Analysis of economic growth in Germany

based on the growth models of

Solow-Swan, Kaldor and Romer

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Declaration

I declare that this thesis is the result of my own research except as cited in the references. The thesis has not been submitted for a degree at any other tertiary education institution.

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Abstract

This thesis analyses West Germany’s economic growth from 1971 to 1990 and the economic growth of the reunited Germany from 1992 to 2011 using the growth models of Solow (1956) - Swan (1956), Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) and Romer (1986).

Applying the Solow (1956) - Swan (1956) model, it was found that TFP growth was the main driver of Germany’s growth during both time periods. However, Germany’s economic growth after the reunification was significantly weaker than it had been before the reunification, mainly because TFP growth and capital accumulation was lower. The findings of this thesis also show that fluctuations in TFP can be explained by the propositions put forward by the Real Business Cycle theory. The German’s experience based on the both periods of study is consistent with the analysis found in Plosser (1989) in that there is a positive relationship between GDP growth and TFP growth.

The application of the technical progress function of Kaldor and Mirrlees (1962) suggested that Germany experienced more technical progress during the second
time period than during the first one. For the reunited Germany capital accumulation contributed 0.68 to every one percent increase in RGDP, whereas for West Germany it contributed 0.44 to every one percent increase in RGDP. The regression (Kaldor’s technical progress function) results suggested that lower TFP growth for the second time period was due to lower capital investments. In addition, it was found that West Germany’s production process from 1971 to 1990 was slightly more capital intensive than the production process of Germany from 1992 to 2011.

The thesis also tested Kaldor’s (1966) three growth laws on the growth experience of the reunited Germany. It was found that only the first proposition was confirmed, suggesting that the manufacturing sector was the driver of Germany’s economic growth. No evidence was found for Kaldor’s (1966) second and third propositions.

The application of Romer’s (1986) growth model was unsuccessful. Neither the use of the number of patents granted, R&D expenditure or R&D personnel as a proxy for knowledge did show a statistically significant relationship with TFP growth or with the evolution of the net capital stock. Therefore, it is concluded that in Germany knowledge accumulation does not lead to technological progress
or capital accumulation. If the number of patents granted, R&D expenditure or
R&D personnel did not played a positive impact on TFP growth, then what is a
significant sector? One such sector could be ”learning-by-doing” as proposed by
Arrow (1962).
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### List of Acronyms

#### Solow-Swan model

- $A_t$: the stance of technology at time period $t$
- $g$: the rate of technological progress
- $K_t$: Capital input in time period $t$
- $L_t$: Labour input in time period $t$
- $n$: the labour growth rate
- $r$: the capital to labour ratio ($\frac{K_t}{L_t}$)
- $s$: the marginal propensity to save
- $y$: the economic growth rate
- $Y_t$: Output in time period $Y$
- $\alpha$: the share of capital
- $\beta$: the share of labour

#### Kaldor’s model

- $h$: the time period within investment costs must be recovered
- $I_t$: investments in time period $t$
- $i_t$: the amount of investment per worker on machine in time period $t$
\( l \) the amount of past periods an entrepreneur uses to form his wage expectations

\( n_t \) the amount of workers available to operate new equipment in time period \( t \)

\( N_t \) the size of the labour force in time period \( t \)

\( p_t \) productivity in time period \( t \)

\( r_t \) the amount of workers available to operate new equipment to the size of the labour force ratio \( \left( \frac{n_t}{N_t} \right) \)

\( s_t \) the share of profits being saved in time period \( t \)

\( T \) the period of obsolescence of equipment

\( w_t \) wages in time period \( t \)

\( w_t^* \) expected wages in time period \( t \)

\( v \) the expected growth rate of wages

\( y_t \) output per head at time \( t \)

\( \rho \) the entrepreneurs estimation of the opportunity cost

\( \pi_t \) share of profits in time period \( t \)

\( \delta \) the radioactive physical depreciation rate

\( \lambda \) the population growth rate

**Romer’s model**

\( c_t \) the consumption at time \( t \)

\( c_t^* \) the optimal path of consumption

\( H \) Hamiltonian

\( k_t \) the firm-specific knowledge at time \( t \)

\( k_t^* \) the optimal path of knowledge

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\( K_t \) the economy wide aggregate knowledge at time \( t \)
\( S_t \) the amount of consumers at time \( t \)
\( x_t \) an aggregation of all labour and capital at time \( t \)
\( \lambda \) costate variable
\( \delta \) the discount rate of the utility function

**Empirical Analysis**

\( i_t \) the inflation rate at time \( t \)
\( I_t \) the gross fixed capital formation at time \( t \)
\( \dot{K}_t \) the gross capital stock in prices of 2000 at time \( t \)
\( K^*_t \) the gross capital stock in current prices of time \( t \)
\( \bar{K}_t \) the gross capital stock in prices of 2005 at time \( t \)
\( 
\dot{K}_t \) the change rate of the net capital stock at time \( t \)
\( K_t \) the net capital stock at time \( t \)
\( \hat{P}_{2000} \) the price index in prices of 2000
\( P_{2005} \) the price index in prices of 2005
Chapter 1: Introduction

1.1 Aim of the thesis

This thesis aims to analyse West Germany’s economic growth from 1971 to 1990 and Germany’s economic growth from 1992 to 2011 using the Solow (1956) - Swan (1956), Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) and Romer (1986) growth models.

Germany is an interesting country to analyse in terms of economic growth. After the second world war it was divided into two countries: The capitalist Federal Republic of Germany (West Germany) and the socialist German Democratic Republic (East Germany). While East Germany experienced little growth, West Germany, on the other hand, was a highly growing, wealthy and prosperous country. After both German countries reunited in 1990 the economic growth performance was poor. This was of little surprise. The long division and the different political and economic systems resulted in both countries being very different in numerous
aspects, including their economic development (Fulbrook 2004). The empirical analysis conducted in this thesis will shed further light into these two very different growth experiences.

The Solow (1956) - Swan (1956) growth model is an excellent framework to analyse Germany’s economic growth under the assumption of constant returns to scale. The model allows to decompose and trace Germany’s economic growth into growth coming from technological progress or factor accumulation (labour and capital stock). This is important because only economic growth that is propelled by technological progress is the type of growth that will be sustainable in the long-run (Solow 1956; Swan 1956; Kaldor 1957; Kaldor and Mirrlees 1962). In contrast, economic growth being derived from factor accumulation (increasing labour and capital inputs) is only a temporary phenomenon, because once the capital to labour ratio is in unity or steady state, diminishing returns will set in (Solow 1956; Swan 1956).

Applying the Solow (1956) - Swan (1956) growth framework to Germany, it is possible to derive which factors contributed positively or negatively to Germany’s economic growth. The application of the Solow (1956) - Swan (1956) model will also demonstrate how West Germany’s economic growth from 1971 to 1990 was
different to the one of Germany from 1992 to 2011. Special attention will be paid to the size of the contribution of technological progress in order to assess whether Germany’s economic growth is sustainable.

Technological change as captured by the Solow (1956) - Swan (1956) model has recently been applied by the Real Business Cycle (RBC) theory to explain fluctuations over the business cycle (Long and Plosser 1983; Prescott 1986). This thesis will run a simple regression in order to test whether the RBC theory holds for the German growth experience.

While technological progress is the key to long-run economic growth, according to the Solow (1956) - Swan (1956) growth model, the model itself does not offer an explanation of the causes of technological progress. This is not satisfactory for policy makers, who need to find out what is driving technological progress. Because of its inability to explain technological progress, the model of Solow (1956) and Swan (1956) is sometimes called an exogenous economic growth model. The growth model of Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) on the other hand is an endogenous growth model which embodies technological progress into capital accumulation. Specifically, it assumes that there is a constant stream of new ideas and the integration of these new ideas is determined through
the rate of investment. This concept is described by Kaldor’s technical progress function (Kaldor and Mirrlees 1962).

Kaldor (1966) also provided three growth propositions. These propositions argue that the manufacturing industry plays a crucial role for economic growth. The reasoning is that the manufacturing sector with its capital intensive production techniques offers a wide range of possibilities for technological progress to occur, leading the manufacturing sector to be subject to increasing returns to scale. According to Kaldor (1966), the increasing returns to scale of the manufacturing sector drive the economic growth of the whole economy.

The empirical analysis of this thesis will include estimations of the technical progress function proposed by Kaldor and Mirrlees (1962) for both West Germany and for the reunited Germany. In addition, Kaldor’s (1966) growth propositions will be tested on the reunited Germany. This is useful because the application of Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model provides additional insights on Germany’s growth experience.

The growth model of Romer (1986) is another endogenous growth model. It is also the first type of the new growth theories. In contrast to previous growth
theories Romer (1986) suggests that there are increasing returns to scale in the whole economy. Romer (1986) also equipped his model with microeconomic foundations in order to overcome weaknesses associated with both the Solow (1956) - Swan (1956) and the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) growth model.

To endogenize technological progress Romer (1986) argued that the accumulation of knowledge is the key to economic growth, because the discovery of new knowledge enables firms to produce a better and more productive capital stock. Hence, like the model of Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966), the Romer (1986) model is another attempt to embody technological progress into capital. A further crucial aspect of the Romer (1986) model is the assumption that knowledge is an externality. New knowledge cannot be kept secret to a full extent and unavoidably spills over to other companies. This implies that firms conduct too little research because they speculate to benefit from the research conducted by other firms. Therefore, the growth model of Romer (1986) predicts a Pareto inefficient outcome because the economy does not grow as strongly as it could since firms fail to invest the Pareto optimal level of resources into knowledge accumulation. In light of the analysis of Romer (1986) this thesis will attempt to determine the relationship of knowledge accumulation to technological progress.
and the capital stock.

In summary, the objective of this thesis is to look at the following questions: According to Solow (1956) and Swan (1956), where did West Germany’s economic growth from 1971 to 1990 come from? Was this growth sustainable? And what about the growth experience of the reunited Germany from 1992 to 2011? What are the differences to West Germany’s growth experience? And do the estimated rates of technological change explain the West Germany’s and Germany’s business cycles, as proposed by the Real Business Cycle theory?

According to Kaldor and Mirrlees (1962), how strong was technical progress in West Germany and in the reunited Germany? How capital intensive was the production in both periods? Do the three growth propositions of Kaldor (1966) fit the growth experience of Germany from 1992 to 2011?

And lastly, does Romer’s (1986) analysis explain Germany’s technological progress after the reunification?

1.2 Structure

To answer these questions, this thesis is structured in the following order: Chapter 2 provides the theoretical foundations by offering a detailed explanation of the three relevant growth models. Chapter 3 presents information on Germany’s
post-war political history, the economic development of West Germany from 1945 to 1970 and a trend analysis for the time period of 1971 to 1990 and one for the time period of 1992 to 2011. In addition, Chapter 3 includes a brief summary of the economic implementation of the reunification. The empirical analysis and a discussion of the results can be found in Chapter 4. Chapter 4 also provides information on the relevant data sources and on any data refinements that were necessary. Lastly, Chapter 5 gives a summary of the findings and concluding remarks. Appendix A provides information on the curvature of production functions and Appendix B shows how the net capital stock was derived.
Chapter 2: Theoretical Framework of Study

2.1 Introduction

In order to achieve long-run sustainable economic growth, output growth of a country must be driven by technological progress. Technological progress allows a country to produce more output with the same amount of input (Solow 1956; Swan 1956; Kaldor 1957; Kaldor and Mirrlees 1962). In contrast, economic growth which is entirely based on factor accumulation will only lead to short-run growth, because such growth is subject to diminishing returns (Solow 1956; Swan 1956). In order to understand the importance of technological progress as the driver of long-run economic growth it is appropriate to start with the building blocks of the Solow (1956) - Swan (1956) growth framework.
2.2 The Solow-Swan growth model

The Solow (1956) - Swan (1956) growth model, which is also called the neoclassical model of economic growth, was developed independently by Robert Solow and Trevor Swan in 1956. Solow’s (1956) motivation was to challenge the Harrod (1939) - Domar (1946) growth model, which is based on the assumption that production takes place under conditions of fixed proportions, without allowing the possibility to substitute labour for capital in production. This assumption is a crucial one because it leads to the model’s conclusion that a healthy economy has to have a balance between the natural rate of growth, which depends on the increase in the labour force, and the warranted rate of growth, which depends on the saving and investment behaviour of households and firms. This balance is very sensitive and a slight change in the key parameters (the savings ratio, the capital-output ratio and the rate of increase of the labour force) can lead to a disproportion causing unemployment or inflation. Solow (1956) stressed that a model which derives its main conclusion from such a questionable assumption can only be rejected. However, Solow (1956) did support the other assumptions which are made by the Harrod (1939) - Domar (1946) model. Thus Solow (1956) proposed a model, which analyses long-run economic growth using all the assumptions of the Harrod (1939) - Domar (1946) model, except the one of fixed proportions.
The aim of Swan (1956), on the other hand, was to contribute to our understanding of the relationship between capital accumulation and the growth of the productive labour force. As Swan (1956) pointed out, this had been subject to extensive research by various famous economists (Smith, Mill, Lewis and Ricardo). Yet, neoclassical economists have not been able to contribute an explanation of this relationship, even though productivity and saving are central components of the neoclassical school of thought. Swan (1956) hoped to provide some insights with his paper.

Solow (1956) and Swan (1956) derived the same model in their articles. While they did follow different approaches to build them, they made the same assumptions and came to the same implications. The following sections describe the model’s assumptions and its dynamics.

2.2.1 Assumptions

The assumptions of the Solow (1956) - Swan (1956) model can be classified in assumptions about outputs and inputs and in assumption about the production function.
2.2.1.1 Assumption concerning outputs and inputs

The model focuses on four variables: Output \((Y)\), capital \((K)\), labour \((L)\) and technology \((A)\). Output refers to net output, meaning that depreciation of capital is deducted. Both Solow (1956) and Swan (1956) assumed that output is either consumed, or saved and invested. The amount which is saved and invested is added to the capital stock, which is assumed to be fully employed (Solow 1956; Swan 1956). Solow (1956) expressed the annual increase of the net capital stock as

\[
\dot{K} = sY_t
\]  

(2.1)

where the dot on \(\dot{K}\) indicates that \(K\) is differentiated with respect to time and \(s\) is the marginal propensity to save. Swan (1956) expressed the annual increase of the capital stock as a relative rate:

\[
k = s \frac{Y}{K}
\]  

(2.2)

where \(k\) is the annual growth rate of capital in per cent (Swan 1956).

The model follows the neoclassical approach to assume full employment and the labour force is assumed to increase at a constant rate \(n\) (Solow 1956; Swan 1956).
Solow (1956) expressed labour growth as:

\[ L_t = L_0 e^{nt} \]  \hspace{1cm} (2.3)

Solow (1956) pointed out that Equation 2.3 can also be referred to as a perfectly inelastic labour supply curve. If the labour supply changes, the wage rate adjusts accordingly, ensuring that all labour is employed (Solow 1956).

Like the labour growth rate, the rate of technological change is assumed to be constant and it is expressed by \( g \) (Solow 1956; Swan 1956). Solow (1956) described the stance of technology using the following equation:

\[ A_t = e^{gt} \]  \hspace{1cm} (2.4)

### 2.2.1.2 Assumptions concerning the production function

The model specifies that a combination of capital, labour and technology creates output (Solow 1956; Swan 1956). Both Solow (1956) and Swan (1956) used the Cobb-Douglas production function to formalise this. Yet, Solow (1956) first introduced his model using an unspecified production function, as this allowed him to demonstrate the model’s general characteristics first. Solow (1956) expressed the
production function as

\[ Y = f(K, L), \quad (2.5) \]

In contrast, Swan (1956) used the Cobb-Douglas production function right from the start and wrote:

\[ Y = K^\alpha L^\beta \quad (2.6) \]

where \( \alpha \) is the share of capital and \( \beta \) is the share of labour. Technological change is ignored in both of these formulations, but it will be introduced later (Solow 1956; Swan 1956).

A crucial assumption of the model is that production has constant returns to scale in its two factors, capital and labour. Thus, \( \alpha + \beta = 1 \). Constant returns to scale means that when labour and capital inputs are increased by the factor \( \lambda \), output also increases by \( \lambda \). This is illustrated with the following equation (Solow 1956; Swan 1956):

\[ f(\lambda K_t, \lambda L_t) = \lambda Y_t \quad (2.7) \]

One implication is that there are no scarce non-augmentable resources in the neoclassical growth model. An example of such a resource is land, which once fully developed, cannot be increased. Allowing for non-augmentable resources would lead to decreasing returns to scale in capital and labour, which was one of the
fundamental assumptions in Ricardo’s model (Solow 1956).

Furthermore, it is assumed that the marginal productivity of both capital and labour is positive, but it is diminishing (Solow 1956; Swan 1956). Therefore, the first derivative of output with respect to capital and labour is positive, whereas the second derivative is negative:

\[
\frac{dY}{dK} > 0, \quad \text{and} \quad \frac{d^2Y}{dK^2} < 0 \quad (2.8)
\]

\[
\frac{dY}{dL} > 0, \quad \text{and} \quad \frac{d^2Y}{dL^2} < 0 \quad (2.9)
\]

Positive marginal productivity of capital and labour means that as capital or labour increases, output increases. However, because of diminishing marginal productivities, it increases at a decreasing rate. Figure 2.1 illustrates this assumption using the example of how output evolves when capital keeps increasing:
Figure 2.1: The Solow-Swan production function

Figure 2.1 shows that while output keeps increasing with an increasing capital-labour ratio, the increase in output becomes smaller. Thus, the production function follows a strictly concave type (see Appendix A).

2.2.2 Dynamics of the model

Solow (1956) and Swan (1956) followed different mathematical approaches to build their models and both ways are outlined in the following. First, it looks at how the model is being derived under the assumption of no technological change and
then it shows how it is adjusted when technological change is introduced.

2.2.2.1 The basic model without technological change

Solow (1956) first defined both $K$ and $L$. The values of $K$ and $L$ can then be used to determine the output $Y$ (after specifying the production function).

In order to determine the accumulation of the capital stock, Solow (1956) substituted his savings function (Equation 2.1) and his labour function (Equation 2.3) into his production function (Equation 2.5) to derive the following:

$$\dot{K} = sf(K, L_0 e^{nt}).$$ \hspace{1cm} (2.10)

The solution to Equation 2.10 gives the only values of $K$ which fully employ the capital stock (Solow 1956).

Next, Solow (1956) derived the time path of labour which is consistent with the one of capital. Solow (1956) defined $r$ as the ratio of capital to labour, $r = \frac{K}{L}$. Employing Equation 2.3, Solow (1956) expressed the capital stock in terms of labour growth: $K = rL = rL_0 e^{nt}$. Differentiating $K$ with respect to time by using both the product rule and the rule for differentiating exponents Solow (1956)
derived:

\[ \dot{K} = \left( \frac{d}{dt} \times L_0 e^{nt} \right) + (r \times nL_0e^{nt}) \quad (2.11) \]

\[ = \dot{r}L_0e^{nt} + rnL_0e^{nt} \quad (2.12) \]

Equations 2.10 and 2.12 both describe \( \dot{K} \). Equalising them Solow (1956) obtained:

\[ sf(K, L_0e^{nt}) = \dot{r}L_0e^{nt} + rnL_0e^{nt} \quad (2.13) \]

\[ sf(K, L_0e^{nt}) = (\dot{r} + nr)L_0e^{nt} \quad (2.14) \]

Equation 2.14 is further simplified by dividing both variables in \( f \) by \( L = L_0e^{nt} \) and by multiplying \( f \) with the same factor (Solow 1956):

\[ sL_0e^{nt}f(K, L_0e^{nt}, 1) = (\dot{r} + nr)L_0e^{nt} \quad (2.15) \]

Next, Solow (1956) divided both sides of Equation 2.15 with the common factor \( L_0e^{nt} \):

\[ sf\left( \frac{K}{L_0e^{nt}}, 1 \right) = \dot{r} + nr \quad (2.16) \]

Finally, by substituting \( r \) for \( \frac{K}{L_0e^{nt}} \) and by rearranging, Solow (1956) turns Equa-
tion 2.16 into his final equation:

\[
\dot{r} = sf(r, 1) - nr
\]  

(2.17)

The value \( \dot{r} \) gives the rate of change of the capital-labour ratio. It depends on the difference of \( sf(r, 1) \) and \( nr \). The function \( f(r, 1) \) is the total product curve with varying amounts of capital employed while keeping the employed labour constant at one unit. The second term, \( nr \) is the labour growth rate times the capital-labour ratio. It describes by how much investment must rise to keep the capital-labour ratio constant, given a specific growth of the labour force (Solow 1956). Figure 2.2 illustrates Solow’s (1956) propositions:
The horizontal axis of Figure 2.2 shows the capital-labour ratio and the vertical axis shows the output-labour ratio. The term $nr$ is illustrated as a straight and upward sloping line. Function $sf(r, 1)$ is described by a curve whose slope goes towards zero as the capital-labour ratio increases. This decreasing slope is the result of the diminishing marginal productivity capital and leads to the intersection of both lines at point $r^*$. At this point $\dot{r}$ equals zero.

