Okun (1962). Using his methodology, b_2 should be equal to $\frac{1}{-0.2} = -5$. The coefficient of determination is the same as in the previous model whereas the residual standard error was estimated at 2.139 percentage points.

Table 3: Results of the OLS method for the Reversed Differences model

$rGDP_t = b_1 + b_2 \Delta u_t$							
Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1995 - 2019	2.46 (0.000)	−2.60 (0.003)	0.517 (0.495)	2.139	11.14 (0.000)	5.26 (0.022)	0.93 (0.336)
1999Q1 - 2019Q4	2.18 (0.000)	−2.25 (0.000)	0.455 (0.448)	2.514	43.29 (0.000)	7.67 (0.006)	46.42 (0.000)

Source: own work.

For quarterly data, b_2 was lower in absolute terms which implies a lower responsiveness of output growth to the changes in the unemployment rate. Due to the presence of heteroskedasticity in the model with annual data, robust standard errors are computed using the Hubert-White estimator. Judging by the Breusch-Godfrey test for AR(1), the null hypothesis for the presence of autocorrelation cannot be rejected. Conversely, the model with quarterly data suffers from both heteroskedasticity and autocorrelation. The latter was estimated using the Breusch-Godfrey test for AR(4).

Accepting that the trend variables of output and unemployment vary over time, (18) will be estimated instead of (17). The model assumes a zero intercept since, theoretically, the two gaps must concurrently be zero. Nevertheless, in our estimations, the constant is statistically significantly different from zero. Therefore, to avoid risking a specification error, the constant was added to the model though it does not have a logical interpretation. If included, $b_2 = -0.32$ and is statistically significant, which means the unemployment gap will decrease by 0.32 percentage points, should the output gap increase by a percentage point on average. Additionally, we can say that the variability in the output gap explains 79.4 percent of the variability in the unemployment gap. The estimated residual standard error is equal to 0.671 percentage points. Looking at the Breusch-Pagan test, we can conclude that heteroskedasticity is not present in the model. On the other hand, the null hypothesis for the presence of autocorrelation can be rejected based on the Breusch-Godfrey test for AR(4).

Table 4: Results of the OLS method for the Modified Gap model

$UG_t = b_1 + b_2 OG_t$							
Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1995 - 2019	0.72 (0.000)	−0.32 (0.000)	0.794 (0.785)	0.671	36.39 (0.000)	1.88 (0.171)	10.12 (0.039)

Source: own work.

The reverse relationship between the gaps yields $b_2 = -2.45$ which is less but still close to the annual estimate of the OC for the differences model. The coefficient is statistically significant. If the unemployment gap rises by a percentage point, the output gap will decrease by 2.45 percentage points on average. The estimated residual standard error is equal to 1.845 percentage points. While the presence of homoskedasticity cannot be rejected, we can reject the null hypothesis for the presence of autocorrelation based on the Breusch-Godfrey test for AR(2).

Table 5: Results of the OLS method for the Reversed Modified Gap model

$OG_t = b_1 + b_2 UG_t$							
Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1995 - 2019	1.62 (0.014)	−2.45 (0.000)	0.794 (0.785)	1.845	83.65 (0.000)	2.76 (0.096)	6.52 (0.038)

Source: own work.

When the elasticity model is fitted to annual data, $b_2 = 0.182$ and is statistically significant, which means the employment rate will increase by 0.182 percent if GDP increases by one percent on average. The determination coefficient in the main regression model suggests 51.7 percent of the variability in the employment rate is explained by the movements in output. The estimated residual standard error is equal to 0.012 percent. For quarterly data,

b_2 and the determination coefficient are slightly higher. Lastly, both fits suffer from the presence of heteroskedasticity and autocorrelation based on the Breusch-Godfrey test for AR(4).