Swan (1956) arranged the model by using his savings function (Equation 2.2), the
growth rate of the labour force $n$, the capital share $\alpha$ and the labour share $\beta$ to derive the annual economic growth rate $y$ (Swan 1956):

$$y = \alpha s \frac{Y}{K} + \beta n \quad (2.18)$$

The interpretation of Equation 2.18 is quite straightforward. Economic growth is the result from saving, which increases the capital stock and from the change rate of the labour force. The share of capital and the share of labour determine to what proportion these factors contribute to economic growth. Figure 2.3 shows Swan’s (1956) diagram:
Figure 2.3: Swan’s growth diagram

Figure 2.3 illustrates the output-capital ratio is on the horizontal axis and the growth rates are on the vertical axis. The diagram shows four lines: The capital function $sY/K$, the contribution line of capital $\alpha sY/K$, the labour growth line $n$ and the economic growth line $y$. The capital function illustrates the growth of capital given a specific output-capital ratio. The dependent contribution line of capital indicates how much the capital growth is contributing to economic growth, given the capital share. Labour growth is illustrated by a horizontal line, as labour is assumed to grow at a constant rate. The dashed line represents the growth line.
of output. All lines except the capital line intersect at the point \( \frac{Y^*}{K^*} \), where the economic growth is 1 per cent.

2.2.2.2 The introduction of technological change

Before looking at the implication of the intersection point, it is useful to point out how the model is adjusted when constant technological change is introduced. Like before, Solow's (1956) approach is outlined first. As Solow (1956) explained, technological change simply multiplies the production function by an increasing scale factor. Equation 2.5 becomes:

\[
Y_t = A_t f(K_t, L_t) \quad (2.19)
\]

where \( A_t \) denotes the stance of technology at time period \( t \) (Solow 1956). Thus, Equation 2.19 suggests that positive technological change increases output. Figure 2.4 demonstrates that positive technological change shifts the production function upwards:
As shown by Figure 2.4 positive technological change enables the economy to create more output with the same level of capital and labour input. How did Solow (1956) include technological change formally into his model? Solow (1956) defined $A_t = e^{gt}$ and recalibrated Equation 2.10 to a Cobb-Douglas type, as shown
in the following:

\[ \dot{K} = sA_t K^\alpha L^\beta \]  
\[ = se^{\rho t} K^\alpha (L_0 e^{nt})^{1-\alpha} \]  
\[ = sK^\alpha (L_0)^{1-\alpha} e^{(n(1-\alpha)+g)t} \]

Following a Cobb-Douglas production function, \( \dot{K} \) can now be integrated into \( K \), transforming Equation 2.22 to become (Solow 1956):

\[ K_t = \left[ (K_0)^\beta - \frac{\beta s}{n\beta + g} (L_0)^\beta + \frac{\beta s}{n\beta + g} (L_0)^\beta e^{(n\beta+g)t} \right]^{\frac{1}{\beta}} \]  

where \( \beta = 1 - \alpha \) because of constant returns to scale. After having obtained \( K_t \), output \( Y_t \) can simply be determined by using the Cobb-Douglas production function (Solow 1956).

In Swan’s (1956) case, technological change can just be added to the output growth Equation 2.18 (Swan 1956):

\[ y = \alpha s \frac{Y}{K} + \beta n + g \]  

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Figure 2.5 demonstrates the consequences of positive technological change, using Swan’s (1956) diagram:

**Figure 2.5: Swan’s diagram for positive technological change**

![Swan's Diagram](image)

Source: Swan (1956), p. 336

As Figure 2.5 shows, technological change shifts $y$ to $y'$ leading to a new equilibrium at point $Y^{**}/K^{**}$. The contribution of technological change to economic growth is the difference between $y$ and $y'$, which can be read of the vertical axis. As savings are higher at the new equilibrium, the growth of the capital stock is increased. The increase of capital stock growth will increase economic growth further. Hence, technological change has a direct impact on economic growth through the shift
of the production function and it also has an indirect impact which comes from the stronger growth of the capital stock which is caused by the stronger growth of output (Solow 1956; Swan 1956).

2.2.2.3 The steady state

Both Solow’s (1956) and Swan’s (1956) graph (Figure 2.2 and Figure 2.3) have shown a point of intersection. This point is a stable equilibrium, the so called steady state. At the steady state, labour, capital and output grow at the same rate. Consequently, per capita growth of output is constant.

An economy always drives towards the steady state. Looking at Figure 2.2, if the economy is at the left of the intersection point \( r^* \), then \( r \) is smaller than \( r^* \). In this case \( nr \) is smaller than \( sf(r, 1) \). Following the implications of Equation 2.17 this means that \( \dot{r} \) is positive and therefore \( r \) will increase towards \( r^* \) over the following time periods. In contrast, when the economy is to the right of the intersection point \( r^* \) then \( nr \) will be greater than \( sf(r, 1) \) and according to Equation 2.17 \( \dot{r} \) will be negative, leading to a decrease in \( r \) over the following time periods. Thus, the economy will again move towards \( r^* \). The same can be seen in Swans’s (1956) diagram (Figure 2.3). Anywhere to the left of the intersection point \( \frac{Y}{K}^* \), output grows faster than capital. Therefore, the output-capital ratio is increasing, meaning that it moves to the right. Anywhere to the right of the intersection point,
capital growth is stronger than output growth, meaning that the output-capital ratio moves to the left. Consequently, the intersection point is the only stable equilibrium. At any other point there is a movement towards the intersection point (Solow 1956; Swan 1956). After having explained the Solow (1956) - Swan (1956) model, the next section provides a brief explanation of how it is applied by the RBC theory.

2.2.3 Real Business Cycle Theory

The RBC theory uses the Solow (1956) - Swan (1956) model to explain business cycles. Business cycle theories attempt to explain the fluctuations of a range of important economic variables such as price, output, employment, consumption and investment from trend over a certain period of time. These fluctuations are persistent over a certain time interval and the economic key variables tend to move together over a business cycle (Long and Plosser 1983).

The Real Business Cycle theory argues that technological fluctuations are the drivers of business cycles (Prescott 1986). Following findings by Nelson and Plosser (1982) these technological fluctuations are assumed to follow a random walk, which means that they are absolutely unpredictable. Real Business Cycle theory views technological progress as the main driver of business cycles because individuals are
assumed to respond to technological fluctuations as utility maximising economic agents. When a positive technological shock sets in, productivity increases and individuals exploit the higher productivity by working and consuming more. In contrast, when a negative technological shock leads to a decrease in productivity, individuals decide to consume and work less in order to enjoy leisure time. This behaviour ensures that the individual's utility, which derives from consumption and leisure time, is maximised and it explains why these economic variables move together (Plosser 1989).

In an influential paper, Prescott (1986) proposed that the total factor productivity (TFP) of the Solow (1956) - Swan (1956) growth framework (which is denoted as \( A \) as discussed previously) is an estimate for technological fluctuations. Deriving his own TFP estimates, Prescott (1986) demonstrated that there is a strong correlation between output growth and TFP growth for the USA. This result was also confirmed by an analysis conducted by Mankiw (1989). As this thesis will estimate TFP growth values for Germany it will be tested whether Germany’s growth experience is consistent with the RBC analysis.
2.3 The Kaldor growth model

The next model to outline is the growth model of Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966). This model was derived in a couple of papers, but the two main articles were *A Model of Economic Growth*, which was published in 1957 and *A New Model of Economic Growth*. Later, Kaldor (1966) extended his growth model by formulating three growth propositions.

Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962) was dissatisfied with existent growth theories back at that time. Empirical evidence indicated that the share of wages and the share of profits in the national income was constant in developed economies. In addition, observations had shown that while the value of capital per worker and the value of output per worker were increasing, the capital per output ratio was not changing. This implies that capital per worker and output per worker were rising at the same rate. Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962) argued that if both the share of profits and the capital per output ratio are constant, then the rate of profit must also be constant. And this hypothesis is in fact confirmed by empirical evidence (Kaldor 1957; Kaldor and Mirrlees 1962). Existing theories including the Solow (1956) - Swan (1956) model were unable to explain these characteristics. Kaldor (1957) and Kaldor and Mirrlees (1962)
attempted to address this shortcoming by building an endogenous growth model, which can explain the constant capital to output ratio.

2.3.1 Assumptions

Most of the model’s assumptions are used to formulate equations, which characterise one important aspect of the model. These equations are then used to describe the dynamics of the model. In total Kaldor and Mirrlees (1962) derived ten independent equations which determine the following ten variables: Investments $I_t$, the amount of investment per operative on machine $i_t$, the number of workers available to operate new equipment $n_t$, productivity $p_t$, wages $w_t$, expected wages $w_t^*$, share of profit $\pi_t$, period of obsolescence of equipment $T$, output $y_t$, and the working population $N_t$.

Four parameters are required to solve these equations: the proportion of profits which is being saved $s$, the period within investment costs must be recovered $h$, the radioactive physical depreciation rate $\delta$ and the population growth $\lambda$ (Kaldor and Mirrlees 1962). The following section looks at a couple of general assumptions of the model.
2.3.1.1 General assumptions

The Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962) model assumes that a growing economy is in a state of full employment in a Keynesian sense. This means that its growth is not constrained by the demand side, but rather by the supply side. This is explained with the assumption that a growing economy utilises its production capabilities to the maximum level. Thus, an increase in monetary demand cannot influence short term growth, because with all production capabilities already being in use, output cannot be increased any further. In such an environment full employment is guaranteed because unless the growth path of capital and income is disturbed, an outcome where output is short of full employment is not stable. For example, if aggregate demand is higher than aggregate supply, firms will decide to increase their output by employing more labour until full employment is reached. Once the economy reaches the full employment state, the equilibrium between aggregate supply and aggregate demand is enforced through the change of prices in relation to costs. Therefore under-employment is not consistent with steady economic growth (Kaldor 1957; Kaldor and Mirrlees 1962).

Another key assumption of the model is that technical progress occurs through the introduction of new equipment, like for example new machines. An economy which introduces new capital at a high rate experiences more technological progress than
one with a low rate of capital accumulation. Kaldor and Mirrlees (1962) captured this characteristic with their technical progress function, which is based on the rate of introduction of new equipment and the obsolescence of capital. Kaldor and Mirrlees (1962) also included radioactive physical depreciation, which represents the decrease of the existing stock of equipment through physical causes such as accidents or fires. The obsolescence and the radioactive physical depreciation both suggest that the productivity of equipment is diminishing. The resulting technical progress function is expressed as followed (Kaldor 1957; Kaldor and Mirrlees 1962):

$$\frac{\dot{p}_t}{p_t} = f\left(\frac{i_t}{i_t}\right)$$

(2.25)

where $p_t$ is productivity and $i_t$ is the amount of investment per operative on machines of vintage $t$, which is determined by the following equation:

$$i_t = \frac{I_t}{n_t}$$

(2.26)

where $I_t$ stands for gross investment in fixed capital and $n_t$ represents the number of workers available to operate new equipment per period. Therefore, the technical progress function (Equation 2.25) represents the growth rate of productivity as a function of the growth rate of investment per operative on machines and the absolute value of investment per operative on machines (Kaldor and Mirrlees 1962). The technical progress function is illustrated by Figure 2.6:
Figure 2.6: The technical progress function of Kaldor and Mirrlees

Source: Kaldor and Mirrlees (1962), p. 176

Figure 2.6 shows that even if there is no growth in investment, there are some increases in productivity, because efficiency can always be improved over time. Furthermore, it is illustrated that additional investment growth increases productivity growth at a decreasing rate (Kaldor and Mirrlees 1962).

Next, it is assumed that entrepreneurs form their investment decisions in a process of careful evaluation. An investment has to fulfill two conditions in order to be pursued: First, the investment must sustain the profitability of the company above a certain minimum. This minimum is dependent on the opportunity cost, as the
profit maximising entrepreneur is not interested in investments that yield inferior rates of return to what other investments could earn. Kaldor and Mirrlees (1962) suggested that the sum of the equipment’s expected profit during its anticipated period of operation is obtained by the following equation:

\[ i_t \leq \int_t^{t+T} e^{-(\rho + \delta)(T-t)}(p_t - w^*_T) dT \]  

(2.27)

where \( T \) represents the anticipated period of the equipment’s lifetime, \( \rho \) is the entrepreneur’s estimate of the opportunity cost, \( w^*_T \) is the expected rate of wages which is an increasing function of \( T \), and \( \delta \) represents the radioactive physical depreciation of the equipment (Kaldor and Mirrlees 1962).

The second condition states that entrepreneurs only invest if the cost of the investment is recovered within a relatively short period of time. Investments which amortise over a long period of time are avoided because they expose the entrepreneur to additional risk deriving from the uncertainty of the future. Kaldor and Mirrlees (1962) expressed the second investment conditions as followed:

\[ i_t \leq \int_t^{t+h} (p_t - w^*_T) dT \]  

(2.28)

where \( h \) represents the time span during which the new equipment must have gen-
erated its initial cost. The model assumes that the first condition (Equation 2.27) is always fulfilled, whenever the second condition (Equation 2.28) is satisfied (Kaldor and Mirrlees 1962).

Furthermore, Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962) followed the traditional Keynesian approach of assuming passive savings. Kaldor and Mirrlees (1962) postulated a mechanism in which savings, which are used for investing, are automatically determined and the investor is not assumed to take an active role in the determination of savings. This mechanism specifies that savings are coming from the profits which are generated by the entrepreneur’s business operations. Savings of wage earners are ignored in this model. The following equation determines the share of profits (Kaldor and Mirrlees 1962):

\[
\pi_t = \frac{I_t}{sY_t} = \frac{r}{s} \frac{i_t}{y_t}
\]

(2.29)

where \(s\) represents the constant proportion of profits which is being saved, \(y_t\) is the per capita income growth, and \(r\) is defined by \(r_t = \frac{n_t}{N_t}\), where \(N_t\) represents the size of the labour force and \(n_t\) denotes the number of labour available to operate new machinery (Kaldor and Mirrlees 1962).

The model also assumes that there is a minimum boundary for wages. Wages
have to be high enough to cover basic living costs, otherwise worker do not have an incentive to work. Similar, profits must also be above a certain minimum rate. If actual returns were below this rate capitalist would not have an incentive to invest (Kaldor 1955). The next section introduces other assumptions Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962) made in order to derive the model.

### 2.3.1.2 Specific assumption

In regards to the number of workers operating equipment it is assumed that when equipment has just been installed, the number of workers operating it is at its highest. The amount of workers operating the new equipment decreases over its life time because of obsolescence and because of the factors described by the radioactive depreciation rate. The effects of this on the labour force are described with the following integral (Kaldor and Mirrlees 1962):

\[
N_t = \int_{t-T}^{t} n_T e^{-\delta(t-T)} dT \tag{2.30}
\]

For total output Kaldor and Mirrlees (1962) derived:

\[
Y_t = \int_{t-T}^{t} p_T n_T e^{-\delta(t-T)} dT \tag{2.31}
\]
Income is either spend on wages or it is treated as profit. Subtracting profits from income, Kaldor and Mirrlees (1962) obtained:

\[ Y_t(1 - \pi_t) = N_t w_t \]  

(2.32)

Thus, income after profits equals the number of people in the workforce times average wages. Another useful equation is given by the fact that equipment is always used up until the point where its profit becomes zero. Accordingly, Kaldor and Mirrlees (1962) wrote:

\[ p_{t-T} = w_t \]  

(2.33)

Population growth is assumed to be constant and it is represented by \( \lambda \) (Kaldor and Mirrlees 1962):

\[ \dot{N}_t = \lambda N_t \]  

(2.34)

The last assumption concerns the expectations of entrepreneurs about the development of wages. Entrepreneurs expect wages to increase at the same rate as they have been over the past periods. Kaldor and Mirrlees (1962) described the expected wage rate at some future time \( T \) to be:

\[ w^*_T = w_t \left( \frac{w_t}{w_t - l} \right)^{\tau - t} \]  

(2.35)
where \( t \) is the amount of past periods which the entrepreneurs use to form their estimation.

### 2.3.2 Dynamics of the model

#### 2.3.2.1 The steady state

Using the assumptions outlined above, Kaldor and Mirrlees (1962) analysed whether there is a steady state, in which productivity, output, investment and wages grow at equal rates and where profits, the period of obsolescence of equipment and the ratio of investment to output remain constant (Kaldor and Mirrlees 1962):

\[
\frac{\dot{p}}{p} = \frac{\dot{y}}{y} = \frac{i}{i} = \frac{w}{w} \quad (2.36)
\]

Such a steady state would be consistent with the empirical observations that were outlined in the introduction of this section and which served as Kaldor’s (1957) motivation of developing a new growth model.

Finding this steady state is simply a mathematical problem. Here, the equations which have been outlined above can be used. To characterise the steady state Kaldor and Mirrlees (1962) integrated Equation 2.28 using Equation 2.35 and
obtained the following equation:

\[ i_t = h p_t - w_t \frac{e^{v t} - 1}{v} \]  

(2.37)

where \( v \) represents the expected growth rate of wages. Equation 2.37 describes that the investment per worker on machine is dependent on the time period during which investment must be recovered multiplied with the productivity subtracted by a term that expresses the development of wages. This equation is very useful to derive a couple of observations (Kaldor and Mirrlees 1962).

First, productivity can only grow faster than investment per worker on machine if wages are increasing faster than productivity. Otherwise Equation 2.37 would lead to a higher increase rate in \( i_t \) than in \( p_t \). But it is not possible that wages increase faster than productivity in the long-run, because this would lead to obsolescence in capital because its operation becomes too expensive (Kaldor and Mirrlees 1962).

Second, productivity can also not grow more slowly than investment per machine in the long-run. According to Equation 2.37 this would lead to a decline in wages. The above analysis has pointed out however, that workers will not work if wages fall below a certain minimum level (Kaldor and Mirrlees 1962).
Kaldor and Mirrlees (1962) also pointed out that if a small deviation of the wage growth rate from the steady state growth rate occurs then the economy will quickly move back to the steady state. Based on Equation 2.28 the rate of change of investment on machine per worker would always increase or decrease depending on whether it is lower or higher than productivity (Kaldor and Mirrlees 1962). Therefore, the Kaldor growth model (Kaldor 1957; Kaldor and Mirrlees 1962) predicts a stable equilibrium. The next section looks at the general characteristics of the model.

### 2.3.2.2 Characteristics of the model

The equations and assumptions that were outlined above can be used to specify the characteristics of the model. In particular, Kaldor and Mirrlees (1962) were interested in specifying productivity, wages, output and investment on machine per worker. To specify these values some mathematical work is required.

The characteristics of the technical progress function suggest that there is some value $\gamma$, where productivity and investment per operative on machine grow at the same rate (Kaldor and Mirrlees 1962):

$$
\gamma = \frac{\dot{p}}{p} = \frac{i}{i}
$$

(2.38)
Next, Kaldor and Mirrlees (1962) characterised the amount of labour available for new equipment. This is obtained by differentiating Equation 2.30 with respect to time. Kaldor and Mirrlees (1962) derived the following equation:

\[ n_t = \dot{N}_t + \delta N_t + n_{t-T}(1 - \frac{dT}{dt})e^{-\delta T} \]  

(2.39)

Equation 2.39 demonstrates that the labour force available for new equipment consists of three factors: The growth of the labour force, represented by \( \dot{N}_t \), the amount of workers who are unoccupied after a physical accident has destroyed the equipment they have previously used, represented by \( \delta N_t \), and the amount of workers who are unoccupied after their previous used equipment became unprofitable because of obsolescence, \( n_{t-T}(1 - \frac{dT}{dt})e^{-\delta T} \) (Kaldor and Mirrlees 1962).

Likewise, Kaldor and Mirrlees (1962) differentiated output, which was given in Equation 2.31:

\[ \dot{Y}_t = p_t n_t - p_{t-T}n_{t-T}(1 - \frac{dT}{dt})e^{-\delta T} - \delta Y_t \]  

(2.40)

Using Equations 2.33 and 2.39 Kaldor and Mirrlees (1962) simplified Equation 2.40 to:

\[ \frac{\dot{y}_t}{y_t} + \lambda + \delta = r \frac{p_t}{y_t} - (r - \lambda - \delta) \frac{w_t}{y_t} \]  

(2.41)

Kaldor and Mirrlees (1962) proposed that wages grow at a constant rate, \( \beta \). As
Kaldor and Mirrlees (1962) demonstrated, a constant $\beta$ leads to a constant period of obsolescence of equipment, if the boundary condition $\gamma < \frac{s}{h} - \lambda - \delta$ is fulfilled. Based on this, Equation 2.39 can be turned into the following equation (Kaldor and Mirrlees 1962):

$$r_t = \lambda + \delta + r_{t-T} e^{-(\lambda+\delta)T}$$

(2.42)

Because $T$ is constant in the above equation, $r_t$ will tend to the constant equilibrium value

$$r = \frac{\lambda + \delta}{1 - e^{-(\lambda+\delta)T}}$$

(2.43)

Rearranging Equation 2.29, Kaldor and Mirrlees (1962) arrived at:

$$y_t = w_t + \frac{r_s i_t}{s}$$

(2.44)

which states that in equilibrium, $y_t$ grows at the equilibrium growth rate $\gamma$ because $r$ is constant. Equation 2.44 can be rewritten as:

$$\frac{r_s i_t}{s y} + \frac{w}{y} = 1$$

(2.45)

As expectations are fulfilled in equilibria, the actual wage equals the expected wage. Hence, it is now possible to evaluate the integral in Equation 2.28. Using an initial wage rate $w_0$, it can be written that $w_t = w_0 e^{\beta t} = w_0 e^{\gamma t}$. Thus (Kaldor
and Mirrlees 1962):

\[ i_t = h p_t - \frac{e^{\gamma h} - 1}{\gamma} w_t \]  \hspace{1cm} (2.46)

which Kaldor and Mirrlees (1962) rewrote as:

\[ \frac{1}{h} i + \frac{e^{\gamma h} - 1}{\gamma} \frac{w}{y} - \frac{r}{w} y = 0 \]  \hspace{1cm} (2.47)

Equation 2.41 can be rewritten as:

\[ (r - \lambda - \delta) \frac{w}{y} - r \frac{p}{y} = -(\gamma + \lambda + \delta) \]  \hspace{1cm} (2.48)

Equation 2.33 can now be used to specify \( T \):

\[ e^{\gamma T} = \frac{p}{w} = \frac{p/y}{w/y} \]  \hspace{1cm} (2.49)

Equation 2.46, Equation 2.47 and Equation 2.48 are employed as simultaneous equations for the derivation of \( i/y \), \( w/y \), and \( p/y \). Using the values found by solving the simultaneous equations Kaldor and Mirrlees (1962) arrived at:

\[ e^{\gamma T} = 1 - \frac{h(\gamma + \lambda + \delta) e^{\gamma h} - 1}{s} + \frac{r}{s} \]  \hspace{1cm} (2.50)

Furthermore, from Equation 2.43 and because of \( e^{\gamma T} = (e^{-(\lambda + \delta)T})^{-\gamma T} \), Kaldor and
Mirrlees (1962) wrote:

\[ e^{\gamma T} = \left[ 1 - \frac{\lambda + \delta}{r} \right]^{-\frac{\gamma}{\lambda + \delta}} \quad (2.51) \]

This finishes the construction of the model as all values are now specified. In summary, the technical progress function determines \( \gamma \). Next, Equation 2.50 determines \( T \), followed by Equation 2.51 determining \( r \). Then, simultaneous solution of Equations 2.48 and 2.49 delivers the values of \( \xi \) and \( \sigma \). Finally, Equation 2.47 gives the value for \( \frac{i}{y} \) (Kaldor and Mirrlees 1962).

From the above analysis it can be seen that besides being the main driver of economic growth, technological progress has many other effects on the economy. It also influences parameters like for example the share of profits, the rate of obsolescence or the average lifetime of equipment (Kaldor and Mirrlees 1962)

### 2.3.3 Kaldor’s growth propositions

Based on his economic growth model Kaldor (1966) formulated three growth propositions. Taylor (2007) summarizes Kaldor’s three growth propositions as followed:
Box 2.1: Kaldor’s (1966) propositions of economic growth

1. There is a strong correlation between the growth of manufacturing output and rate of growth of GDP.

2. Growth of labour productivity in the manufacturing sector, $p_m$, is positively related to growth of manufacturing output, $g_m$. Kaldor (1966) also assumed that growth rate of manufacturing output is equal to the sum of productivity growth, $p_m$ and employment growth, $e_m$ which can be expressed as

\begin{equation}
 g_m = p_m + e_m \tag{7.1}
\end{equation}

where

\begin{equation}
 p_m = \alpha + \beta g_m \tag{7.2}
\end{equation}

\begin{equation}
 e_m = -\alpha + (1 - \beta) g_m \tag{7.3}
\end{equation}

Only if equations (7.2) and (7.3) are equal will the estimates be the same. The sum of the constants of equations (7.2) and (7.3) should be zero, and the sum of the regression coefficients unity, irrespective of the correlations involved.

3. Overall productivity growth is positively correlated with employment growth in the manufacturing sector and negatively related with growth of employment in the non-manufacturing sector.


These growth propositions put a strong emphasis on the manufacturing sector. Since Kaldor’s model (Kaldor 1957; Kaldor and Mirrlees 1962) assumed that technical progress occurs through the implementation of new capital equipment, Kaldor (1966) advocated that the capital intensive manufacturing sector can experience
the strongest technological progress of all sectors. In fact, Kaldor (1966) argued that because the manufacturing sector offers so many possibilities for technological progress to occur, it experiences increasing returns to scale. Therefore, economic growth of the manufacturing sector can be very strong. The output it produces leads to additional demand of good and services and hence drives the economic growth of the whole economy (Taylor 2007).

2.4 The Romer growth model

The last model to be discussed is the Romer (1986) growth model. The Romer (1986) model was the first one of the new growth theory models, which challenge traditional growth theories. With regards to data on economic growth rates since the industrialisation Romer (1986, p. 1008) wrote: “...it is useful to ask whether there is anything in the data that should cause economists to choose a model with diminishing returns, falling rates of growth, and convergence across countries rather than an alternative without these features.” Consequently, Romer (1986) provided an endogenous growth model which advocated increasing returns to scale (Romer 1986).

Similar to Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966), Romer (1986) embodied technological progress into capital. But in contrast to Kaldor
(Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966), technological progress in the Romer (1986) model is not driven by the capital investments but by the accumulation of new knowledge. Romer (1986) equipped his model with microeconomic foundations and treats economic growth as a consumer choice problem, where society has to choose between consumption and economic growth. Romer’s (1986) model also suggests a Pareto inefficient outcome, which calls for government intervention in order to raise society’s wealth.

2.4.1 Assumptions

2.4.1.1 General assumptions

As explained, Romer (1986) assumed increasing returns to scale and hence per capita output could grow at an increasing rate over time. Romer (1986) provided historical evidence in order to support this assumption. As Romer (1986) pointed out, data provided by Maddison (1982) on the productivity level since 1700 had shown that the productivity growth rate of the country with the highest level of productivity is increasing. Another source of evidence is coming from Maddison (1979) who reported per capita GDP growth rates for the United States from 1800 to 1978. Putting the data into five subcategories, Romer (1986) demonstrated that the per capita growth rate is increasing over subsequent time periods. In addition, Romer (1986) provided results of a simple non-parametric test for trend
for several countries. Using data from Maddison (1982), Romer (1986) reported a high probability, that for any two randomly chosen decades, the later decade has a higher growth rate.

Romer (1986) formalised increasing returns to scale into his model using two assumptions. First, Romer (1986) integrated knowledge into the production function and assumes that knowledge has an increasing marginal productivity. Second, Romer (1986) dropped the assumption of diminishing marginal productivity of capital and labour and postulates that both have constant marginal productivities. Therefore, driven by the increasing marginal productivity of knowledge, the production function of these three inputs (capital, labour and knowledge) has increasing returns to scale (Romer 1986).

There are two further important assumptions concerning knowledge. First, Romer (1986) assumed that knowledge creation exhibits diminishing returns. When one doubles the inputs in knowledge creation (e.g. research technology), the creation of new knowledge is not doubled. Second, knowledge is assumed to be an externality. The reason behind this is that knowledge can never be patented or kept secret to a full extent. When a firm discovers new knowledge, at least some of this knowledge will spill-over to other firms. Consequently, new knowledge does not only increase
the production possibility of the firm which discovered it, it also increases the
production possibilities of other firms. As this suggests that each firm benefits
from the research conducted by other firms, knowledge is an externality (Romer
1986).

2.4.1.2 Specific assumptions

The specific assumptions of Romer’s (1986) model are outlined in the following.
The production function of a firm is described by the following function:

\[ f(k_t, K_t, x_t) \] (2.52)

where \( k_t \) represents the firm-specific knowledge at time \( t \), \( K_t \) is the economy wide
aggregate knowledge at time \( t \), and \( x_t \) is an aggregation of all other inputs (e.g.
labour and capital) at time \( t \) (Romer 1986).

To simplify the derivation of the model, Romer (1986) assumed that the inputs
represented by \( x_t \) are constant. Furthermore, the firm-specific knowledge of a firm
\( k_t \), depends on the path of the economy wide aggregate knowledge \( K_t \).

The production of knowledge involves a trade-off. Given the scarcity of resources,
money can either be spend on consumption or it can be invested in research. Money
invested in research is denoted with $I$ and the function describing the growth of firm-specific knowledge is given by (Romer 1986):

$$\dot{k} = G(I, k)$$

This function is assumed to be strictly concave and to have constant returns to scale. Hence, both sides can be divided by $k$ to obtain:

$$\frac{\dot{k}}{k} = g\left(\frac{I}{k}\right)$$

A crucial assumption about Equation 2.53 is that the function is bound from both above and below. Mathematically, this means that $g$ moves between an interval. Economically, Equation 2.53 being bound from above means that $g$ experiences strong diminishing returns as it cannot increase above a given constant $\alpha$. The bound below is by the value $g(0) = 0$, because when a firm conducts no research then $k$ does not change. This implies that knowledge cannot depreciate (Romer 1986).

Incorporating his economic growth model with micro foundations, Romer (1986) treated it like a consumer choice problem. The utility of a consumer is determined by his consumption, which the consumer aims to maximise over time. The
following integral expresses the consumer's utility:

\[ \int_0^\infty U(c_t)e^{-\delta t}dt \]  \hspace{1cm} (2.54)

where \( c_t \) denotes the consumer’s consumption and \( \delta \) is the discount factor which is assumed to be greater than zero. Given the trade-off between consumption and investment, this is a maximisation problem in mathematical terms.

### 2.4.2 Dynamics of the model

The consumer choice in Romer’s (1986) model is that the economy has to choose between consumption and economic growth. If the economy chooses high consumption, it will experience low economic growth. In contrast, if it chooses low consumption, it will experience high growth. The choice between these alternatives is made according to the societies utility. Since the time horizon is infinite, this is a dynamic optimisation problem. To solve for the highest utility, Romer (1986) used the Hamiltonian approach. Two maximisation problems are outlined: The first one characterises the social optimum and the second one the competitive equilibrium (Romer 1986).
2.4.2.1 The social optimum

This section looks at the social optimum. Here, the perspective of a social planner is taken. Naturally, a social planner seeks to achieve the Pareto efficient outcome for the economy as a whole. As outlined above, a crucial assumption of Romer’s (1986) model is that knowledge is an externality. The existence of externalities requires the social planner to take these into account (Romer 1986).

Therefore, the production function, Equation 2.52, has to be modified. It is specified that \( x = \bar{x} \), where \( \bar{x} \) denotes the per capita and per firm endowment. It is assumed that \( \bar{x} \) is a constant and therefore it is left out for simplicity. Furthermore, Romer (1986) defined \( S \) as the amount of consumers and states that \( K_t = S_t k_t \). For the social optimum problem the following production function is derived (Romer 1986):

\[
F(k, S_k, \bar{x}) = f(k, S_k) = f_{so}(k)
\]  

(2.55)

This function is constant over time and convex. Using this production function the following optimisation problem is obtained (Romer 1986):
$PS_{\infty}(k)$:

\[
\begin{align*}
\text{maximisation} & \quad \int_{0}^{\infty} U(c_t)e^{-\delta t}dt \\
\text{subject to} & \quad \frac{\dot{k}_t}{k_t} = g\left(\frac{f_{so}(k_t)-c_t}{k_t}\right)
\end{align*}
\]

where $\dot{k}_t \geq 0$ for all $t \geq 0$ and $k(0) = k_0$ (Romer 1986). In words, the goal is to maximise the utility $U$, which is determined by a function which uses consumption $c$ as an input. Thus, the optimal path of consumption, $c^*_t$ has to be determined.

It is crucial to note that $c$ only serves as a control variable and the real interest is the optimal path of the state variable, $k^*_t$. But mathematically, the path of $k^*_t$ can only be obtained by finding the one of the control variable $c$. Therefore, the first task is to determine the optimal path of the control variable and then the optimal path of the state variable can be derived (Chiang 1992).

Romer (1986) provided a theorem which guarantees that this problem is solvable. The theorem includes the assumption of a couple of boundaries for $f_{so}$ and $g$ as well as the assumption of $U$, $f$, and $g$ being continuous functions (Romer 1986).

In order to find the solution to this optimisation problem Romer (1986) employed
the Hamiltonian approach:

\[ H(k, \lambda) = \max_c U(c) + \lambda [kg(\frac{f_{so}(k) - c}{k})] \]  

(2.57)

The Hamiltonian function introduces the so-called costate variable \( \lambda \). The costate variable measures the shadow price of the state variable. Therefore, it tells us by how much the utility increases if one unit of \( k \) is added. To solve a Hamiltonian function, two conditions have to be satisfied (Chiang 1992). Romer (1986) employed these conditions to derive \( \dot{k} \) and \( \lambda \).

The first condition is that the differentiation of the Hamiltonian function with respect to the state variable \( k \) equals the discount rate \( \delta \) multiplied with the costate variable \( \lambda \) minus the derivative of the costate variable \( \lambda \) (Chiang 1992):

\[ \frac{\partial H}{\partial k} = \delta \lambda - \dot{\lambda} \]  

(2.58)

\[ \implies \dot{\lambda} = \delta \lambda - H_k(k, \lambda) \]  

(2.59)

The second condition is that the derivative of the Hamiltonian with respect to the state variable \( k \) equals the discount rate \( \delta \) multiplied with the

54
costate variable $\lambda$ equals the derivative of the state variable $\dot{k}$ (Chiang 1992):

$$\frac{\partial H}{\partial \lambda} = \dot{k} \tag{2.60}$$

$$\implies \dot{k} = H_{\lambda}(k, \lambda) \tag{2.61}$$

These conditions are subject to two boundaries. First, the initial condition $k(0) = k_0$ and second the transversality condition $\lim_{t \to \infty} \lambda_t k_t e^{-\delta t} = 0$ (Romer 1986). This means that at time zero, there is some initial value for knowledge and that when time goes towards infinity, the discounted value for knowledge goes towards zero.

Romer (1986) then proceeded to analyse the path of the control variable $c$. Determining this path enabled him to derive the path of the state variable $k$. Romer (1986) postulated that if $\lim_{c \to 0} U'(c) = \infty$, then the following conditions have to hold (Romer 1986):

When the constraint $\dot{k} \geq 0$ is not binding:  
$$U'(c) = \lambda g' \left( f_{so}(k) \frac{c}{k} \right) \tag{2.62}$$

When the constraint $\dot{k} \geq 0$ is binding:  
$$c = f_{so}(k) \tag{2.63}$$

These conditions can then be used to derive equations for $\dot{k}$ and $\dot{\lambda}$ that only depend on $k$ and $\lambda$. Therefore, the dynamic optimisation problem is solved. Romer (1986) used the following phase plane to show that the social optimum is not reached:
Figure 2.7: Phase plane for a social optimum

Figure 2.7 illustrates the state variable $k$ on the horizontal axis and the costate variable $\lambda$ on the vertical axis. Three curves are shown, one where $\dot{k} = 0$, one where $\dot{\lambda} = 0$ and the social optimum SO (Romer 1986).

For the first case, both conditions (Equation 2.62 and Equation 2.63) have to hold, because of $\dot{k}$ being equal to zero. Thus, the following equation defines the $\dot{k} = 0$ curve (Romer 1986):

$$U'(f_{so}(k)) = \lambda$$  \hspace{1cm} (2.64)
As $U$ was assumed to be concave, the curve of its derivative, $U'$ must be a non-increasing curve (Romer 1986).

For the second case, when $H_\lambda(k, \lambda)$ is investigated along the $\dot{k}$ curve, the equation for $\dot{\lambda}$ can be written as (Romer 1986):

$$\frac{\dot{\lambda}}{\lambda} = \delta - f'_{so}(k)$$  \hspace{1cm} (2.65)

From Equation 2.65 it is evident that if $f'_{so}$ is increasing without limits, then there must exist some value of $k$ from where $f'_{so}(k) > \delta$. This value is referred to as $\hat{k}$ in the following. For all the values of $k > \hat{k}$, the $\dot{\lambda}$ curve lies above the $\dot{k}$ curve. Figure 2.7 demonstrates the case where all values of $\dot{k}$ are above $\hat{k}$ and the $\dot{\lambda} = 0$ curve is therefore always above the $\dot{k} = 0$ curve. The social optimum curve must also be above the $\dot{k} = 0$ curve, implying that $k_t$ grows without a bound. In contrast, if the social optimum was crossing the $\dot{k} = 0$ curve, the transversality condition would be violated. Therefore it is evident that when firms take the economy wide knowledge $K_t$ as given, the social optimum is not reached, unless there is government intervention (Romer 1986).

2.4.2.2 The competitive equilibrium

So what happens in the absence of government intervention? The economy reaches a suboptimal equilibrium. In this case, Romer (1986) stated the following produc-
tion function:

\[ F(k, K, \bar{x}) = f(k, K) \]  \hspace{1cm} (2.66)

In contrast to the production function for the social optimum (Equation (2.55)), this production function is concave and time dependent on the path of the economy wide knowledge \( K_t \) (Romer 1986). Therefore, the optimisation problem in this case is:

\[ P_\infty(K) : \]

\[
\begin{align*}
\text{maximisation} & \quad \int_0^\infty U(c_t) e^{-\delta t} dt \\
\text{subject to} & \quad \frac{\dot{k}_t}{k_t} = g\left(\frac{f(k_t, K_t) - c_t}{k_t}\right); \\
& \quad (2.67)
\end{align*}
\]

To solve this optimisation problem, the following Hamiltonian function is used:

\[
\tilde{H}(k, \lambda, K) = \max_c U(c) + \lambda \left[ kg\left(\frac{f(k, K) - c}{k}\right)\right] 
\]

\hspace{1cm} (2.68)

Here, the Hamiltonian is denoted as \( \tilde{H} \), in order to distinguish it from the one used in the social optimum problem. To solve the Hamiltonian function, the same conditions as above have to be fulfilled. From these conditions, \( \dot{k} \) and \( \dot{\lambda} \) can be obtained. In addition, \( S\dot{k}_t \) can be substituted for \( K_t \). Therefore, Romer (1986)
stated:

\[
\frac{\partial \hat{H}}{\partial \lambda} = \dot{k} \tag{2.69}
\]

\[\Rightarrow \dot{k} = \hat{H}_\lambda(k_t, \lambda_t, K_t) \tag{2.70}\]

\[\Rightarrow \dot{k} = \hat{H}_\lambda(k_t, \lambda_t, Sk_t) \tag{2.71}\]

\[
\frac{\partial \hat{H}}{\partial k} = \delta \lambda - \dot{\lambda} \tag{2.72}
\]

\[\Rightarrow \dot{\lambda} = \delta \lambda t - \hat{H}_k(k_t, \lambda_t, K_t) \tag{2.73}\]

\[\Rightarrow \dot{\lambda} = \delta \lambda t - \hat{H}_k(k_t, \lambda_t, Sk_t) \tag{2.74}\]

As for the social optimum, these conditions are subject to the boundary conditions

\( k(0) = k_0 \) and \( \lim_{t \to \infty} \lambda_t k_t e^{-\delta t} = 0 \).

In addition to the theorem stated above, a further theorem has to be introduced. This theorem guarantees that for any initial value of knowledge, \( k_0 \) there is a value of \( \lambda_0 \) while the transversality condition is still satisfied. This ensures that the equations for \( \dot{k} \) and \( \dot{\lambda} \) determine a unique trajectory through any point in the phase plane. The theorem therefore specifies that besides the assumptions of theorem 1, \( U, f \) an \( g \) are also assumed to be twice continuously differentiable. Furthermore, the theorem characterizes the asymptotic behaviour of the functions \( f \) and \( g \) (Romer 1986).
The analysis involving the phase plane is quite similar to the one for the social optimum. In fact, using the conditions 2.62 and 2.63 again, the same outcome for the $\dot{k} = 0$ curve in the competitive equilibrium as for the social optimum can be obtained (Romer 1986).

The case is different for the equation of $\dot{\lambda}$. While the Hamiltonian function of the competitive equilibrium is equal to the one of the social optimum ($H(k, \lambda) = \dot{H}(k, \lambda, Sk)$), their derivatives are different. For the social optimum, it is $f'_{so}(k) = f'(k, Sk) + Sf'(k, Sk)$, while for the competitive equilibrium it is $f' = f'(k, Sk)$. Consequently, the derivative of the Hamiltonian function of the social optimum is always larger than the one of the competitive equilibrium. Subsequently, the $\dot{\lambda} = 0$ curve for the competitive equilibrium lies below the one for the social optimum (Romer 1986).

Therefore, the equilibrium is not Pareto efficient, because firms fail to conduct enough research. This results from the fact that new knowledge is an externality. As knowledge can spill over to other firms and increase their production possibilities, firms are less inclined to conduct research themselves. Instead, they choose to invest their resources elsewhere. As each firm speculates to free-ride on the
discovery of new knowledge through other firms, aggregate research investment is too low (Romer 1986). Pareto efficiency can be achieved by any intervention which increases research. Romer (1986) suggested to implement subsidy schemes in order to reach the social optimum.