Table 6: Results of the OLS method for the Elasticity model

$$lnN_t = b_1 + b_2 lnGDP_t - b_3 t$$

Period	b_1	b_2	b_3	$R^2(\bar{R}^2)$	s_e	F
1995 - 2019	2.70 (0.000)	0.182 (0.000)	−0.004346 (0.000)	0.517 (0.495)	0.012	14.91 (0.000)
	BP	BG				
	10.96 (0.04)	20.25 (0.000)				
	b_1	b_2	b_3	$R^2(\bar{R}^2)$	s_e	F
1999Q1 - 2019Q4	2.45 (0.000)	0.235 (0.000)	−0.00127 (0.000)	0.527 (0.515)	0.013	27.93 (0.000)
	BP	BG				
	19.36 (0.000)	65.44 (0.000)				

Source: own work.

In an attempt to prove that Okun's intuition shown in Appendix 2 holds, we also estimated an auxiliary potential GDP growth regression model. Firstly, the time trend variable can explain 96.1 percent of the variability in potential GDP. Secondly, both parameters are statistically significant whereby $a_2 = 0.024$, which means that the potential GDP annual growth rate during the observed period is equal to 2.4 percent. Multiplying a_2 with b_2 should yield approximately b_3 which is true since $0.024 * 0.182 = 0.004368$.

Table 7: Results of the OLS method for the Auxiliary Potential GDP Growth model

$$lnGDP_t^P = a_1 + a_2 t$$

Period	a_1	a_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1995 - 2019	10.09 (0.000)	0.024 (0.000)	0.961 (0.959)	0.037	157.44 (0.000)	0.885 (0.347)	22.83 (0.000)

Source: own work.

Lastly, the estimated dynamic model with dummy variables corresponds to the one used in Kajzer, Hribernik, Perko and Selan (2013, p. 7) whereby the number of lags was chosen based on the AIC criterion and D_{Crisis} encompasses the period of the double-dip recession in Slovenia (2008Q1-2013Q4). Based on the estimates, ceteris paribus, a rise in the current GDP growth by a percentage point leads to a decrease in the current change of the unemployment rate by 0.081 percentage points during non-crisis years on average. The current change in the unemployment rate also seems to be statistically significantly determined by the change in the previous period. Should the change in the unemployment rate rise by a percentage point in the previous period ceteris paribus, the current change in the unemployment rate rises by 0.65 percentage points during non-crisis years on average.

Looking at the crisis period, the relationships meaningfully change whereby both GDP growth coefficients become statistically significant. The first one gains a positive sign and the second one has a much larger negative effect. To interpret the latter, should GDP growth increase by a percentage point in the previous period ceteris paribus, the current change in the unemployment rate decreases by an additional 0.16 percentage points during the crisis period in comparison to non-crisis years on average. If the change in the unemployment rate in the previous period also increases by a percentage point ceteris paribus, the current change in the unemployment rate rises by 0.33 percentage points during the crisis period on average.

Overall, the fit is much better in comparison to the simple contemporaneous differences model because movements in the regressors explain 78.2 percent of the variability in the current change of the unemployment rate. The presence of homoskedasticity cannot be rejected while autocorrelation is present based on the Breusch-Godfrey test for AR(4). We also tested for signs of multicollinearity with GVIF scores. Since all were smaller than 2, no serious problems are present in this regard.

Table 8: Results of the OLS method for the Dynamic Dummy model

$$\Delta u_t = b_1 + b_2 rGDP_t + b_3 rGDP_{t-1} + b_4 \Delta u_{t-1} + b_5 D_{Crisis} + b_6 rGDP_t D_{Crisis} + b_7 rGDP_{t-1} D_{Crisis} + b_8 \Delta u_{t-1} D_{Crisis}$$

Period	b_1	b_2	b_3	b_4	
1999Q1 - 2019Q4	0.11 (0.635)	−0.081 (0.008)	−0.002 (0.967)	0.65 (0.000)	
	b_5	b_6	b_7	b_8	
	0.42 (0.120)	0.13 (0.000)	−0.16 (0.000)	−0.32 (0.000)	
	$R^2(\bar{R}^2)$	s_e	F	BP	BG
	0.782 (0.761)	0.500	476.02 (0.000)	5.707 (0.574)	21.64 (0.000)

Source: own work.