2.5 Conclusion

This finishes the review of the growth models which will be used in the forthcoming chapters to empirically quantify the economic growth of Germany. In summary, the Solow (1956) - Swan (1956) model focuses on capital, labour and technological progress. It assumes constant returns to scale and diminishing marginal productivities in capital and labour. As it employs the Cobb-Douglas production function it can be used to decompose economic growth into capital accumulation, labour accumulation and technological progress. However, as it does not explain how technological progress occurs it is an exogenous growth model.

Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) growth model differs significantly to the Solow (1956) - Swan (1956) growth model. It is an endogenous growth model which embodies technological progress into capital replacement. Therefore the assumption of diminishing marginal productivity in capital is dropped and it is argued that capital intense sectors like the manufacturing
sectors can have increasing returns to scale, because they offer many opportunities for technological progress.

Romer’s (1986) model is also an endogenous growth model which is based on microeconomic foundations. Romer (1986) assumed increasing returns to scale for the whole economy and argues that technological progress is a result of knowledge accumulation.

All three growth models will be estimated in Chapter 4. But before that, the following chapter provides some information about the political and economic development of Germany after the second World War.
Chapter 3: Germany’s historical and economic development

3.1 Introduction

This chapter begins by providing some historical information about Germany’s development from 1945 to 2011. This is important for the aim of this thesis, because Germany’s economic growth is deeply related to the most important aspect of its post-war history: the existence of two Germanies from 1949 to 1990, and the reunification of these two countries in 1990. The reunification also marks the disconnection of the two different time periods which are analysed empirically in this thesis.

This chapter is organised as followed: Section 3.2 provides a summary of Germany’s historical development from 1945 to 2011. Section 3.3 takes a closer look at West Germany’s economic development from 1945 to 1970. This is followed by a detailed analysis of the two time periods which are empirically analysed in this thesis. West Germany’s economic development from 1971-1990 is outlined...
in Section 3.4 and the one of the reunited German’s is described in Section 3.6.
Furthermore, some economic background information about the reunification is
provided in Section 3.5.

3.2 Post-war political history of Germany

3.2.1 Early post-war years and the foundation of the two Germanies

After the end of the second world war in 1945, Germany’s future was uncertain. The allies did not have any specific plans of how post-war Germany should look like. What they did decide so far was the division of Germany into four zones with each one being administrated by one ally. In addition, they decided to denazify, demilitarise and democratise Germany. But as specific policy proposals did not exist, each ally was free to follow its own agenda (Fulbrook 2004).

In the Soviet zone, radical socio-economic changes were implemented. A land reform redistributed land to labourers or to state ownership. Large companies were nationalised and small enterprises were pushed out of business. At the same time, the Soviet Union extracted significant amounts of reparations out of its zone. In addition, the Socialist Unity Party (SED) was created by a forced merger of the Communist Party (KPD) and the Social Democratic Party (SPD) in April 1946.
With the support of the Soviet Union, the SED achieved predominance in political life in the Soviet Zone over the following years (Fulbrook 2004).

Things were pretty different in the western occupation zones. Several political parties were founded or refounded, for example the SPD, the Christian Democratic Union (CDU) and the Free Democratic Party (FDP). Unlike in the Soviet zone, there were no severe socio-economic changes and with the exception of France, the western allies abstained from extracting significant amounts of reparations. But a big problem faced by the western occupation powers was feeding the German population, which in fact became increasingly difficult with large numbers of refugees arriving from former German territories, which were now belonging to Poland (Fulbrook 2004).

In 1947, the USA announced the Marshall Plan, which aimed at reconstructing Europe and included generous aids to West Germany. Together with the Truman Doctrine, which was targeted at limiting the Soviet influence in Europe, the Marshall Plan was a first step to integrate West Germany into the community of the western countries. In addition, England and the USA agreed on merging their two zones into a Bizone. The Bizone developed its own government and was later joined by the French zone and became a Trizone (Fulbrook 2004).
As the old German currency, the *Reichsmark* was virtually without value, a currency reform was required. This reform was based on terms, which were unacceptable for the Soviet Union. It was implemented in June 1948 and the new currency was called *Deutsche Mark*. Later in the same year, the Soviet zone introduced its own new currency. At this point of time it was clear that the western allies and the Soviet Union will follow separate paths. After West Germany agreed on a new constitution, the Federal Republic of Germany (FRG or West Germany) was founded in May 1949. A few months later, the Soviet Zone founded the German Democratic Republic (GDR or East Germany) (Fulbrook 2004).

### 3.2.2 The history of the two Germanies from 1949 until the reunification 1990

While West Germany was a representative democracy with free elections, East Germany was controlled by one party, the SED. The first Chancellor of West Germany was Konrad Adenauer, who belonged to the CDU which formed a coalition with the FDP. During Adenauer’s reign, Germany experienced an *economic miracle*, referring to very strong economic growth rates. Under Adenauer, West Germany also gained membership in the Organisation for European Economic Cooperation (OEEC), the European Coal and Steel Community (ECSC), the Council of Europe

East Germany was governed by Walter Ulbricht. During the 1950s it soon became evident that the socialist East Germany could not keep up with the economic success of capitalist West Germany and dissatisfaction with the socialist government amongst the East German citizens increased. Many East Germans decided to leave the GDR with the hope to find a better future in West Germany. The mass emigration of skilled labour turned into a serious thread for the existence of East Germany. In the morning of 13th August 1961, East German soldiers began to construct a wall on the border to West Germany in order to stop the emigration. This wall made it impossible for East Germans to leave the GDR (Fulbrook 2004).

Besides the end of East German immigration, the 1960s brought further changes to West Germany. In 1963, Konrad Adenauer resigned as a Chancellor and was succeeded by Ludwig Erhard, who has been minister for economics before. But Erhard’s government was of short life and collapsed because of weak leadership and because of a recession which occurred in 1965/66. Kurt Georg Kiesinger from the CDU became new Chancellor and formed a coalition with the SPD. This coalition
had a very strong majority in the parliament and provoked the rise of a protest movement, which mainly consisted of young Germans who were highly critical of West Germany’s society and government (Fulbrook 2004).

The Kiesinger government did not last long either. In 1969, Willy Brandt from the SPD became Chancellor of a coalition with the FDP. Brandt enforced a change in West Germany’s foreign policy. He emphasised the improvement of the relations with the Soviet Union and with East Germany, in which Walter Ulbricht was replaced by Erich Honecker as the SED party leader in 1971. As a result of Brandt’s politics, the FRG and GDR formally agreed on recognising each other. Subsequently, both countries became full members of the United Nations in 1973 (Fulbrook 2004).

Domestically, West Germany faced a couple of serious challenges during the 1970s. A terrorist movement, the Red Army Fraction (RAF), which originated from the protest movement of the 1960s spread fear among citizens and created worries about the stability of the German democracy. In addition, the oil crisis of 1973 and a world recession gave rise to many economic problems. Willy Brandt had to resign as the Chancellor because of a spy affair in 1974. Brandt’s fellow party member Helmut Schmidt became the new Chancellor. During the time of Schmidt’s
government West Germany was confronted by the most severe terrorist attacks in the history of the RAF, it suffered from rising unemployment and struggled with budget problems which soon started to challenge the existence of the welfare system. In 1982, the FDP decided to leave the coalition in order to form a new government with the CDU. The new Chancellor was Helmut Kohl (Fulbrook 2004).

During the 1980s the European integration was enforced. In 1987 the member states agreed on forming the Single European Market (SEM). Like within a country, goods, services, capital and people were ought to move freely within the SEM. The deadline to enforce the SEM was the 31 December 1992 (Ardy and El-Agraa 2011).

East Germany also underwent some changes during the leadership of Honecker from 1971 to 1989. Consumer satisfaction became a more important concern and the government thrived to increase the availability of desired goods like TVs and cars. From the 1980s onwards it also became easier for East Germans to travel to the west (Fulbrook 2004).

But during the 1980s it became obvious that the Soviet Union would lose the cold war. Its economic weakness made it impossible to continue competing with the
US in terms of defense spending. At the same time the Soviet leader Gorbachev introduced reforms which started a process of democratisation and economic restructuring. Other east European countries underwent reforms as well. When a new government in Hungary decided to waive visa restrictions of East Germans to travel to the west, it induced a process which would eventually lead to the German reunification (Fulbrook 2004).

First, the high numbers of East Germans going to Hungary in order to emigrate to West Germany became a problem. Then, demonstrations against the SED government in East Germany started and under the pressure of Gorbachev, Honecker had to resign as a party leader and he was replaced by Egon Krenz. Nevertheless, the demonstrations did not end. In fact, they actually kept increasing in size and thus raised the pressure on the SED government. In an effort to calm things down, an East German government spokesman announced the relaxation of travel restrictions for East Germans from 9th November 1989 onwards. As this announcement implied that the wall which divided East Germany from the West lost its purpose, thousands of East and West Germans rushed to the wall to tear it down. In the following weeks, the stream of refugees fleeing from the East to the West was so strong that some kind of solution was necessary. West Germany’s Chancellor Kohl took the opportunity and suggested a unification of the two Ger-
manies. After negotiations between East and West Germany, as well as between West Germany and the allies, the two Germanies agreed on reuniting. The first step was the formation of an economic and monetary union which came to power in July 1990. The reunification was completed by the formation of a political union on 3rd October 1990 (Fulbrook 2004).

3.2.3 Germany since 1990

The reunited Germany adopted the West German constitution and economic system. It was challenging for both policy makers and citizens to integrate a socialist country into a capitalist country. The high cost of the reunification also made tax increases necessary (Fulbrook 2004).

In 1992 the European integration made further progress. Through the Maastricht Treaty members of the European Union (EU) agreed on forming an economic and monetary union (EMU). The aim was to establish a common monetary policy, conducted by the yet to establish European Central Bank (ECB) and similar economic policies. Ultimately, a common currency should be introduced. These measures were to be implemented in three different stages over the following few years (Mayes and El-Agraa 2011).
Chancellor Kohl lost the election in 1998. A new government was formed by the SPD and the Greens and Gerhard Schröder became new Chancellor (Fulbrook 2004). On the 1st January 1999 the Euro became the new currency (European Commission 2002). After years of slow economic growth and high unemployment, the Schröder government started to implement a fundamental reform of the German welfare state in 2003 (Jacobi and Kluve 2006). Schröder lost the following election in 2005 and Angela Merkel from the CDU became the new Chancellor. She formed a coalition with the SPD. After the election in 2009 the FDP replaced the SPD as the coalition partner. In the same year, Germany experienced its worst post-war recession, as a consequence of the global financial crisis (OECD 2012; Maddison 1991). The financial crisis led to enormously high budget deficits of some countries of the European Monetary Union. As some of these countries already had very high levels of debt before the financial crisis these increasingly high deficits started to threat their ability to refinance themselves. This led to the Euro crisis which became a serious threat for the existence of the common currency.

3.3 Economic history of West-Germany from 1945 to 1970

After having introduced the political history, the following sections take a closer look at the economic developments. As this thesis is only analysing West Ger-
many’s growth and the one of the reunited Germany, this section looks at the West German economic development from 1945 to 1970 and ignores the economic development in East Germany. The information provided in this section will help to put the West German economic development during the time period from 1971 to 1990 into context.

3.3.1 Currency reform and the social market economy

In the early post-war years, most Germans did not believe in capitalism. Therefore, they wanted West Germany to implement a socialist system. A socialist West Germany was also favoured by the British and French, because they believed that a socialist Germany would not be as dangerous as a capitalist one. But Americans had other plans for West Germany’s economic future. In 1948, they appointed the economist Ludwig Erhard as economic director of the Economic Council. Erhard, a proponent of the free market, had a big influence on the West German economic development over the following two decades (Bark and Gress 1993b).

At the time of Erhard’s appointment approximately half of the trading occurred on the black market. The official currency, the Reichsmark was basically worthless, because of the strong expansion of the money supply during war. In fact, West Germans were actually using cigarettes and chocolate as their currency. There-
fore, Erhard and the leadership of the Trizone decided to implement a currency reform (Carlin 1996). The new currency, the *Deutsche Mark* was printed in the US and was introduced promptly after its announcement. The enforced exchange with a devalued Reichsmark was a success. It ended the black market and led to a redistribution of wealth in which holders of real assets were favoured at the cost of holders of financial assets. In addition, the currency reform filled the shops with products which were withheld from trade before (Carlin 1996). The introduction of a new currency also had important psychological effects. Together with the announcement of the Marshal plan it increased the confidence in a better economic future for West Germany. Simultaneously to the implementation of the currency reform, Erhard also stopped price controls and rationing, which both were measures that were normally only used in command economies (Bark and Gress 1993b).

The currency reform could only be a first step towards a more prosperous future. In fact, while shops were now offering products they have not been offering before, Germans did not possess the money to buy these products. The currency reform also led to an increase in unemployment over the following months because employers did not have enough money to pay wages to their workers (Bark and Gress 1993b).
Besides implementing the currency reform, Erhard also designed the economic system of West Germany - the *Social Market Economy*. This system is based on *ordo-liberal* ideas put forward by the German economist Walter Eucken and a group of other scholars. While they advocate an economic system which is anti-interventionist and guided by the price mechanism, they also demand a strong state to enforce social responsibility. Completely free markets are rejected on the grounds that they can give too much power to monopolies, unions or other groups which then have the potential to undermine the free market for self benefit (Tribe 1995 and Carlin 1996).

### 3.3.2 The economic performance from 1950 to 1970

Both the currency reform and the social market economy were a good basis for economic success. Figure 3.1 shows West Germany’s economic growth from 1950 to 1970:
Figure 3.1: RGDP growth rate, West Germany 1950-1970

Source: Maddison (1991)

Figure 3.1 shows that with the exception of 1958, West German economic growth during the 1950s was extremely strong. The average growth rate during this decade was 8.50 per cent\(^1\). Economic growth slowed down over the 1960s, but it was still at a fairly strong 4.89 per cent on average, even though West Germany experienced a mild recession in 1967. After the recession growth accelerated quickly and the economy grew by more than 5 per cent in the last three years of the time period. In total, average economic growth was at 6.68 per cent over the period from 1950-1970 (Maddison 1991).

\(^1\)This refers to the geometric average. All averages in this thesis are given as the geometric average, because it is a better measure than the arithmetic average when dealing with time-series data.
At the same time unemployment declined significantly, as shown by Figure 3.2:

Figure 3.2: Unemployment rate, West Germany 1950-1970

Source: Maddison (1991)

Figure 3.2 illustrates that while unemployment was at over 8 per cent in 1950, it dropped to 1 per cent in only ten years time and it then fell even further to 0.5 per cent in 1965. During the recession it increased to 1.7 per cent, but fell to its pre-recession level soon after (Maddison 1991).

3.3.3 The economic miracle

West Germany’s remarkable economic performance from 1950 to 1966 is commonly referred to as the *Wirtschaftswunder*, or the economic miracle (Wolf 1995). What
are the reasons behind West Germany’s extraordinarily strong economic performance? While the Marshall plan, the currency reform and the German economic system served as a good foundation for economic success, they were not the factors which triggered the economic miracle. The literature credits the strong growth rates to two other factors. One is the Korean War, from which the West Germany economy benefited strongly. While the US, England and Western European countries used almost all over their production capabilities to create goods needed for the Korean War, West Germany had a lot of free production capacities. It started to use these capacities in order to produce industrial goods such as machine tools, steel and construction equipment. As the other countries used all their resources producing war material, the international demand for these industrial goods was very high. Because West Germany was able to sell so many of these goods, it regained its leadership in many of its traditional markets (Bark and Gress 1993b). The strong demand also enabled strong investments into new capital equipment, leading to a comparable young capital stock and hence a higher productivity (Carlin 1996).

The second reason for the extraordinary growth rates was that West Germany benefited enormously from the immense inflow of highly educated workers coming from East Germany. Many of the East German immigrants were engineers or doc-
tors. Through the inflow of free human capital West Germany did not only save money on education, it also gained from the increasing consumer demand. The mass immigration of highly trained human capital has actually often been identified as the main reason why West Germany did not experience just an economic boom but a miracle (Bark and Gress 1993b).

As noted above, the mass inflow of East Germans ended with the construction of the Wall in 1961 (Bark and Gress 1993b). To address the resulting labour shortage, West Germany started to recruit foreign workers from other countries. However, most of these foreign workers had very low qualifications and worked in low-skilled industry jobs (Carlin 1996).

Economic growth was also strongly supported by the housing market. As reconstructing was still ongoing and with the big stream of immigrants arriving in Germany, the demand for new houses and flats was high (Bark and Gress 1993b).

### 3.3.4 The first recession

The period of the economic miracle ended when West Germany entered its first recession in 1966/67. While output decreased only modestly, unemployment increased from 0.6 per cent to 1.7 per cent during this time (Maddison 1991). In
response to the recession the Kiesinger government implemented the *Law to promote stability and growth to the economy*. This law established greater government influence in economic planning and was conform with the belief of many German policy makers of the late 1960s which advocated that business cycles and economic growth could be controlled by direct government action. Therefore, it marked a change in West German economic policy making, because the stabilisation law violated the rules of the social market economy (Bark and Gress 1993a).

A positive effect of the recession was that it led to an increase in productivity over subsequent years, because it revealed over and misinvestments. In addition, it led to an improvement in the allocation of labour between industries (Carlin 1996). Therefore, economic growth reached high levels again and the unemployment rate fell quickly, as indicated previously in Figure 3.1 and Figure 3.2.

However, from the mid 60s onwards, the government subsequently increased its expenditure, often at rates higher than economic growth. This is in particular true for the Brandt government, which took power in 1969 (Bark and Gress 1993a).
3.4 Trend analysis: West Germany from 1971 to 1990

This section will look at West Germany’s economic performance from 1971 to 1990 in more detail. The aim is investigate patterns and reasons for these patterns before this time period is analysed empirically. First, it is looked at the developments of real GDP growth, growth in net capital stock and employment. Then possible reasons which were found in the literature are discussed. The information provided will help interpreting the empirical results.

3.4.1 The evolution of RGDP, the net capital stock and employment

3.4.1.1 RGDP

Figure 3.3 demonstrates the change in RGDP:
Figure 3.3: Change in RGDP, West Germany 1971-1990

Source: OECD (2012)
The average economic growth of West Germany over this time period was 2.61 per cent, which is a lot lower than the 6.68 per cent it had experienced over the period from 1950 to 1970. As Figure 3.3 shows, the economy grew strongly with growth rates of more than 3 per cent in the first three illustrated years. Then growth declined and West Germany suffered from a recession in 1975. After the recession growth accelerated quickly and the economy grew steadily during the years from 1976 to 1979. This was followed by fairly weak growth in the years from 1980 to 1987, including another recession in 1982. After 1987 the West Germany economy started to grow strongly again, leading to its highest GDP growth in the illustrated period in the year of 1990. Overall, it can be seen that the RGDP trend was very volatile during this time period.

Figure 3.4 and Table 3.1 decompose the RGDP evolution into agriculture, industry and selected service sectors:²

---
²It is important to note that some sectors have been omitted and the numbers will therefore not add up to total RGDP. The same applies to all other decompositions including capital and labour in the remainder of this chapter.
Figure 3.4: Decomposition of RGDP growth, West Germany 1971-1990

Source: OECD (2012)
Notes: This decomposition does not include all sectors that build total RGDP. Selected service sectors refers to an aggregation of wholesale and retail trade, repairs; hotels and restaurants; transport; Financial intermediation; real estate, renting and business activities; other service activities.
Table 3.1: Decomposition of RGDP into key sectors, West Germany 1971-1990

<table>
<thead>
<tr>
<th></th>
<th>RGDP</th>
<th>Agriculture</th>
<th>Industry</th>
<th>Selected Service Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average growth</td>
<td>2.61%</td>
<td>1.50%</td>
<td>1.17%</td>
<td>3.59%</td>
</tr>
<tr>
<td>Share 1971</td>
<td>100.00%</td>
<td>1.15%</td>
<td>28.99%</td>
<td>46.66%</td>
</tr>
<tr>
<td>Share 1990</td>
<td>100.00%</td>
<td>0.94%</td>
<td>25.21%</td>
<td>55.39%</td>
</tr>
</tbody>
</table>

Source: OECD (2012)

From Figure 3.4 and from Table 3.1 it can be seen that the selected service industries have the highest share in RGDP and that this aggregate experienced the strongest economic growth. In fact, the economic growth rate of the selected service sectors was more than three times as big as the one of the industry sector and more than double as big as the one of the agricultural sector. The share of the agricultural sector is by far the lowest, and it decreased further over the sample period. The share of the industry sector decreased slightly and the one of the selected service sectors increased by almost 10 per cent.

3.4.1.2 Net Capital Stock

Figure 3.5 shows the evolution of the net capital stock:
Figure 3.5: Change in Net Capital Stock, West Germany 1971-1990

Source: Statistische Ämter des Bundes und der Länder (2006)
The net capital stock grew by only 0.33 per cent on average over the sample period. Figure 3.5 shows that in the first three years the net capital stock growth was around 2 per cent. But this growth slowed down in 1974 and 75, where West Germany experienced a recession as explained above. In the following five years the net capital stock growth was slightly above 0.50 per cent which is far below to what it had been before the recession. In 1980, which was one year after economic growth started to weaken, the capital stock growth declined to even lower levels. In fact, from 1982 onwards, which is the year of the recession, the net capital stock decreased. Net capital stock growth remained negative until the end of the time period and achieved its lowest value of around -0.7 per cent in 1987. From 1987 onwards the net capital stock growth increased slightly. In summary it is learnt that the two recessions had strong and persistent adverse effects on West Germany’s capital stock growth.

Figure 3.6 and Table 3.2 provide insights on West Germany’s capital formation:
Figure 3.6: Decomposition of Gross Fixed Capital formation, West Germany 1971-1990

Source: OECD (2012)
Notes: The graph does not show all factors that contribute to gross fixed capital formation.
Looking at Figure 3.6 and Table 3.2 it can be seen that gross fixed capital formation increased over the sample period. However, it is shown to be very volatile. Two downward movements can be identified in 1974/75 and in 1980/81 which falls together with the two recessions. After both recessions an increasing trend is apparent.

Figure 3.6 and Table 3.2 also demonstrate that most investments went into housing or other constructions. However, an increasingly share of investments was absorbed by metal products and machineries, especially during the 1980s. This is surprising given the fact that the previous section has demonstrated that the share of the industry in relation to RGDP was decreasing. It can also be seen that the importance of both housing and other constructions is declining, because both
sectors experienced a lower growth rate than total gross fixed capital formation did.

3.4.1.3 Employment

Figure 3.7 shows the development of employment over the sample period:
Figure 3.7: Change in Employment, West Germany 1971-1990

Source: OECD (2012)
On average, employment increased by 0.48 per cent on average over the total sample period. Figure 3.7 indicates that employment grew over the first three years of the sample period. As outlined above, West Germany experienced strong economic growth during these years. Employment decreased in the year from 1974 to 1976 with the decrease in 1975 being especially strong. This development is in line with the observations about the developments of GDP and capital stock growth. However, it can be seen that the recession affected employment more strongly than RGDP and capital stock growth. From 1977 to 1980 employment increased again. This recovery in employment is lagging one year behind the recovery in terms of RGDP growth. The second recession brought another decrease of employment. This time it lasted four years, but the strongest decrease in 1983 was not as severe as the one in 1975. From 1985 onwards total employment started to increase. Strong growth rates were achieved in the years of 1986 and 1989, and a very strong growth occurred in 1990 during which RGDP growth was also extraordinarily strong.

Figure 3.8 and Table 3.8 decompose total employment into three different sectors:
Figure 3.8: Decomposition of Employment, West Germany 1972-1989

Source: International Labour Organization Department of Statistics (2012)

Notes: This decomposition does not include all sectors that build total employment. Selected service sectors refers to an aggregation of wholesale and retail trade, repairs; hotels and restaurants; transport; Financial intermediation; real estate, renting and business activities; other service activities. No data was available for the years 1971 and 1990.
<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Agriculture</th>
<th>Manufacturing</th>
<th>Selected Service Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth rate</td>
<td>0.22%</td>
<td>-3.99%</td>
<td>-0.69%</td>
<td>1.16%</td>
</tr>
<tr>
<td>Share 1972</td>
<td>100.00%</td>
<td>7.70%</td>
<td>36.82%</td>
<td>44.54%</td>
</tr>
<tr>
<td>Share 1989</td>
<td>100.00%</td>
<td>3.71%</td>
<td>31.56%</td>
<td>56.51%</td>
</tr>
</tbody>
</table>

Source: International Labour Organization Department of Statistics (2012)

Attention should be drawn to the fact that Figure 3.8 and Table 3.8 do not include the years 1971 and 1990, because no data was available for these years. Table 3.8 shows that during this sample period employment in the selected service sectors increased by over one per cent on average. In contrast, employment in agriculture decreased strongly and employment in manufacturing decreased modestly. Therefore, West Germany’s economy experienced a structural change in terms of employment. In addition, as it was shown before that both the RGDP of agriculture and the RGDP of industry were rising and because of increasing investments into machinery, it appears that labour saving technological progress was occurring in both sectors.

3.4.1.4 Summary

Figure 3.9 shows the evolution of the RGDP, net capital stock and employment in one graph:
Figure 3.9: Change in RGDP, Capital Stock and Employment, West Germany 1971-1990

Sources: OECD (2012) and Statistische Ämter des Bundes und der Länder (2006)
Figure 3.9 shows a strong positive correlation between RGDP and employment growth with employment lagging behind RGDP growth. In contrast to RGDP and employment growth, the capital growth is moving quite smoothly, but its correlation with the other factors is quite weak. The following sections are explaining the reasons behind the observed trends.

3.4.2 Inflation and the first Oil-Crisis

The strong economic growth from 1970 to 1974 was a consequence of the 1966/67 recession. The 1966/67 recession had spurred on the restructuring of the production capacity of West Germany’s economy leading to a significant rise in productivity growth (Bark and Gress 1993a). A problem for the West German economy during the 1970s, however, was the inflation rate which reached pretty high levels as demonstrated by Figure 3.10:
Figure 3.10 illustrates that after experiencing low inflation rates of less than two per cent in the first three years, inflation steadily rose up until 1973. The raising inflation rates were a result from the increasing spending of the Brandt government and from high wage demands of the unions (Bark and Gress 1993a). The price levels were pushed even further when an oil embargo of the oil exporting Arab states in 1973 increased the oil price to four times its average value from 1972 (Maddison 1991). This led the inflation rate to climb to levels of around 7 per cent in both 1973 and 1974. Energy prices became higher than they had ever been.

Source: OECD (2012)
before and this hit the West German economy with its energy consuming industry at a very sensitive spot. Besides production becoming more expensive, some of West Germany’s capital stock also became obsolete, because the new energy prices made its usage simply unprofitable (Siebert 2005).

The decrease of the West German production capacity led to a constant loss in purchasing power (Siebert 2005). As a result, West Germany was experiencing a recession in 1975 and unemployment rose from around 1 per cent in 1973 to over 4 per cent in 1975 (OECD 2012). Given the high inflation and increasing unemployment, Germany was suffering from stagflation. The high inflation rates also made new investments fairly unattractive. After 1974, inflation started to decrease but it remained on higher than normal levels.

The first oil-crisis was an important lesson to West Germany because it highlighted its dependence of the oil exporting countries. Over the following years both the government and enterprises worked hard on decreasing this dependence. For example, companies focused on decreasing the oil consumption of their capital stock. In addition West Germans became more responsible with their energy consumption. As a result the overall energy consumption decreased and West Germany even managed to achieve a trade surplus with some of the oil exporting countries
3.4.3 Years of weakening economic growth and the second Oil-Crisis

The first oil price shock has marked the beginning of a period during which the extraordinary post-war economic growth rates became unreachable. Comparing Figure 3.1 with Figure 3.3 it is clearly evident that the strength of economic growth declined. This was not only the case for West Germany, but also for the other OECD countries (Maddison 1995).

Maddison (1995) identified various reasons for the weak economic growth of West Germany and other OECD countries during this time. Besides the already mentioned oil price shocks the downfall of the Bretton Woods fixed exchange rate system in 1971 also had a weakening effect on economic growth during this time. Both policy makers and entrepreneurs had to learn how to deal with floating exchange rates. Therefore, there was a transitional period during which stakeholders were adapting to the new system. Similar to this, there was also a general caution among policy makers which resulted from the disappearance of the consensus on macroeconomic theory, like the Philips-curve. Whereas the Philips-curve had been a trusted policy tool during the 1960s, policy makers were becoming more
and more unsure about the Philips-curve’s applicability in particular and Keynesian policies in general (Maddison 1995).

Nevertheless, one of the most important reasons for West Germany’s slowing economic growth is illustrated in Table 3.4:

Table 3.4: Level of GDP per man hour - Comparison West Germany and USA, 1950-1982

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>West Germany</td>
<td>36</td>
<td>55</td>
<td>77</td>
<td>94</td>
</tr>
<tr>
<td>USA</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Maddison (1995)

Table 3.4 shows the West German level of GDP per man hour in relation to the US level, which was the highest level in productivity of all countries. It can be seen that West Germany’s productivity as proxied by man hours was far behind the one of the US during the 1950s and 60s. Hence, it was fairly easy for West Germany to increase its productivity because it could simply implement the existing advances in production technology which were already being used by other countries like the US. Therefore, productivity increased quickly and the West German economy was growing strongly. However, as West Germany’s productivity approached US levels, the catch-up bonus disappeared. West Germany now had to implement new production techniques at the speed at which these advances were being made.
Therefore, economic growth slowed down (Maddison 1995).

From 1978 rising inflation rates became a concern again as previously shown in Figure 3.10. Since West Germany’s economy was very dependent on its exports, the decrease in competitiveness through the increase in prices was very harmful to its economic growth. In 1980 a second oil price shock occurred (Bark and Gress 1993a). Like the first oil crisis, it led to a decrease in employment and investment and to a recession, which occurred in 1982. As a result unemployment reached 8 per cent in 1983 as shown by Figure 3.11:

Figure 3.11: Unemployment rate, West Germany 1971-1990

Source: OECD (2012)
The high unemployment led to increasing government expenditure, because more people had to be supported by the welfare system. As inflation continued to be high, West Germany began to experience another stagflation (Siebert 2005).

### 3.4.4 The recovery of the 1980s

From 1981 onwards, the inflation rate started to decrease. One reason was that wage demands of the unions were very moderate. In addition, the Kohl government managed to achieve a surplus in the federal budget, after years of deficits. At the same time the economy was stimulated through tax cuts which were implemented over several steps (Siebert 2005). As a consequence economic success returned to West Germany. It achieved strong GDP growth and increasing employment, as demonstrated by previously by Figure 3.9. Therefore, unemployment started to fall as shown previously by Figure 3.11. The next sections offers some details on the German reunification.

### 3.5 The reunification

West Germany and East Germany reunited in 1990. The German Economic, Monetary and Social Union (GEMSU) took effect on 1. July 1990, whereas the political union started on 3. October 1990. Compared to the capitalist West German economy, the socialist East German economy was extremely backwards and
it was estimated that East Germany’s per capita GDP was only one third of West Germany’s at the time of the reunification (Lange and Pugh 1998). In addition the GDR was basically bankrupt (Bark and Gress 1993a).

The West German Chancellor Helmut Kohl was warned by many economists about implementing the economic and the political unification too quickly, because it would lead to enormous costs (Lange and Pugh 1998). But to Chancellor Kohl it was clear that once the chance for the reunification was given it had to be taken and acted upon immediately. Furthermore, the German population wanted the reunification at whatever the cost would involve (Bark and Gress 1993a).

With the GEMSU the Deutsche Mark became the currency of the GDR. The conversion rate of the East German to the West German Mark was set to 1 to 1. In addition, the West German welfare system was extended to cover East Germans and East Germany adopted the social market economy. This meant that most East German state-owned enterprises had to be privatised. The privatisation was managed by the Treuhandanstalt (Lange and Pugh 1998).

For the East German economy, the reunification led to what Akerlof et al. (1991, p. 5) have called a depression ‘without historic precedent’. By December 1990,
production of goods had fallen to 46 per cent of its 1989 level and unemployment was increasing rapidly. Several reasons were behind this. First, East German companies were not able to survive in a competitive environment. Their capital equipment was too old and their wage expenditure was too high (Akerlof et al. 1991). They were also suffering enormously from the consequences of the 1 to 1 conversion rate, because this implied an appreciation of the East German Mark of over 400 per cent (European Commission 2002). The conversion rate also set wrong wage expectations among East Germans, leading to unrealistic demands in wage negotiations. As the West German institutional framework of collective bargaining was applied to East Germany, West German unions achieved wage increases for East Germans, which were totally out of line with East German productivity. This made East Germany very unattractive for investments (Siebert 2005).

Further reasons for the severe downturn were the collapse of traditional East German trading patterns resulting from the collapse of the Soviet Union. With the end of the GDR East German companies were also cut-off from their usual source of credit (the government) and they were suddenly exposed to an economic environment which was absolutely new to them (Lange and Pugh 1998).

These developments demonstrated the German government that the costs of the
reunification were higher than expected. As a consequence, Chancellor Kohl had to break his promise that no tax increases were necessary in order to finance the reunification. The tax increases were implemented in 1991 (Bark and Gress 1993a).

After having shed some light on the economic implications of the reunification on the East German economy, the next section looks at the economic development of Germany over the following period.

3.6 Trend analysis: Germany from 1992 to 2011

The time period from 1992 to 2011 is the second period which is analysed empirically in this thesis. The year of 1991 is excluded from the empirical analysis, because as a result of the reunification, both the labour stock and the capital stock experienced very strong changes, which would bias the estimations. In addition, it was impossible to aggregate a robust estimate of the capital stock in 1991.

Like before, the general trends are outlined first and then the reasons will be analysed.
3.6.1 The evolution of RGDP, the net capital stock and employment

3.6.1.1 RGDP

Figure 3.12 shows the development of RGDP from 1992 to 2011:
Figure 3.12: Change in RGDP, Germany 1992-2011

Source: OECD (2012)
Germany’s RGDP grew by 1.33 per cent on average over the sample period, which is fairly weak. Figure 3.12 indicates that shortly after the reunification the economy was hit by a recession in 1993, where RGDP contracted by one per cent. Following the recession, Germany experienced eight years of weak economic growth, with the exception of 1994 and 2000, where growth was strong. RGDP contradicted again in 2002 and 2003. This was followed by five years of economic growth, including two years of growth higher than 3 per cent. In 2009, Germany was hit by a massive recession, where GDP declined by slightly more than 5 per cent, which is by far the strongest recession it has experienced in its post-war history (OECD 2012; Maddison 1991). In 2010 and 2011 the German economy recovered, achieving growth rates higher than 3 per cent in both years. But in total, Germany’s economic growth performance in the time period from 1992 to 2011 could not keep up with the one of the time period from 1971 to 1990.

Figure 3.13 and Table 3.5 show the decomposition of RGDP into selected time periods for 1992 to 2010 (there was no data available for 2011):
Figure 3.13: Decomposition of RGDP growth, Germany 1992-2010

Source: OECD (2012)
Notes: This decomposition does not include all sectors that build total RGDP. Selected service sectors refers to an aggregation of wholesale and retail trade, repairs; hotels and restaurants; transport; Financial intermediation; real estate, renting and business activities; other service activities. No data was available for 2011.
Table 3.5: Decomposition of RGDP into key sectors, Germany 1992-2010

<table>
<thead>
<tr>
<th></th>
<th>RGDP</th>
<th>Agriculture</th>
<th>Industry</th>
<th>Selected Service Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average growth</td>
<td>1.24%</td>
<td>0.18%</td>
<td>0.34%</td>
<td>2.11%</td>
</tr>
<tr>
<td>Share 1992</td>
<td>100.00%</td>
<td>0.84%</td>
<td>23.89%</td>
<td>57.18%</td>
</tr>
<tr>
<td>Share 2010</td>
<td>100.00%</td>
<td>0.72%</td>
<td>20.97%</td>
<td>65.84%</td>
</tr>
</tbody>
</table>

Source: OECD (2012)

Figure 3.13 shows that the gross value added of the industrial sector decreased after the reunification and again during the financial crisis. Regarding the overall development of the industrial sector over this time period Table 3.5 indicates a very weak growth of 0.34 per cent. The agricultural sector grew even less strongly than that. Only the aggregate of the selected service sectors grew at a moderate rate of over 2 per cent. In comparison to the previous time period the growth of all sectors was weaker: the agricultural sector by roughly 1.3 per cent, the growth of the industrial sector by around 0.8 per cent and the one of the selected service sectors by roughly 1.5 per cent.

The development of the shares of the sectors to total RGDP is similar to the one of the period from 1971 to 1990. The share of both agriculture and industry decreased and the share of the selected service sectors increased. In addition it can be seen that the share of the agricultural sector in 1992 was marginally higher.
than it was in 1990, which is a result of the reunification, because East Germany had a strong agricultural sector.

3.6.1.2 Net Capital Stock

Looking at the development of the capital stock, which is shown in Figure 3.14, a strong negative trend is apparent:
Figure 3.14: Change in Net Capital Stock, Germany 1992-2011

Source: Statistische Ämter des Bundes und der Länder (2010)
Notes: The values for 2009 - 2011 are estimates based on own calculations. Refer to Chapter 5 for details.
Over the total period the net capital stock decreased by 0.88 per cent on average. After a weak growth in 1992 the net capital stock started to decrease during the recession of 1993. The decline of the net capital stock became stronger over the subsequent years and then remained at around -0.80 per cent for the years from 1998 to 2000. After 2000 the decline became stronger again and reached -1.40 per cent in 2005. During this time span economic growth was very weak as shown previously by Figure 3.12. In the years that followed 2005 the decline of the net capital stock growth was less strong but it remained far below positive growth rates.

Figure 3.15 and Table 3.6 are showing the decomposition of the gross fixed capital formation:
Figure 3.15: Decomposition of Gross Fixed Capital formation, Germany 1992-2011

Source: OECD (2012)

Notes: The graph does not show all factors that contribute to gross fixed capital formation.
Table 3.6: Decomposition of Gross Fixed Capital formation, Germany 1992-2011

<table>
<thead>
<tr>
<th></th>
<th>Gross fixed capital formation</th>
<th>Metal products and machinery</th>
<th>Transport equipment</th>
<th>Housing</th>
<th>Other constructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average growth</td>
<td>0.92%</td>
<td>1.84%</td>
<td>1.08%</td>
<td>0.52%</td>
<td>-0.67%</td>
</tr>
<tr>
<td>Share 1992</td>
<td>100.00%</td>
<td>24.35%</td>
<td>9.86%</td>
<td>32.23%</td>
<td>31.58%</td>
</tr>
<tr>
<td>Share 2011</td>
<td>100.00%</td>
<td>30.78%</td>
<td>11.91%</td>
<td>28.29%</td>
<td>21.71%</td>
</tr>
</tbody>
</table>

Source: OECD (2012)

In total, gross fixed capital formation increased by slightly less than one per cent over the sample period as indicated by Table 3.6. This growth is around 0.80 per cent below the growth rate of the period from 1971 to 1990. From Figure 3.15 it can be seen that the gross fixed capital formation decreased at the same time as RGDP decreased as previously indicated by Figure 3.12.

As Table 3.6 illustrates, investments into metal products and machinery increased the strongest over the time period. Therefore, the trend of the previous period continued. At the end of the period investments into metal products and machinery actually had the highest share in total investment. In regards to other investments, investments in housing grew very weakly and investments into other constructions declined over the sample period.
3.6.1.3 Employment

Lastly, looking at employment the overall impression from Figure 3.16 is that the evolution in employment was very erratic:
Figure 3.16: Change in Employment, Germany 1992-2011

Source: OECD (2012)
Figure 3.16 highlights that employment decreases by more than 1 per cent in both 1992 and 1993. During the years 1994, 1996 and 1997 employment continued to decrease, but at a smaller rate. In 1998 employment increased strongly, even though no extraordinarily strong increase in GDP was observed for that year. This increase in employment was first followed by a decrease and then by two years during which employment increased. During 2002 and 2003 employment decreased strongly, but this was followed by four years where it increased strongly. These four years of strong growth in employment fell together with a time during which RGDP also increased, as previously shown in Figure 3.12. Surprisingly, employment decreased only modestly in 2009, which was the year during which Germany suffered from its worst post war recession. Following the recession employment increased slightly in 2010, but in 2011 it decreased again. The average growth rate in employment over the whole period was 0.16 per cent, which is very weak and less than in the time period of 1971 to 1990.

Figure 3.17 and Table 3.17 decompose total employment into three sectors:
Figure 3.17: Decomposition of Employment, Germany 1992-2008

Source: International Labour Organization Department of Statistics (2012)
Notes: This decomposition does not include all sectors that build total employment. Selected service sectors refers to an aggregation of wholesale and retail trade, repairs; hotels and restaurants; transport; Financial intermediation; real estate, renting and business activities; other service activities. No data was available for the years after 2008.
Table 3.7: Decomposition of Employment, Germany 1992-2008

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Agriculture</th>
<th>Manufacturing</th>
<th>Selected Service Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. change rate</td>
<td>0.30%</td>
<td>-2.82%</td>
<td>-1.48%</td>
<td>1.38%</td>
</tr>
<tr>
<td>Share 1992</td>
<td>100.00%</td>
<td>3.73%</td>
<td>29.29%</td>
<td>57.29%</td>
</tr>
<tr>
<td>Share 2008</td>
<td>100.00%</td>
<td>2.25%</td>
<td>21.99%</td>
<td>68.08%</td>
</tr>
</tbody>
</table>

Source: International Labour Organization Department of Statistics (2012)

Table 3.7 shows that employment in manufacturing decreased by over one per cent on average, resulting in a decrease to a share of roughly one fifth of total employment in 2008. The agricultural sector suffered from an even stronger decrease, with average growth rates of almost minus three per cent. The employment of the selected service sectors increased. Therefore, the structural change which was already observed for the period of 1971 to 1990 continued.

3.6.1.4 Summary

Figure 3.18 shows the evolution of RGDP, the net capital stock and employment in one graph:
Figure 3.18: Change in RGDP, Capital Stock and Employment, Germany 1992-2011

Sources: OECD (2012) and Statistische Ämter des Bundes und der Länder (2010)
As for the period from 1971 to 1990, a positive correlation between GDP growth and employment growth can be observed in Figure 3.18, but the correlation appears to be less strong than it was in the period from 1971 to 1990. There is also a correlation between capital stock growth and RGDP growth, but it seem to be very weak. After having set out the general trends the following section looks at the reasons behind these developments.