CONCLUSION

Conceptually, the thesis is split in two, with a gradual shift from theory to practice. In the first half, the dynamics behind the OL were explained holistically with the help of three core macroeconomic models. In doing so, the otherwise complex phenomenon of macroeconomic fluctuations was presented in a relatively simple, yet systematic way. In essence, the labor, goods, and money markets are deeply intertwined because changes in one lead to movements in the other. Most importantly, the inverse relationship between output and unemployment was theoretically established. When inspecting the regression models included in Okun’s paper, two things should be noted regarding the value of the OC. Firstly, the inverse relationship should not be followed by an inverse of the OC but a new model, and secondly, its effect is substantially larger than predicted by the production function due to omitted variables. In the second half, the literature review suggested that the OC exhibits a certain degree of cross-country heterogeneity and time variance. This proved critical in forming the hypotheses which were tested in the last chapter.

The regression analysis proved that the relationship between output and unemployment in Slovenia is statistically significant across all four models, even though the differences and elasticity models fitted to our dataset yielded lower absolute values of OC than in the Okun's analysis. Namely, the OC for the differences model was equal to -0.2, while his estimation came out at -0.3. Furthermore, the OC of the elasticity model was equal to 0.182 for annual and 0.235 for quarterly data while his estimation was in the range of 0.35-0.40. Moving on, our analysis also showed that the current change in the unemployment rate follows its prior movements. This can be seen from the dynamic dummy model estimations whereby the regression coefficient of the first lag of the change in the unemployment rate is statistically significant and is equal to 0.65. Furthermore, there also exists a dynamic relationship between the current change in the unemployment rate and lagged output growth variables in Slovenia which became statistically significant during the double-dip recession. This can be inferred from the regression coefficient of the first lag of output growth multiplied by the dummy variable which is equal to -0.16. We can also conclude that the relationship changed during this period since the regression coefficient of the current output growth variable becomes positive and that of the lagged output growth becomes statistically significant. The relationship between the current change in the unemployment rate and its prior movements also becomes less positive.

To sum up, the OL is valid but shows signs of instability for Slovenia. Needless to say, there is a lot of room for future research on this topic. For example, the OL could be broken down by various demographics like gender or age whereby one could specifically look at youth unemployment rates in relation to others. Moreover, the OL could also be disaggregated by following the production function approach, although this might shorten the observed period due to data restrictions. Additionally, more estimations for the gap models would be preferable since the results are highly sensitive to the method of obtaining the trend variables.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Diplomsko delo je namenjeno preverbi veljavnosti ter stabilnosti Okunovega zakona za Slovenijo, k čemur pristopi karseda celostno. Temu primerno je strukturno razdeljeno na štiri poglavja, tematsko pa na dve polovici, pri čemer se prva nanaša na teoretični ter metodološki vidik problematike, ki jo druga dopolnjuje s prakso. Ker Okunov zakon v osnovi le formalizira povezavo med gospodarsko rastjo ter brezposelnostjo, se prvo poglavje osredotoča na obravnavo pojava makroekonomskih nihanj preko uporabe treh sodobnih modelov, ki med seboj povezujejo trg dela, denarja ter proizvoda, upoštevaje nominalno rigidnost ter nepopolno konkurenco. Prvi je predstavljen s pomočjo krivulj postavljanja plač in cen, kjer ključno vlogo pri doseganju ravnotežne realne plače igrata pogajalska moč ter višina marže podjetij. Poleg tega je kompenzacija odvisna tudi od inflacijskih pričakovanj, ki se konkretizirajo v pogodbenih razmerjih. Na drugi strani se dinamika na trgu proizvoda prikazuje s Keynesianskim križem, naposled prevedenim v krivuljo investicij in varčevanja.