### 3.6.2 The first few years after reunification

The low economic growth rates during the 1990s had a couple of reasons. One reason was the severe economic depression in East Germany following the reunification. This strong economic downfall in East Germany affected the performance of the whole German economy. In addition, the reunification led to a decline in competitiveness. This was especially challenging as Germany was now competing on the Single European Market, where goods, capital and people could move freely across the participating European countries. Having to bear the huge cost of the reunification, which had required tax increases, made it very hard to succeed in such a competitive economic environment (Carlin 2009). Another reason for slow growth was the strong appreciation of the Deutsche Mark in the beginning of the 1990s (European Commission 2002). This made goods produced in Germany more expensive. In addition, domestic demand, especially private consumption
and construction investment, was fairly weak during the 1990s (European Commission 2002).

Therefore, the low economic growth rates during the 1990s were not surprising. The recession which occurred in 1993 as indicated by Figure 3.12 was mainly a consequence of a general downturn of the world economy in 1992 (Siebert 2005). As a consequence of the weak economic growth performance employment decreased. Figure 3.19 illustrates that this led to an increase of unemployment from 5 per cent in 1990 to almost 10 per cent in 1997:

Figure 3.19: Unemployment Rate, Germany 1990-1999

Source: OECD (2012)
3.6.3 Limited policy measures to stimulate growth

Germany’s economic tools to fight the weakness were fairly limited. The EMU member states were now conducting a common European monetary policy, which made it impossible for Germany to stimulate economic growth using monetary policy (Carlin 2009). Stimulating the economy using fiscal policy was also impossible, because Germany was bound to the Maastricht treaty, which established strict economic criteria on the member states of the EMU. For example, the government budget deficit was not allowed to be more than 3 per cent of GDP (Mayes and El-Agraa 2011). As Table 3.8 indicates, Germany had a deficit of 9.5 per cent in 1995. Shortly before the introduction of the Euro, the deficit was pushed below 3 per cent:

Table 3.8: Government deficit/surplus in percent to GDP, Germany 1995-1999

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>-9.5</td>
<td>-3.4</td>
<td>-2.8</td>
<td>-2.3</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

Source: Eurostat (2012)

Decreasing the government budget deficit was especially challenging because the German welfare state had to support an increasing number of unemployed people as Figure 3.19 has shown previously. Thus, the budget did not leave any room to pursue strong expansionary fiscal policy.
3.6.4 The wage policy

Besides the aftermaths of the reunification, weak economic growth also resulted from a more fundamental problem. The German economy wasted huge amounts of labour. Figure 3.19 has previously shown that unemployment over the 1990s increased strongly and unemployment continued to rise during the early 2000s (OECD 2012).

Why did the German economy fail to integrate so many unused resources? It has been argued that wage policy is one of the main reasons behind high unemployment (e.g. European Commission 2002; Siebert 2005). In Germany, wages are not determined by the market, but in a sector-wide bargaining process between the unions and the employers associations, which usually results in wages being set nationwide (Siebert 2005). Figure 3.20 uses the example of the growth rate in hourly earnings in the manufacturing sector to highlight that wage policy did not lead to an appropriate development of wages:
Figure 3.20: Growth rate of hourly earnings in manufacturing, Germany 1991-2000

Source: OECD (2012)

Figure 3.20 shows that especially during the early 1990s wages increased very strongly. Since unemployment was increasing at the same time as previously shown by Figure 3.19, this wage development provides evidence for a malfunctioning in the labour market resulting from inappropriate wage policy.

Since the mid-1990s the wage policy changed. The East German states and many small firms in West Germany left to collective wage setting agreement and started to negotiate their own wages, often using the sectoral agreement as a point of reference. In addition, unions lost both members and influence over the 1990s (Burda
and Hunt 2011; Carlin 2009). As a result, wage increases in subsequent years were less strong (Carlin 2009). For the time span of 2001 to 2008 wages even stayed constant (Burda and Hunt 2011).

From the mid-1990s onwards, the German industry also improved its production processes, making more use of cheap inputs from abroad. Both the reform of the wage setting system and improvements in the production processes increased the competitiveness of the German economy. As a result, Germany experienced an export boom over the following years (Carlin 2009). This even led to a fairly strong economic growth of more than 3 per cent in 2000, as Figure 3.12 demonstrated.

### 3.6.5 The reform of the welfare system

Nevertheless, Germany still did not manage to achieve strong long-run economic growth. Consequently, the German economy was outperformed by almost all other European countries during the 1990s and early 2000s (European Commission 2002). In addition, during the early 2000s the situation on the labour market continued to get worse, as Figure 3.21 illustrates:
To fight the high rate of unemployment, the Schröder government started to implement the most extensive welfare system reform in Germany’s post-war history, known as the *Hartz Reform*. The Hartz reform included four laws that were implemented over the time period from 2003 to 2005 (Jacobi and Kluve 2006).

Before the Hartz reform the German welfare system had been very generous. It provided unemployment payments which were sufficient to maintain the recipients’ social status, because they were linked to his or her previous earnings. The Hartz reform excluded low skilled labour from generous unemployment payments.
and only provides them with support to cover their basic living expenses (Carlin 2009). The intention behind this was to induce unemployed people to accept jobs that they would normally not want to do. Another part of the Hartz reform was the reformulation of the rights and duties of the unemployed by revising the legal and constitutional framework. Recipients of welfare payments are now forced to apply to a certain amount of jobs per month and they can lose their welfare payments if they do not accept a job offer (Jacobi and Kluve 2006). Other measures of the reform included changes in the regulation of the labour market and measures that were aiming to increase the efficiency of employment service agencies (Jacobi and Kluve 2006).

As shown by Figure 3.18, RGDP and employment started to increase strongly from 2003 onwards. In addition, the unemployment rate started to decrease significantly from 2005 onwards as illustrated by Figure 3.21. The Hartz reform was considered to be a great success.

3.6.6 The global financial crisis

In 2009, Germany was hit firmly by the global financial crisis and fell into its deepest recession of its post-war history (Maddison 1991; OECD 2012). The immense collapse of the economy was mainly due to the severe decline in world trade, which
affected the on exports relying German economy especially strong. However, in contrast to other economies, eg. the US economy, employment in Germany did not decrease much during the global financial crisis (Burda and Hunt 2011).

Burda and Hunt (2011) identified a couple of reasons for this. First, Burda and Hunt (2011) estimated that employers hired less than expected during the preceding boom period. In addition the use of working time accounts played a role. During the crisis a lot of workers only worked short hours (Burda and Hunt 2011). Therefore, less employment reductions were necessary. As indicated by Figure 3.12 the German economy recovered soon after the crisis and experienced strong economic growth over the two following years.

### 3.7 Conclusion

This chapter provided details about Germany’s political and economic development. It was shown that West Germany’s early economic development was supported by the Cold War (Marshall Plan, mass immigration into West Germany) and the Korea War (high demand for German production goods). This led to a period of high economic growth during the 1950s and 1960s. As such, West Germany’s turned into a wealthy and prosperous country just within two decades after a destructive war.
Growth slowed down over the period from 1971 to 1990 as West Germany was hit by two oil crises and its catch-up bonus disappeared. Economic growth rates were still moderately strong but unemployment started to increase. The reunification in 1990 brought further challenges, because East Germany was relatively poor and its enterprises were not used to compete on the world market. This and a couple of other problems led to a poor economic performance of Germany after the reunification. The rising unemployment and the weak economic growth led to an extensive reform of the welfare state in the mid-2000s. After this reform economic growth accelerated and unemployment started to decrease.
Chapter 4:  Empirical Analysis

4.1  Introduction

This chapter provides the empirical analysis of the growth models which were introduced in Chapter 2. Section 4.2 provides details on the data sources and any necessary data manipulation. Then the different growth models are estimated in the following sections. It is started with the application of Solow (1956) - Swan (1956) growth framework which is found in Section 4.3. The application of the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model is found in Section 4.4 and the one of the Romer (1986) model is provided in Section 4.5.

4.2  Data

All growth models require values for output, capital input and labour input. In addition, the estimation of the Solow (1956) - Swan (1956) model requires an estimate for income shares. For the estimation of the Kaldor (Kaldor 1957; Kaldor
and Mirrlees 1962; Kaldor 1966) model data on the real output of the manufacturing sector and the employment in the manufacturing sector are needed. Lastly, the Romer (1986) model requires data which can serve as a proxy for knowledge. This thesis experiments with the number of patents, the research and development expenditure and the number of research and development personnel as possible proxies.

4.2.1 Output

The Gross Domestic Product (GDP) has been chosen as the proxy for output. This differs to Solow (1957), who chose Gross National Product (GNP) as the proxy for output in his paper, but it is in accordance with recent influential papers like Young (1994); Mankiw et al. (1992); Barro (1991). The GDP measures the estimated value of all goods and services produced within a country in a given year. In contrast, the GNP measure the estimated value of all goods and services produced by citizens of a country within this country or abroad. Therefore, the GDP is regarded as a more suitable choice for the aims of this thesis, as it attempts to analyse the economic growth of the German economy. Values for the GDP have been obtained from the OECD (2012). In particular, the *Gross Domestic Product, national currency, constant prices, OECD base year, millions* was taken. Therefore, the GDP values were in Euro and they were already adjusted to prices of 2005.
(which is the OECD base year), making an adjustment for inflation unnecessary.

4.2.2 Capital

4.2.2.1 Period 1970 - 1990

Next, the values for capital are required and this turned out to be a little bit more complicated. The best proxy for capital is the net capital stock, because it is a measurement of the total capital which is available for production. For the period from 1970 to 1990 the \( \text{Gross Capital Stock in prices of 2000} \) \( (\hat{K}_t) \) was obtained from Statistische Ämter des Bundes und der Länder (2006). These values required a few refinements, which are described in the following. The different steps can be followed by looking at Table Appendix B.1.

First of all, the obtained gross capital stock values have to be transformed into the same price level as the GDP values, which are in 2005 prices. Therefore, inflation rates \( i_t \) for the time period from 1970 to 2005 were obtained from the OECD (2012). Using these inflation rates, an inflation index \( \hat{P}_t \) with \( \hat{P}_{2000} = 1.00 \) was created using the following formula:

\[
\hat{P}_{t-1} = \frac{\hat{P}_t}{1 + i_t}
\] (4.1)
Using the 2000-inflation index, the gross capital stock was transformed to current prices through multiplication with the 2000-inflation index:

\[ K_t^* = \hat{K}_t \times \hat{P}_t \] (4.2)

Next, another price index, \( P_{2005} = 1.00 \) was created using the same formula as above. Using the new price index the gross capital stock in current prices is transformed into the gross capital stock in constant prices of 2005 by dividing it by the 2005-inflation index:

\[ \tilde{K}_t = \frac{K_t^*}{P_t} \] (4.3)

The final step is to transform the gross capital stock into the net capital stock. Therefore, it has to be adjusted for depreciation. The literature suggests a depreciation rate of 3 percent (eg. Romer 1989; Nehru and Dhareshwar 1993). Unfortunately, actual numbers for the net capital stock cannot be calculated, because the net capital stock of 1969 is unknown. Therefore, the net capital stock of 1970 is defined as \( K_{1970} = 100 \). Then, the change rate of the gross capital stock is calculated and depreciation is subtracted in order to derive the change of the net capital stock:

\[ \dot{K}_t = \frac{\bar{K}_{t+1} - \bar{K}_t}{\bar{K}_t} - 0.03 \] (4.4)
Accordingly, the relative values of the net capital stock are calculated as:

\[ K_t = K_{t-1} \times \dot{K}_t \]  

(4.5)

The results are shown in Table Appendix B.1.

4.2.2.2 Period 1991 - 2011

Values of the gross capital stock from 1991 to 2008 were obtained from the same source as the values of the previous period (Statistische Ämter des Bundes und der Länder 2010). For the years up until 2008, the same transformations as outlined above were performed. In regards to the creation of the two price indexes, for any years greater than the base year, the following equation has to be applied:

\[ P_t = P_{t-1} \times (1 + i_t) \]  

(4.6)

The results for the transformation of the gross capital stock in 2000 prices into the net capital stock in 2005 prices are shown in Table Appendix B.2. It is important to note that \( K_{1991} \) was defined to equal 100, and therefore the values of the net capital stock of this period cannot be compared with those of the previous period.

As this data source did not provide values for the gross capital stock for the years
2009 - 2011, these values were estimated. To do that, the *Gross fixed capital formation, national currency, constant prices, OECD base year, millions* \((I_t)\) for these years was extracted from OECD (2012) as a proxy for investments. These values were added to the gross capital stock:

\[
\tilde{K}_t = \tilde{K}_{t-1} + I_t
\]  

(4.7)

The obtained values were used to calculate \(\dot{K}_t\) and \(K_t\) applying the equation outlined above. The results can be seen in Table Appendix B.3. Unfortunately, these estimations are not satisfying, because net capital stock growth jumps from −0.991 percent in 2008 to 0.698 per cent in 2009. As it is quite unrealistic that the capital stock suddenly started to increase so sharply during the financial crisis, these estimates are not considered to be accurate and will therefore not be used.

As such, another approach is tested. The gross capital stock in current prices for the years 2009 to 2011 is estimated using the average change rate of the three previous years. Accordingly:

\[
\dot{K}_t^* = K_{(t-1)}^* \times \left( \frac{\dot{K}_{(t-1)}^* + \dot{K}_{(t-2)}^* + \dot{K}_{(t-3)}^*}{3} + 1 \right)
\]  

(4.8)

These estimates are transformed into the net capital stock using the exact same
method as outlined above. Table Appendix B.4 illustrates the results. Again, these estimates are somewhat problematic, because they advocate an increasingly strong decline in capital stock for 2010 and 2011. While it would be realistic that because of the global financial crisis the German capital stock decreased strongly in 2009, reasons for an increasingly strong decline for the years of 2010 and 2011 were not found in the analysis conducted in the previous chapter. Thus, these estimations are rejected as well.

The third approach is simply to calculate the average change in the net capital stock change rate of the three previous years and to estimate the net capital stock for 2009 to 2011 using these rates:

\[
\dot{K}_t = \frac{\dot{K}_{(t-1)} - \dot{K}_{(t-2)} - \dot{K}_{(t-3)}}{3} \tag{4.9}
\]

The results are shown in Table Appendix B.5. While they are not perfect, these estimates are considered to be the best ones because they are in line with the change rates of the previous periods. There surely is a concern whether the net capital stock estimates are a little bit too high, because the actual net capital stock in 2009 probably decreased more strongly as a result of the global financial crisis. Nevertheless, this method delivered the most realistic estimates as compared to the other methods. Hence these estimates are used to analyse Germany’s economic
growth.

4.2.3 Labour

*Total employment in persons* is used as a proxy for labour as it captures the size of the labour stock. This number was also obtained from the OECD (2012). Using total employment as a proxy for labour has its limitations, because it does not distinguish between part-time and full-time work. Nevertheless, for the aims of this thesis using total employment in persons is sufficient, because the derivation of other measures like total working hours is very time consuming and complex for the limited amount of time and resources to complete this thesis.

4.2.4 Factor shares

To estimate the Solow (1956) - Swan (1956) model, estimates for the factor shares are required. Actually it is enough if either a value for the capital share \( \alpha \) or the labour share \( \beta \) is obtained, because under the assumption of constant returns to scale the sum of \( \alpha \) and \( \beta \) equals one. Thus, if one value is obtained, the other one can be calculated by subtracting the obtained value with one \((1 - \alpha \text{ or } 1 - \beta)\).

A recent influential paper on the estimation of the labour share is Gollin (2002). Gollin (2002) challenged the traditional method of estimating the labour share
by arguing that this method leads to an underestimation of the labour income of small firms. Gollin (2002) provides three different techniques which correct for this error. The correction of an underestimation of labour income of small firms makes Gollin’s (2002) methods particularly interesting for an analysis of Germany’s economy, because small and medium-sized enterprises make up a high share of Germany’s economy (European Commission 2011). In addition, Gollin’s (2002) factor share estimates are remarkably constant over time. Constant factor shares is something that economic theory has often suggested, but traditional factor share estimation methods did not confirm (Gollin 2002).

While Gollin (2002) himself did not use his approach to calculate Germany’s labour share, this was done by Bernanke and Gürkaynak (2002). Their calculations are based on average data from 1980 to 1995. For West Germany they apply two of the three techniques put forward in Gollin (2002) and they arrive at a labour share of 0.69 or 0.71 (implying a capital share of 0.31 or 0.29), while the traditional method yields a labour share of 0.63 (implying a capital share of 0.37) (Bernanke and Gürkaynak 2002).

Other influential papers on factor shares include Christensen et al. (1980) and Dougherty (1991). Christensen et al. (1980) provide yearly estimates of Germany’s
capital shares for the time period from 1950 to 1973. The average of these esti-
mations has been reported to be 0.39 (Maddison 1987); with the lowest estimate
being 0.34 in 1950 and the highest one being 0.43 in 1968 (Christensen et al.
1980). Dougherty (1991) reports Germany’s capital share to be 0.40 during the
time period from 1960-90. These estimations are higher than the ones derived by
Bernanke and Gürkaynak (2002), but they are quite close to the one Bernanke and
Gürkaynak derived by using the traditional method.

As the new estimation techniques of Gollin (2002) offers some improvement over
the traditional approaches used in other papers, this paper will use 0.30 as a
capital share. This is the average of the two estimates obtained by Bernanke and
Gürkaynak (2002) and it is also the value which was suggested by Maddison (1987).

4.2.5 Other data

Additional data was required for the estimations of the Kaldor (Kaldor 1957;
Kaldor and Mirrlees 1962; Kaldor 1966) and the Romer (1986) model. The
\textit{Gross Value added of the Manufacturing sector, national currency, constant prices,}
\textit{OECD base year, millions} is used as a proxy for manufacturing output and was
obtained from the OECD (2012). In addition, \textit{total employment in the manu-
factoring sector} serves as a proxy for manufacturing labour. These values were
taken from the International Labour Organization Department of Statistics (2012).
Since only values until 2008 are published, the values for the three following years were estimated using the average growth rate of the three previous years (moving average).

For the estimation of the Romer (1986) model a proxy of knowledge is required. Romer (1986) did not specify which statistic could serve as a proxy. Therefore, this thesis will experiment with the number of patent grants of the German Patent Office, which were extracted from the World Intellectual Property Organization (2012). In addition, it will test the total gross domestic expenditure on Research and Development, national currency, constant prices, OECD base year and the amount of total Research and Development personnel, which were both obtained from the OECD (2012).

4.2.6 Deriving the change rates

Using the raw numbers to derive the percentage change rate is quite simple. The following equation is used:

$$\dot{X}_t = \frac{X_t - X_{t-1}}{X_{t-1}},$$

(4.10)

where $X$ can be substituted by any factor.
4.3 Application of the Solow-Swan model

This section provides the estimation of the Solow (1956) - Swan (1956) model. The Solow (1956) - Swan (1956) model can be used to trace economic growth to its factors of production, capital and labour and to technological progress (TFP growth). Therefore, researchers can learn what drives the economic growth of a country. In the following, this analysis will be applied to Germany.

4.3.1 Literature Review

Before applying the Solow (1956) - Swan (1956) framework, this section takes a brief look at previous TFP studies which included Germany. A famous paper is Young (1994), who applies the Solow-Swan framework to a wide range of countries. For the time period from 1970 to 1985 Young (1994) estimates the West German TFP growth to be 0.9 per cent on average, ranking it 43rd of his 118 sample countries in terms of TFP growth as shown by Table 4.1:
Table 4.1: Young’s (1994) estimation of annual TFP growth of selected countries, 1970-1985

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>TFP Growth</th>
<th>Rank</th>
<th>Country</th>
<th>TFP Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Egypt</td>
<td>3.5</td>
<td>23</td>
<td>Guinea</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>Pakistan</td>
<td>3.0</td>
<td>24</td>
<td>South Korea</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>Botswana</td>
<td>2.9</td>
<td>25</td>
<td>Iran</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>Congo</td>
<td>2.8</td>
<td>26</td>
<td>Burma</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>Malta</td>
<td>2.6</td>
<td>27</td>
<td>Mauritius</td>
<td>1.4</td>
</tr>
<tr>
<td>6</td>
<td>Hong Kong</td>
<td>2.5</td>
<td>28</td>
<td>China</td>
<td>1.3</td>
</tr>
<tr>
<td>7</td>
<td>Syria</td>
<td>2.5</td>
<td>29</td>
<td>Denmark</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>Zimbabwe</td>
<td>2.4</td>
<td>30</td>
<td>Israel</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>Gabon</td>
<td>2.4</td>
<td>31</td>
<td>Greece</td>
<td>1.2</td>
</tr>
<tr>
<td>10</td>
<td>Tunisia</td>
<td>2.4</td>
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<td>Japan</td>
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<td>Cameroon</td>
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</tr>
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<td>Lesotho</td>
<td>2.2</td>
<td>34</td>
<td>Yugoslavia</td>
<td>1.1</td>
</tr>
<tr>
<td>13</td>
<td>Uganda</td>
<td>2.1</td>
<td>35</td>
<td>Tanzania</td>
<td>1.1</td>
</tr>
<tr>
<td>14</td>
<td>Cyprus</td>
<td>2.1</td>
<td>36</td>
<td>Colombia</td>
<td>1.1</td>
</tr>
<tr>
<td>15</td>
<td>Thailand</td>
<td>1.9</td>
<td>37</td>
<td>Sweden</td>
<td>1.0</td>
</tr>
<tr>
<td>16</td>
<td>Bangladesh</td>
<td>1.9</td>
<td>38</td>
<td>Malaysia</td>
<td>1.0</td>
</tr>
<tr>
<td>17</td>
<td>Iceland</td>
<td>1.8</td>
<td>39</td>
<td>Malawi</td>
<td>1.0</td>
</tr>
<tr>
<td>18</td>
<td>Italy</td>
<td>1.8</td>
<td>40</td>
<td>Brazil</td>
<td>1.0</td>
</tr>
<tr>
<td>19</td>
<td>Norway</td>
<td>1.7</td>
<td>41</td>
<td>Panama</td>
<td>0.9</td>
</tr>
<tr>
<td>20</td>
<td>Finland</td>
<td>1.5</td>
<td>42</td>
<td>United Kingdom</td>
<td>0.9</td>
</tr>
<tr>
<td>21</td>
<td>Taiwan</td>
<td>1.5</td>
<td>43</td>
<td>West Germany</td>
<td>0.9</td>
</tr>
<tr>
<td>22</td>
<td>Ecuador</td>
<td>1.4</td>
<td>44</td>
<td>Mali</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Source: Young (1994), p. 970

Notes: Young (1994) only ranked the top 66 countries out of the 118 countries which were examined in his study.