V splošnem velja med višino obrestnih mer ter količino potrošnje obratna povezava. Ob nižjih obrestnih merah večja količina potrošnje rezultira v večjem obsegu proizvodnje, kar ob večjem dohodku proizvodnih dejavnikov še bolj spodbuja potrošno aktivnost. V tem primeru torej prihaja do multiplikativnih učinkov. Analiza je dopolnjena z denarnim trgom, ki določa višino omenjene obrestne mere. Njegovo delovanje lahko razumemo kot posledico likvidnostnih preferenc ter odločitev posameznikov v odnosu do ponudbe denarja s strani centralne banke. Razmerje prikazuje krivulja likvidnostne preference ter ponudbe denarja. V kolikor združimo slednjo ter prej omenjeno krivuljo investicij ter varčevanja, lahko iz njunih presečišč izpeljemo krivuljo agregatnega povpraševanja, ki povezuje gospodarsko aktivnost ter raven cen. Druga silnica makroekonomskih nihanj je krivulja agregatne ponudbe, ki jo lahko izpeljemo iz Phillipsove krivulje, tj. formalizacija povezave med gibanjem plač in brezposelnostjo, naposled pa cen ter brezposelnostjo in Okunovega zakona, saj ta v enačbo vnese člen gospodarske aktivnosti.

Za razliko od povpraševanja ponudba prikazuje pozitivno povezavo med cenami ter gospodarsko aktivnostjo. Njuna skupna obravnava je sicer zajeta v modelu krivulj ponudbe ter povpraševanja, ki gospodarstvo razdeli na kratek in dolg rok, temu pa konceptualno sledi tudi krivulja ponudbe. Na področju pod ravnjo potencialne gospodarske aktivnosti je ta na kratek rok zelo položna, medtem ko njeno preseganje postopoma vodi v hude cenovne pritiske. Ponudba tukaj stežka ustreže dodatnemu povpraševanju, kar se poglavitno odraža le v višjih cenah. Tudi brezposelnost v tem primeru težko postane nižja od lastne naravne stopnje, sestavljene iz frikcijske ter strukturne brezposelnosti. Na drugi strani se v primeru negativne proizvodne vrzeli povečano povpraševanje močneje odraža v znižanju cikličnega dela brezposelnosti in zgolj neznatnemu pritisku na cene. Poleg tega naj odpuščanja, v primeru recesije, ne bi bila primarni kanal zniževanja stroškov podjetij. Razlogi stojijo v stroških uvajanja, morali, transakcijskih stroških ter striktnosti pogodbenih razmerij. Potemtakem naj bi se na začetku prilagoditvene spremembe izvajale preko zmanjševanja produktivnosti in delovnih ur.

Povezavo med gospodarsko rastjo ter brezposelnostjo je prvi kvantificiral Okun (1962) na podatkih za Združene države Amerike. V svoji raziskavi je predstavil tri različne regresijske modele, pri čemer je z vsemi prišel do približno enakih rezultatov. Ti so predmet drugega poglavja. Omeniti je treba še, da se je želel s svojim raziskovanjem dokopati do metode, s katero bi lahko ocenil raven potencialne gospodarske aktivnosti na podlagi tekoče stopnje brezposelnosti ob predpostavki, da je njena naravna stopnja enaka štirim odstotkom. Ob tem je sicer naletel na dve metodološki napaki, ki sta v analizi za Slovenijo upoštevani. Kasneje je Prachowny (1993) pokazal, da s pripadajočimi modeli ne upoštevamo vseh merodajnih spremenljivk, kot so produktivnost, delovne ure ter ponudba dela, kar se odraža v visokem regresijskem koeficientu spremembe brezposelnosti kot neodvisne spremenljivke. Za referenčno vrednost se pri tem sklicuje na vrednost proizvodne elastičnosti dela v Cobb-Douglasovi produkcijski funkciji.

Tretje poglavje vsebuje širši pregled literature, ki potrjuje, da Okunov zakon velja skorajda povsod (povezava med gospodarsko aktivnostjo ter brezposelnostjo je statistično značilna), vendar pa je njegova stabilnost vprašljiva. Natančneje, večina raziskav potrjuje domnevo, da se njegova vrednost v času spreminja, še posebej v povezavi s pomembnimi ekonomskimi dogodki, kot so gospodarske krize. IMF (2010) na primer trdi, da bi bila lahko časovna variabilnost zlasti posledica finančnih kriz, panožnih šokov ter diskrecijskih ekonomskih politik, medtem ko Knotek (2007) izpostavlja, da bi bila lahko tovrstna spremenljivost povezana s poslovnim ciklom. Vrednost koeficienta se sicer razlikuje tudi med državami, pri čemer naj bi bili pomembni dejavniki striktnost zakonodaje o varnosti zaposlitve, velikost nadomestil za brezposelnost, razširjenost pogodb o zaposlitvi za določen čas ter sistemi postavljanja plač. V splošnem sledi, da imajo države z bolj rigidnim trgom dela navadno nižje koeficiente. V praksi se velikokrat pojavlja primerjava med Severno Ameriko ter Evropo in Japonsko, čeprav se je v novejših raziskavah tovrstna ločnica zabrisala.

Za potrebe regresijske analize, predstavljene v četrtem poglavju, so bile postavljene tri hipoteze. Predpostavljali smo, da Okunov zakon za Slovenijo velja neodvisno od uporabljenega regresijskega modela, čeprav se vrednost koeficienta po vsej verjetnosti razlikuje od Okunove. Domnevali smo tudi, da obstaja statistično značilna povezava med trenutno spremembo stopnje brezposelnosti ter predhodno stopnjo gospodarske rasti, pri čemer sprememba stopnje brezposelnosti sledi predhodnemu trendu rasti. Kot zadnjo smo predpostavljali spremembo v dinamiki v obdobju finančne in bančne krize med letoma 2008 in 2013 napram nekriznim letom. Izkazalo se je, da naših hipotez ne moremo zavrniti. Okunov zakon je bil v vseh primerih veljaven, vendar je imel v primeru dveh modelov rahlo nižje vrednosti. Poleg tega je skozi celotno obdobje trenutna sprememba stopnje brezposelnosti sledila predhodnim vrednostim. Če se je v predhodni periodi povečala, se je v trenutni prav tako. V obdobju dveh kriz se je dinamika rahlo spremenila. Trenutna sprememba stopnje brezposelnosti je postala statistično značilno povezana z gospodarsko rastjo v predhodni periodi, zmanjšalo pa se je tudi trendno povečanje v trenutni spremembi stopnje brezposelnosti v povezavi s predhodnim.

Appendix 2: Derivation of the Elasticity model

There exists a constant elasticity relationship between the ratio of actual (GNP) to potential output (GNP^P) and likewise the employment rate (N) as a fraction of its potential level (N^P) where $N = 100 - u$ (Okun, 1962).

$$\frac{N_t}{N_t^P} = \left(\frac{GNP_t}{GNP_t^P}\right)^{\varepsilon} \tag{27}$$

We assume a constant growth rate (r) of GNP^P starting from some level such that at time t:

$$GNP_t^P = GNP_0^P e^{rt} \tag{28}$$

The result of subsequent substitution and rearrangement results in (29):

$$N_t = \frac{GNP_t^{\varepsilon} N_t^P}{(GNP_0^P e^{rt})^{\varepsilon}} \tag{29}$$

Okun (1962) also took the logarithm of the equation to get a linear relationship between the variables. From it, we can see that the logarithm of N is related to the logarithm of GNP and a time trend (t) (see Equation 30).

$$lnN_t = ln\left(\frac{N_t^P}{GNP_0^{P\varepsilon}}\right) + \varepsilon\, lnGNP_t - (\varepsilon r)t \tag{30}$$