However, Young’s (1994) approach of measuring the capital stock differs substantially to the one pursued in this thesis. Young (1994) estimated the capital stock by accumulating investments from the previous ten years and he employed a depreciation rate of 6 per cent. Therefore, Young’s (1994) capital stock values are
different to the one used in this paper and hence it is expected that the TFP estimations derived in this thesis are substantially different to the ones of Young (1994).

Another study is Burda and Hunt (2001). Burda and Hunt (2001) estimated Germany’s TFP growth after the reunification. For the years from 1992 to 1995 and from 1995 to 1999 Burda and Hunt (2001) found the TFP growth to be 0.9 per cent respectively (Burda and Hunt 2001).

The last study to be mentioned is European Commission (2002). The European Commission (2002) found Germany’s TFP growth to be 1.2 per cent from 1971 to 2000. For the period from 1991 to 2000 the European Commission (2002) estimated it to be 0.9 per cent. Unfortunately, the European Commission (2002) did not provide any details on their calculation and it cannot be understood how they estimated Germany’s capital stock or which capital share they used.

The mentioned studies differ in the sample period, but they arrive at very similar TFP growth estimates. Lastly, it should be noted that at the beginning of the 1990s the Solow (1956) - Swan (1956) growth framework was often applied to analyse the remarkably high economic growth rates of East Asian countries. In a famous
article in the magazine *Foreign Affairs* Krugman (1994) introduced these studies to the general public. Krugman (1994) pointed out that these papers reported that only little growth came from technological progress and most growth came from factor accumulation. Krugman (1994) argued that without technological progress the production function does not shift upwards and therefore economies with low TFP growth will move towards the steady state level. This implies that growth rates will fall as they will experience diminishing marginal productivity of capital and labour by moving to the steady state level. As such, Krugman (1994) concluded that economic growth which is purely based on factor accumulation is not sustainable. Constant technological progress on the other hand ensures that the economy is far away from the point of steady state and thus the economy’s growth is sustainable (Krugman 1994). Following Krugman’s (1994) analysis and observation, this thesis will also evaluate whether Germany’s economic growth rates are sustainable.

4.3.2 Methodology

This section describes the methodology which will be applied to estimate the TFP growth rates. First, using the Cobb-Douglas production function, the Solow (1956) - Swan (1956) model can be written as:

\[ Y_t = A_t K_t^\alpha L_t^{1-\alpha} \]  

(4.11)
where $A_t$ denotes the stance of technology, $K_t$ is capital, $L_t$ is labour and $\alpha$ is the capital share. Using change rates this function can be rewritten as:

$$\dot{Y}_t = \dot{A}_t + \alpha \times \dot{K}_t + (1 - \alpha) \times \dot{L}_t \tag{4.12}$$

Thus, the rate of economic growth equals the rate of technological progress plus the capital share times the change in the capital stock plus the labour share times the change in the labour stock. In the above equation, there is only one unknown variable, which is $\dot{A}_t$. Accordingly, the above equation can be rewritten as:

$$\dot{A}_t = \dot{Y}_t - \alpha \times \dot{K}_t - (1 - \alpha) \times \dot{L}_t \tag{4.13}$$

Substituting growth rates into the right hand side of the above equation will yield an estimate for the TFP growth, $\dot{A}_t$. The next section estimates $\dot{A}_t$ for the time period 1971 to 1990.

### 4.3.3 TFP Estimation 1: Period 1971 to 1990, West Germany

Table 4.2 shows the results of the estimations for the first time period:
<table>
<thead>
<tr>
<th>Year</th>
<th>$Y_t$ in mio. €</th>
<th>$K_t$ (with $K_{1970} = 100$)</th>
<th>$L_t$ in thousand</th>
<th>$\dot{Y}_t$</th>
<th>$\dot{K}_t$</th>
<th>$\dot{L}_t$</th>
<th>Capital contribution</th>
<th>Labour contribution</th>
<th>TFP $\dot{A}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>1,064,334</td>
<td>100.00</td>
<td>26,668</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>1,097,676</td>
<td>102.28</td>
<td>26,772</td>
<td>3.13%</td>
<td>2.28%</td>
<td>0.39%</td>
<td>0.68%</td>
<td>0.27%</td>
<td>2.17%</td>
</tr>
<tr>
<td>1972</td>
<td>1,144,880</td>
<td>104.53</td>
<td>26,875</td>
<td>4.30%</td>
<td>2.20%</td>
<td>0.38%</td>
<td>0.66%</td>
<td>0.27%</td>
<td>3.37%</td>
</tr>
<tr>
<td>1973</td>
<td>1,199,576</td>
<td>106.57</td>
<td>27,160</td>
<td>4.78%</td>
<td>1.95%</td>
<td>1.06%</td>
<td>0.58%</td>
<td>0.74%</td>
<td>3.45%</td>
</tr>
<tr>
<td>1974</td>
<td>1,210,253</td>
<td>108.01</td>
<td>26,829</td>
<td>0.89%</td>
<td>1.35%</td>
<td>-1.22%</td>
<td>0.41%</td>
<td>-0.85%</td>
<td>1.34%</td>
</tr>
<tr>
<td>1975</td>
<td>1,199,764</td>
<td>108.79</td>
<td>26,110</td>
<td>-0.87%</td>
<td>0.72%</td>
<td>-2.68%</td>
<td>0.22%</td>
<td>-1.88%</td>
<td>0.79%</td>
</tr>
<tr>
<td>1976</td>
<td>1,259,143</td>
<td>109.33</td>
<td>25,974</td>
<td>4.95%</td>
<td>0.49%</td>
<td>-0.52%</td>
<td>0.15%</td>
<td>-0.36%</td>
<td>5.17%</td>
</tr>
<tr>
<td>1977</td>
<td>1,301,289</td>
<td>109.84</td>
<td>26,008</td>
<td>3.35%</td>
<td>0.47%</td>
<td>0.13%</td>
<td>0.14%</td>
<td>0.09%</td>
<td>3.12%</td>
</tr>
<tr>
<td>1978</td>
<td>1,340,438</td>
<td>110.33</td>
<td>26,219</td>
<td>3.01%</td>
<td>0.45%</td>
<td>0.81%</td>
<td>0.13%</td>
<td>0.57%</td>
<td>2.31%</td>
</tr>
<tr>
<td>1979</td>
<td>1,396,072</td>
<td>110.87</td>
<td>26,652</td>
<td>4.15%</td>
<td>0.49%</td>
<td>1.65%</td>
<td>0.15%</td>
<td>1.16%</td>
<td>2.85%</td>
</tr>
<tr>
<td>1980</td>
<td>1,415,740</td>
<td>111.41</td>
<td>27,059</td>
<td>1.41%</td>
<td>0.49%</td>
<td>1.53%</td>
<td>0.15%</td>
<td>1.07%</td>
<td>0.19%</td>
</tr>
<tr>
<td>1981</td>
<td>1,423,232</td>
<td>111.65</td>
<td>27,033</td>
<td>0.53%</td>
<td>0.22%</td>
<td>-0.10%</td>
<td>0.07%</td>
<td>-0.07%</td>
<td>0.53%</td>
</tr>
<tr>
<td>1982</td>
<td>1,417,613</td>
<td>111.45</td>
<td>26,725</td>
<td>-0.39%</td>
<td>-0.18%</td>
<td>-1.14%</td>
<td>-0.05%</td>
<td>-0.80%</td>
<td>0.46%</td>
</tr>
<tr>
<td>1983</td>
<td>1,439,904</td>
<td>111.03</td>
<td>26,347</td>
<td>1.57%</td>
<td>-0.38%</td>
<td>-1.41%</td>
<td>-0.11%</td>
<td>-0.99%</td>
<td>2.68%</td>
</tr>
<tr>
<td>1984</td>
<td>1,480,551</td>
<td>110.50</td>
<td>26,297</td>
<td>2.82%</td>
<td>-0.48%</td>
<td>-0.19%</td>
<td>-0.14%</td>
<td>-0.13%</td>
<td>3.10%</td>
</tr>
<tr>
<td>1985</td>
<td>1,515,018</td>
<td>109.81</td>
<td>26,397</td>
<td>2.33%</td>
<td>-0.62%</td>
<td>0.38%</td>
<td>-0.19%</td>
<td>0.27%</td>
<td>2.25%</td>
</tr>
<tr>
<td>1986</td>
<td>1,549,671</td>
<td>109.08</td>
<td>26,913</td>
<td>2.20%</td>
<td>-0.66%</td>
<td>1.95%</td>
<td>-0.20%</td>
<td>1.37%</td>
<td>1.12%</td>
</tr>
<tr>
<td>1987</td>
<td>1,571,400</td>
<td>108.35</td>
<td>27,236</td>
<td>1.40%</td>
<td>-0.67%</td>
<td>1.20%</td>
<td>-0.20%</td>
<td>0.84%</td>
<td>0.76%</td>
</tr>
<tr>
<td>1988</td>
<td>1,629,655</td>
<td>107.65</td>
<td>27,416</td>
<td>3.71%</td>
<td>-0.64%</td>
<td>0.66%</td>
<td>-0.19%</td>
<td>0.46%</td>
<td>3.44%</td>
</tr>
<tr>
<td>1989</td>
<td>1,693,156</td>
<td>107.08</td>
<td>27,989</td>
<td>3.90%</td>
<td>-0.53%</td>
<td>2.09%</td>
<td>-0.16%</td>
<td>1.46%</td>
<td>2.59%</td>
</tr>
<tr>
<td>1990</td>
<td>1,782,131</td>
<td>106.71</td>
<td>29,323</td>
<td>5.26%</td>
<td>-0.35%</td>
<td>4.77%</td>
<td>-0.10%</td>
<td>3.34%</td>
<td>2.02%</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.61%</td>
<td>0.33%</td>
<td>0.48%</td>
</tr>
</tbody>
</table>
The first three columns show the raw data which was used for the estimations. After transforming these values into the change rates which are shown in columns four to six, columns seven to nine are calculated using the approach outlined in Equation 4.13.

The last row of Table 4.2 gives the average values for the time period. It can be seen that West Germany economy grew by 2.61 per cent on average and that TFP growth was 2.18 per cent on average during this time period. Therefore, roughly four fifths of West Germany’s economic growth was coming from technological progress. Factor accumulation only plays a minor role, with labour accumulation contributing 0.34 per cent and capital accumulation contributing 0.10 per cent. Figure 4.1 illustrates the results of Table 4.2 graphically:
Figure 4.1: Solow (1956) - Swan (1956) decomposition of economic growth, West Germany 1971-1990
Figure 4.1 and Table 4.2 show that over the sample period of 1971 to 1990, technological progress was always positive, but it was very volatile. For example, in 1975 TFP growth was 0.79 per cent and one year later it was 5.17 per cent. Technological progress was the main driver of economic growth for most years. Only in 1980, 1986, 1987 and 1990 labour accumulation contributed more strongly to economic growth.

The strongest rate of technological progress was achieved in 1976, where technological progress was 5.17 per cent, leading to economic growth of 4.95 per cent as factor accumulation was negative. Over the time period of 1971 to 1990, there were actually several years where factor accumulation was negative, but the West German economy still managed to grow because technological progress was so strong. Figure 4.1 also shows a strong correlation between RGDP growth and TFP growth, but this will be analysed in the Real Business Cycle section below in detail.

Table 4.3 breaks Table 4.2 down into four periods of five year time intervals:
Table 4.3: Solow (1956) - Swan (1956) estimation decomposed into five year average growth rates, West Germany 1971-1990

<table>
<thead>
<tr>
<th></th>
<th>RGDP growth</th>
<th>Capital Share</th>
<th>Labour Share</th>
<th>TFP growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971-1975</td>
<td>2.42%</td>
<td>0.51%</td>
<td>-0.29%</td>
<td>2.22%</td>
</tr>
<tr>
<td>1976-1980</td>
<td>3.37%</td>
<td>0.14%</td>
<td>0.50%</td>
<td>2.71%</td>
</tr>
<tr>
<td>1981-1985</td>
<td>1.36%</td>
<td>-0.09%</td>
<td>-0.35%</td>
<td>1.80%</td>
</tr>
<tr>
<td>1986-1990</td>
<td>3.30%</td>
<td>-0.17%</td>
<td>1.49%</td>
<td>1.98%</td>
</tr>
</tbody>
</table>

As shown by Table 4.3, with growth rates being greater than 3 per cent economic growth was very strong during two of these four periods. In the first period, economic growth was decent and in the third period it was fairly weak. Looking at the second column with the contribution of the capital stock to economic growth a trend is noticeable. During all four periods, the contribution of capital accumulation to economic growth declined. This is especially interesting because in the period from 1986-1990, which was the period with the second strongest output growth, capital contribution was the lowest. Labour accumulation and TFP growth, in contrast, do not show a clear trend. Labour accumulation was positive and negative in two time periods respectively. It is noticeable that the labour contribution to economic growth was pretty strong in the last period, but referring to Table 4.2 it can be seen that this was mainly the influence of the last year of the sample period. As the previous chapter pointed out, immigration to West Germany was very high in 1990, because of the downfall of the Wall in
1989. The TFP growth rates showed little variation when calculated as five year
averages. During the period of 1976-1980 the rate of technological progress was
the highest with 2.71 per cent and during the period of 1981-1985 it was the lowest.

With so little economic growth coming from factor accumulation and with constant
and strong technological growth, which shifted the production function upwards
over many years, the West German economy must have been far away from the
steady state (see Figure 2.2, Chapter 2, p. 19). Therefore, even if technological
progress had suddenly stopped, factor accumulation could provide strong growth
for many years before diminishing productivity would set in.

It can be concluded that West Germany’s economic growth was mainly driven by
technological progress. In addition, West Germany’s technological progress was
both strong and stable. It averaged over two percent during the total sample
period and it does not show a declining trend. Following the analysis of Krugman
(1994), West Germany’s economic growth is very sustainable. The next section
will test the sustainability of Germany’s long-run growth. If TFP is positive and
significant in the period 1971-1990, it must have some positive impacts to the
forthcoming years. In other words, the Solow (1956) - Swan (1956) residuals can
have a positive impact on output growth in the coming years.
4.3.4 TFP Estimation 2: Period 1992 to 2011, Germany

This section provides the application of the Solow (1956) - Swan (1956) growth framework to the German economic growth experience after the reunification. Table 4.4 provides the results:
Table 4.4: Application of the Solow (1956) - Swan (1956) model, Germany 1992-2011

<table>
<thead>
<tr>
<th>Year</th>
<th>$Y_t$ in mio. €</th>
<th>$K_t$ (with $K_{1991} = 100$)</th>
<th>$L_t$ in thousand</th>
<th>$\dot{Y}_t$</th>
<th>$\dot{K}_t$</th>
<th>$\dot{L}_t$</th>
<th>Capital contribution</th>
<th>Labour contribution</th>
<th>TFP $\dot{A}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>1,873,167</td>
<td>100.00</td>
<td>37,373</td>
<td>1.91%</td>
<td>0.15%</td>
<td>-1.33%</td>
<td>0.05%</td>
<td>-0.93%</td>
<td>2.80%</td>
</tr>
<tr>
<td>1992</td>
<td>1,908,980</td>
<td>100.15</td>
<td>36,875</td>
<td>2.47%</td>
<td>-0.29%</td>
<td>-0.74%</td>
<td>-0.09%</td>
<td>-0.52%</td>
<td>3.08%</td>
</tr>
<tr>
<td>1993</td>
<td>1,889,850</td>
<td>100.09</td>
<td>36,444</td>
<td>-1.00%</td>
<td>-0.07%</td>
<td>-1.17%</td>
<td>-0.02%</td>
<td>-0.82%</td>
<td>-0.16%</td>
</tr>
<tr>
<td>1994</td>
<td>1,936,563</td>
<td>99.80</td>
<td>36,174</td>
<td>2.47%</td>
<td>-0.29%</td>
<td>-0.74%</td>
<td>-0.09%</td>
<td>-0.52%</td>
<td>3.08%</td>
</tr>
<tr>
<td>1995</td>
<td>1,969,039</td>
<td>99.40</td>
<td>36,176</td>
<td>1.68%</td>
<td>-0.40%</td>
<td>0.01%</td>
<td>-0.12%</td>
<td>0.00%</td>
<td>1.79%</td>
</tr>
<tr>
<td>1996</td>
<td>1,984,610</td>
<td>98.83</td>
<td>36,045</td>
<td>0.79%</td>
<td>-0.58%</td>
<td>-0.36%</td>
<td>-0.17%</td>
<td>-0.25%</td>
<td>1.22%</td>
</tr>
<tr>
<td>1997</td>
<td>2,019,088</td>
<td>98.14</td>
<td>35,897</td>
<td>1.74%</td>
<td>-0.69%</td>
<td>-0.41%</td>
<td>-0.21%</td>
<td>-0.29%</td>
<td>2.23%</td>
</tr>
<tr>
<td>1998</td>
<td>2,056,680</td>
<td>97.41</td>
<td>35,897</td>
<td>1.86%</td>
<td>-0.74%</td>
<td>1.51%</td>
<td>-0.22%</td>
<td>1.05%</td>
<td>1.03%</td>
</tr>
<tr>
<td>1999</td>
<td>2,095,162</td>
<td>96.70</td>
<td>36,281</td>
<td>1.87%</td>
<td>-0.74%</td>
<td>-0.43%</td>
<td>-0.22%</td>
<td>-0.30%</td>
<td>2.39%</td>
</tr>
<tr>
<td>2000</td>
<td>2,159,225</td>
<td>96.00</td>
<td>35,546</td>
<td>0.06%</td>
<td>-0.72%</td>
<td>0.51%</td>
<td>-0.22%</td>
<td>0.36%</td>
<td>2.92%</td>
</tr>
<tr>
<td>2001</td>
<td>2,191,924</td>
<td>95.17</td>
<td>35,546</td>
<td>1.51%</td>
<td>-0.86%</td>
<td>0.30%</td>
<td>-0.26%</td>
<td>0.21%</td>
<td>1.56%</td>
</tr>
<tr>
<td>2002</td>
<td>2,192,146</td>
<td>94.00</td>
<td>36,245</td>
<td>0.01%</td>
<td>-1.23%</td>
<td>-0.91%</td>
<td>-0.37%</td>
<td>-0.64%</td>
<td>1.01%</td>
</tr>
<tr>
<td>2003</td>
<td>2,183,916</td>
<td>92.64</td>
<td>35,546</td>
<td>-0.38%</td>
<td>-1.44%</td>
<td>-1.10%</td>
<td>-0.43%</td>
<td>-0.77%</td>
<td>0.83%</td>
</tr>
<tr>
<td>2004</td>
<td>2,209,274</td>
<td>91.26</td>
<td>35,245</td>
<td>1.16%</td>
<td>-1.49%</td>
<td>-0.01%</td>
<td>-0.45%</td>
<td>-0.01%</td>
<td>1.62%</td>
</tr>
<tr>
<td>2005</td>
<td>2,224,400</td>
<td>89.83</td>
<td>36,555</td>
<td>0.68%</td>
<td>-1.56%</td>
<td>1.43%</td>
<td>-0.47%</td>
<td>1.00%</td>
<td>0.15%</td>
</tr>
<tr>
<td>2006</td>
<td>2,306,703</td>
<td>88.55</td>
<td>37,172</td>
<td>3.70%</td>
<td>-1.43%</td>
<td>2.25%</td>
<td>-0.43%</td>
<td>1.57%</td>
<td>2.55%</td>
</tr>
<tr>
<td>2007</td>
<td>2,382,110</td>
<td>87.53</td>
<td>37,989</td>
<td>3.27%</td>
<td>-1.15%</td>
<td>2.20%</td>
<td>-0.35%</td>
<td>1.54%</td>
<td>2.08%</td>
</tr>
<tr>
<td>2008</td>
<td>2,407,913</td>
<td>86.66</td>
<td>38,541</td>
<td>1.08%</td>
<td>-0.99%</td>
<td>1.45%</td>
<td>-0.30%</td>
<td>1.02%</td>
<td>0.36%</td>
</tr>
<tr>
<td>2009</td>
<td>2,284,459</td>
<td>85.63</td>
<td>38,471</td>
<td>-5.13%</td>
<td>-1.19%</td>
<td>-0.18%</td>
<td>-0.36%</td>
<td>-0.13%</td>
<td>-4.64%</td>
</tr>
<tr>
<td>2010</td>
<td>2,368,764</td>
<td>84.68</td>
<td>38,738</td>
<td>3.60%</td>
<td>-1.11%</td>
<td>0.69%</td>
<td>-0.33%</td>
<td>0.49%</td>
<td>3.54%</td>
</tr>
<tr>
<td>2011</td>
<td>2,439,722</td>
<td>83.75</td>
<td>38,583</td>
<td>3.00%</td>
<td>-1.10%</td>
<td>-0.40%</td>
<td>-0.33%</td>
<td>-0.28%</td>
<td>3.60%</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td>1.33%</td>
<td>-0.88%</td>
<td>0.16%</td>
<td>-0.26%</td>
<td>0.11%</td>
<td>1.48%</td>
</tr>
</tbody>
</table>
Looking at the average values, which are given in the last row of Table 4.4, it can be seen that the performance was weaker than in the previous period. Average economic growth was 1.33 per cent and average TFP growth was 1.48 per cent. The implication of TFP growth being higher than RGDP growth is that factor accumulation must have been negative. And in fact, the results show that the declining capital stock led to capital accumulation contributing negative 0.26 per cent to economic growth and labour accumulation contributed only 0.11 per cent.