The term ε claims the role of the first partial regression coefficient (b_2) in (19) and can be interpreted as the employment elasticity, which means the percentage change in N associated with a percentage change in GNP. This can also be formally shown by differentiating both sides of the equation and solving for $\frac{\partial N}{\partial GNP}$ (Kapsos, 2006, p. 3):

$$\left(\frac{\partial N}{N}\right) = \varepsilon\left(\frac{\partial GNP}{GNP}\right) \Rightarrow \left(\frac{\partial N}{\partial GNP}\right)\left(\frac{GNP}{N}\right) = \varepsilon \tag{31}$$

To understand the formalization, one has to make use of calculus from which we know that $(lnx_t - lnx_{t-1}) \approx (x_t - x_{t-1})/x_{t-1}$ is the relative change in x while the same can be said for the dependent variable (Gujarati & Porter, 2009, p. 160). On the other hand, the second partial regression coefficient (b_3) of the time trend is simply the product of elasticity ε and r. The latter can be estimated by regressing the logarithm of GNP^Pon t (Wooldridge, 2012, p. 365):

$$lnGNP_t^P = a_1 + a_2 t \tag{32}$$

where a_2 is the estimated r and multiplying it by ε should yield an approximate value of b_3.

Appendix 3: Results of the OLS method using Quarterly Changes

Table 1: Results of the OLS method for the Differences model

$$\Delta u_t = b_1 + b_2 rGDP_t$$

Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1999Q1 - 2019Q4	0.02 (0.691)	−0.10 (0.010)	0.043 (0.031)	0.611	7.01 (0.010)	0.077 (0.781)	26.63 (0.000)

Source: own work.

Table 2: Results of the OLS method for the Reversed Differences model

$$rGDP_t = b_1 + b_2 \Delta u_t$$

Period	b_1	b_2	$R^2(\bar{R}^2)$	s_e	F	BP	BG
1999Q1 - 2019Q4	0.62 (0.000)	−0.42 (0.061)	0.043 (0.031)	1.245	3.61 (0.061)	1.36 (0.243)	7.19 (0.120)

Source: own work.

Table 3: Results of the OLS method for the Dynamic Dummy model

$$\Delta u_t = b_1 + \sum_{i=0}^{4} \hat{\gamma}_i rGDP_{t-i} + \sum_{i=1}^{4} \hat{\delta}_i \Delta u_{t-i} + b_2 D_{Crisis} + \sum_{i=0}^{4} \hat{\theta}_i rGDP_{t-i} D_{Crisis} + \sum_{i=1}^{4} \hat{\sigma}_i \Delta u_{t-i} D_{Crisis}$$

Period				
1999Q1 - 2019Q4	b_1	b_2	$\hat{\gamma}_0$	$\hat{\gamma}_1$
	0.15 (0.410)	0.18 (0.386)	−0.16 (0.060)	−0.14 (0.040)
	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$	$\hat{\delta}_1$
	−0.07 (0.356)	0.03 (0.699)	0.02 (0.646)	−0.29 (0.010)
	$\hat{\delta}_2$	$\hat{\delta}_3$	$\hat{\delta}_4$	$\hat{\theta}_0$
	−0.24 (0.029)	−0.10 (0.246)	0.50 (0.000)	0.27 (0.004)
	$\hat{\theta}_1$	$\hat{\theta}_2$	$\hat{\theta}_3$	$\hat{\theta}_4$
	−0.16 (0.117)	0.14 (0.265)	−0.14 (0.181)	−0.11 (0.144)
	$\hat{\sigma}_1$	$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
	0.1 (0.673)	−0.26 (0.195)	−0.23 (0.249)	−0.27 (0.153)
	$R^2(\bar{R}^2)$	s_e / F	BP	BG
	0.576 (0.440)	0.475 / 131.2 (0.000)	16.99 (0.591)	9.91 (0.043)

Source: own work.