Table 4.5 compares the Solow (1956) - Swan (1956) estimation results of both time periods and thus provides some insights on why Germany grew less strongly during the second period than during the first one.

Table 4.5: Comparison of the Solow (1956) - Swan (1956) estimation results of both time period, West Germany 1971-1990 and Germany 1991-2011

<table>
<thead>
<tr>
<th></th>
<th>RGDP growth</th>
<th>Capital Share</th>
<th>Labour Share</th>
<th>TFP growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971-1990</td>
<td>2.61%</td>
<td>0.10%</td>
<td>0.34%</td>
<td>2.18%</td>
</tr>
<tr>
<td>1992-2011</td>
<td>1.33%</td>
<td>-0.26%</td>
<td>0.11%</td>
<td>1.48%</td>
</tr>
<tr>
<td>Difference</td>
<td>1.28%</td>
<td>0.36%</td>
<td>0.23%</td>
<td>0.70%</td>
</tr>
</tbody>
</table>

As shown, the first period dominated the second one in all three aspects that contribute to economic growth. During the first period, capital accumulation contributed 0.36 per cent, labour accumulation 0.23 per cent and TFP growth 0.70 per cent more to economic growth than during the second one. This indicates that
the reunited Germany was significantly less innovative than West Germany. It was also not able to accumulate capital or labour at the rates that West Germany managed to achieve.

It is possible that the decline in TFP growth as compared to the 1971-1990 period can be explained by the decline in capital investment, as suggested by Kaldor and Mirrlees (1962). The importance of capital investments will be tested empirically in the forthcoming sections.

Nevertheless, the results of Table 4.4 also have good implications. Over this time period economic growth was completely driven by technological progress. With the capital stock decreasing and the labour stock increasing only modestly, Germany was still able to increase its total output by almost one third. Like for the previous period, Figure 4.2 indicates that technological progress contributed the highest share to economic progress in most years:
Figure 4.2: Solow (1956) - Swan (1956) decomposition of economic growth, Germany 1992-2011
However, unlike in the period before, Germany experienced two years of technological regress. The first time was during the recession in 1993 and second time was during the global financial crisis in 2009. Figure 4.2 also shows that from 2004 until the global financial crisis, labour accumulation contributed a high share to economic growth. This development falls together with the reform of the welfare state, which was outlined in the previous chapter and which had the goal to activate the low-skilled labour force. After a decline in TFP in 2009, which resulted from the global financial crisis, TFP growth in the two years that followed was very strong. As for the period before, Figure 4.2 indicates that there is a strong correlation between RGDP and technological growth.

Table 4.6 decomposes the estimation results into five year average growth rates:

<table>
<thead>
<tr>
<th>Period</th>
<th>RGDP growth</th>
<th>Capital Share</th>
<th>Labour Share</th>
<th>TFP growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992-1996</td>
<td>1.16%</td>
<td>-0.07%</td>
<td>-0.50%</td>
<td>1.74%</td>
</tr>
<tr>
<td>1997-2001</td>
<td>2.00%</td>
<td>-0.23%</td>
<td>0.21%</td>
<td>2.02%</td>
</tr>
<tr>
<td>2002-2006</td>
<td>1.02%</td>
<td>-0.43%</td>
<td>0.23%</td>
<td>1.23%</td>
</tr>
<tr>
<td>2006-2011</td>
<td>1.13%</td>
<td>-0.33%</td>
<td>0.52%</td>
<td>0.94%</td>
</tr>
</tbody>
</table>

As shown by Table 4.6, economic growth was the strongest during the 1997-2001 period, during which Germany experienced an export boom as discussed in the
previous chapter. The other three time periods highlight almost identical economic growth rates. The contribution of capital accumulation was declining over the first three periods and was negative for all four periods. In the fourth period the decrease was less strong, but it has to be kept in mind that the quality of the net capital stock estimates for the years 2009 to 2011 may not be that good. Economic growth coming from labour accumulation shows an increasing trend. After the first years following the reunification, labour accumulation contributed negative economic growth but during the following three periods it was positive. Looking at the decomposition of TFP growth rates into four periods shows that during the two periods after reunification technological progress was stronger than it had been in the two most recent periods. Even though TFP growth in the two most recent periods was still reasonably high, a further decline over subsequent periods would be alarming.

In regards to the analysis of Krugman (1994) it can be said that Germany is still far away from the steady state, because of the decent technological progress and the weak factor accumulation during the 1990s. Nevertheless, the weaker TFP growth of the 2000s raises concerns that Germany may have to increase its factor accumulation to sustain short-run economic growth. However, it has to be kept in mind that the low TFP growth during the fourth period is strongly biased by the steep
technological regression resulting from the global financial crisis. Accordingly, one has to await the development over the following years before a conclusion on the trend of TFP growth rates can be made.

In conclusion, economic growth after the reunification was substantially weaker than before. Most of this decline can be accredited to weaker technological progress, but factor accumulation, especially capital, was also weaker. Technological growth was the driver of economic growth with factor accumulation contributing negative economic growth during the sample period. There are some concerns about TFP growth to decline further, but this impression could also be biased by the severe and extraordinary effects on technological growth by the global financial crisis.

The next section analyses the relationship between TFP and aggregate output growth based on the RBC. In doing so, the analysis found in this thesis will be more complete.

4.3.5 Estimation of the Real Business Cycle Theory

Figure 4.1 and 4.2 gave the impression that there is a strong correlation between technological progress and real GDP growth. This is also one of the main theses of the Real Business Cycle theory, which was briefly introduced in the second
chapter of this thesis. The Real Business Cycle theory applies the Solow (1956) - Swan (1956) framework in order to estimate technological fluctuations, which are believed to be the driver of business cycles. This section will test the relationship between output growth and technological progress using the auto regressive error specification.

In testing the real business cycle theory, the following equation is estimated:

\[ \dot{Y} = \alpha + \beta \dot{A} + u_t, \]  

(4.14)

where \( \beta \) denotes the coefficient, which is expected to be greater than zero, \( \alpha \) denotes the constant, \( \dot{Y} \) is the change rate in output, \( \dot{A} \) is the TFP change rate and \( u_t \) is the error term, where for AR(1) \( u_t = p u_{t-1} + \epsilon_t, \epsilon_t \sim N(0, \sigma^2_\epsilon), t = 1, 2, ..., n \) (Taylor 2007, p. 149) and for AR(2)

\[ u_t = p_1 u_{t-1} + p_2 u_{t-2} + \epsilon_t, \epsilon_t \sim N(0, \sigma^2_\epsilon), t = 1, 2, ..., n \] (Taylor 2007, p. 133).

Equation 4.14 is used to estimate the gap between RGDP and TFP growth. Real Business Cycle theory suggests that this gap is very small, because both variables

\[ V(u_1) = V(u_2) = \sigma^2_\epsilon (1 - p_2)/ (1 + p_2) - p_1^2 (1 + p_2) \]  

(4.15)

\[ Cov(u_1, u_2) = \sigma^2_\epsilon p_1/(1 + p_2) - p_1^2 (1 + p_2) \]  

(4.16)

(Taylor 2007, p. 142)
move together. The coefficients will be estimated using the auto regressive error specification, which is more robust than the standard OLS approach for the estimation of time series data (Taylor 2007).

4.3.5.1 RBC Estimation 1: 1971-1990

Table 4.7 illustrates the results for the first estimation:

Table 4.7: Estimation of the Real Business Cycle theory, West Germany 1971-1990

<table>
<thead>
<tr>
<th>1. AR(1) Inverse Interpolation Method Converged after 7 iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ((\alpha))</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>-0.09</td>
</tr>
<tr>
<td>(0.16)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Exact AR(2) Newton-Raphson Iterative Method converged after 6 iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ((\alpha))</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>-0.13</td>
</tr>
<tr>
<td>(0.13)</td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \(d_l\) and \(d_u\) at 5 per cent significance level: \(d_l = 1.20\) and \(d_u = 1.41\) (Gujarati and Porter 2010).

As Table 4.7 shows, both the AR(1) and the AR(2) method were tested. The results of the AR(1) estimation did not turn out to be statistically robust, because the Durbin-Watson statistic has a value of 1.08, which is below \(d_l\). Therefore, there is evidence of positive first-order serial correlation meaning that the estimations
are not reliable (Gujarati and Porter 2010).

The AR(2) method, on the other hand, provides reliable estimations, as the Durbin-Watson ($DW$) statistic was found to be above 1.41 and below 2.00, indicating that there is no evidence of positive first-order serial correlation (Gujarati and Porter 2010). The coefficient of $\hat{A}, C_2$ is estimated to be 1.14. This means that when TFP increases by one per cent, then RGDP increases by 1.14 per cent. The value of 0.78 for $R-Bar^2$ indicates that 78 per cent of the movements of RGDP can be explained by the movements of TFP. This is a fairly strong correlation. Thus it can be concluded that fluctuations in TFP do affect RGDP, which is consistent with the RBC analysis.

4.3.5.2 RBC Estimation 2: 1992-2011

The estimation for the second period is shown in Table 4.8:

Table 4.8: Estimation of the Real Business Cycle theory, Germany 1992-2011

<table>
<thead>
<tr>
<th>Constant ($\alpha$)</th>
<th>Coefficient ($\beta$)</th>
<th>$R-Bar^2$</th>
<th>$DW$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.07</td>
<td>1.06 [0.000]*</td>
<td>0.89</td>
<td>1.84</td>
</tr>
<tr>
<td>(0.07)</td>
<td>(0.07)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of $d_l$ and $d_u$ at 5 per cent significance level: $d_l = 1.20$ and $d_u = 1.41$ (Gujarati and Porter 2010).
Here, the AR(1) method provided useful results since the Durbin-Watson statistic is above 1.41 and below 2.00. It can also be seen that with $R-Bar^2$ being 89 per cent, the correlation between TFP and RGDP growth is even stronger in this period than in the one before (RBC Estimation 1). For this time period a change in TFP of 1 per cent leads to a change of 1.06 per cent in RGDP, which is a little bit less than in the previous period. Therefore, the gap between RGDP and TFP became smaller and therefore the influence of TFP fluctuations in the second time period was higher than in the first one.

In conclusion, these estimations give supporting evidence for the Real Business Cycle theory.

### 4.3.6 Policy implications

Based on the Solow (1956) - Swan (1956) analysis one reason why West Germany achieved stronger economic growth than the reunited Germany was that West Germany’s technological progress was stronger. To increase growth rates, German policy makers should pursue measures that stimulate technological progress. As outlined in the second chapter of this thesis, Romer (1986) suggested that technological progress is a result of knowledge accumulation. Following Romer’s (1986) analysis, German policy makers could increase research and development expendi-
ture or provide tax cuts for companies that do research and development in order to increase knowledge accumulation.

An alternative view is suggested by Lucas (1988). Lucas (1988) argued that technological progress is a result of improvements in human capital. Thus, policy makers should implement measures that improve education. For example, the government could provide more incentives for citizens to undergo further education. Another policy to increase technological progress would be to improve the education system.

Besides having found weaker technological progress during the second time period, the Solow (1956) - Swan (1956) analysis has also highlighted that Germany’s economic growth coming from capital accumulation was weaker in the second period. This is not surprising as the previous chapter has shown that the German capital stock decreases in size. Thus, another measure to stimulate economic growth is to increase investments. One possibility is by offering tax cuts or subsidies for investments. Based on Kaldor and Mirrlees (1962) increasing investments would also lead to increases in technological progress, and as such TFP growth.
4.3.7 Limitations

The application of the Solow (1956) - Swan (1956) growth framework has some limitations, which are outlined in the following section. The purpose of this section is to point out that the results of the Solow (1956) - Swan (1956) estimation are highly dependent on a number of assumptions and on the quality of the data inputs. This means that the numbers derived in this thesis can only be considered as a point of reference.

4.3.7.1 Capital Stock

The estimation results depend strongly on the size of the net capital stock. One crucial assumption in the derivation of the net capital stock is the depreciation rate. Based on findings in the literature this thesis assumed that the depreciation rate is three per cent. Using the period from 1971-1990 as an example, Table 4.9 shows how different depreciation rates lead to different net capital stock and Table 4.10 shows how this affects TFP growth estimates:
Table 4.9: Influence of different depreciation rates on the Net Capital Stock, West Germany 1971-1990

<table>
<thead>
<tr>
<th>Year</th>
<th>$\delta = 1.0$</th>
<th>$\delta = 1.5$</th>
<th>$\delta = 2.0$</th>
<th>$\delta = 2.5$</th>
<th>$\delta = 3.0$</th>
<th>$\delta = 3.5$</th>
<th>$\delta = 4.0$</th>
<th>$\delta = 4.5$</th>
<th>$\delta = 5.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
<td>$K_t$</td>
</tr>
<tr>
<td>1970</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td><strong>100.00</strong></td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>1971</td>
<td>104.28</td>
<td>103.78</td>
<td>103.28</td>
<td>102.78</td>
<td><strong>102.28</strong></td>
<td>101.78</td>
<td>101.28</td>
<td>100.78</td>
<td>100.28</td>
</tr>
<tr>
<td>1972</td>
<td>108.66</td>
<td>107.62</td>
<td>106.59</td>
<td>105.56</td>
<td><strong>104.53</strong></td>
<td>103.51</td>
<td>102.50</td>
<td>101.49</td>
<td>100.48</td>
</tr>
<tr>
<td>1973</td>
<td>112.95</td>
<td>111.33</td>
<td>109.73</td>
<td>108.14</td>
<td><strong>106.57</strong></td>
<td>105.01</td>
<td>103.47</td>
<td>101.94</td>
<td>100.43</td>
</tr>
<tr>
<td>1974</td>
<td>116.74</td>
<td>114.51</td>
<td>112.31</td>
<td>110.14</td>
<td><strong>108.01</strong></td>
<td>105.91</td>
<td>103.83</td>
<td>101.79</td>
<td>99.78</td>
</tr>
<tr>
<td>1975</td>
<td>119.92</td>
<td>117.05</td>
<td>114.24</td>
<td>111.49</td>
<td><strong>108.79</strong></td>
<td>106.14</td>
<td>103.55</td>
<td>101.00</td>
<td>98.50</td>
</tr>
<tr>
<td>1976</td>
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<td>119.39</td>
<td>115.95</td>
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<td>106.14</td>
<td>103.02</td>
<td>99.98</td>
<td>97.02</td>
</tr>
<tr>
<td>1977</td>
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<td>121.73</td>
<td>117.65</td>
<td>113.69</td>
<td><strong>109.84</strong></td>
<td>106.10</td>
<td>102.47</td>
<td>98.95</td>
<td>95.53</td>
</tr>
<tr>
<td>1978</td>
<td>129.02</td>
<td>124.11</td>
<td>119.36</td>
<td>114.77</td>
<td><strong>110.33</strong></td>
<td>106.05</td>
<td>101.91</td>
<td>97.91</td>
<td>94.05</td>
</tr>
<tr>
<td>1979</td>
<td>132.23</td>
<td>126.57</td>
<td>121.13</td>
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<td><strong>110.87</strong></td>
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<td>101.39</td>
<td>96.92</td>
<td>92.63</td>
</tr>
<tr>
<td>1980</td>
<td>135.52</td>
<td>129.09</td>
<td>122.93</td>
<td>117.04</td>
<td><strong>111.41</strong></td>
<td>106.02</td>
<td>100.86</td>
<td>95.94</td>
<td>91.23</td>
</tr>
<tr>
<td>1981</td>
<td>138.53</td>
<td>131.31</td>
<td>124.43</td>
<td>117.88</td>
<td><strong>111.65</strong></td>
<td>105.72</td>
<td>100.08</td>
<td>94.71</td>
<td>89.60</td>
</tr>
<tr>
<td>1982</td>
<td>141.05</td>
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<td>98.90</td>
<td>93.12</td>
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<td><strong>111.03</strong></td>
<td>104.08</td>
<td>97.53</td>
<td>91.37</td>
<td>85.56</td>
</tr>
<tr>
<td>1984</td>
<td>145.52</td>
<td>135.91</td>
<td>126.89</td>
<td>118.43</td>
<td><strong>110.50</strong></td>
<td>103.06</td>
<td>96.09</td>
<td>89.56</td>
<td>83.44</td>
</tr>
<tr>
<td>1985</td>
<td>147.53</td>
<td>137.10</td>
<td>127.37</td>
<td>118.29</td>
<td><strong>109.81</strong></td>
<td>101.91</td>
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<td>81.26</td>
</tr>
<tr>
<td>1986</td>
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<td>138.25</td>
<td>127.80</td>
<td>118.09</td>
<td><strong>109.08</strong></td>
<td>100.72</td>
<td>92.96</td>
<td>85.76</td>
<td>79.09</td>
</tr>
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<td>1987</td>
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<td>128.22</td>
<td>117.89</td>
<td><strong>108.35</strong></td>
<td>99.54</td>
<td>91.41</td>
<td>83.90</td>
<td>76.98</td>
</tr>
<tr>
<td>1988</td>
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<td>140.59</td>
<td>128.68</td>
<td>117.72</td>
<td><strong>107.65</strong></td>
<td>98.40</td>
<td>89.90</td>
<td>82.10</td>
<td>74.94</td>
</tr>
<tr>
<td>1989</td>
<td>155.79</td>
<td>141.95</td>
<td>129.28</td>
<td>117.69</td>
<td><strong>107.08</strong></td>
<td>97.39</td>
<td>88.53</td>
<td>80.44</td>
<td>73.05</td>
</tr>
<tr>
<td>1990</td>
<td>158.37</td>
<td>143.59</td>
<td>130.12</td>
<td>117.87</td>
<td><strong>106.71</strong></td>
<td>96.56</td>
<td>87.33</td>
<td>78.95</td>
<td>71.33</td>
</tr>
</tbody>
</table>
Table 4.10: Influence of different depreciation rates on the TFP estimates, West Germany 1971-1990

<table>
<thead>
<tr>
<th>Year</th>
<th>$\delta = 1.0$</th>
<th>$\delta = 1.5$</th>
<th>$\delta = 2.0$</th>
<th>$\delta = 2.5$</th>
<th>$\delta = 3.0$</th>
<th>$\delta = 3.5$</th>
<th>$\delta = 4.0$</th>
<th>$\delta = 4.5$</th>
<th>$\delta = 5.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
<td>TFP</td>
</tr>
<tr>
<td>1971</td>
<td>1.57%</td>
<td>1.72%</td>
<td>1.87%</td>
<td>2.02%</td>
<td>2.17%</td>
<td>2.32%</td>
<td>2.47%</td>
<td>2.62%</td>
<td>2.77%</td>
</tr>
<tr>
<td>1972</td>
<td>2.77%</td>
<td>2.92%</td>
<td>3.07%</td>
<td>3.22%</td>
<td>3.37%</td>
<td>3.52%</td>
<td>3.67%</td>
<td>3.82%</td>
<td>3.97%</td>
</tr>
<tr>
<td>1973</td>
<td>2.85%</td>
<td>3.00%</td>
<td>3.15%</td>
<td>3.30%</td>
<td>3.45%</td>
<td>3.60%</td>
<td>3.75%</td>
<td>3.90%</td>
<td>4.05%</td>
</tr>
<tr>
<td>1974</td>
<td>0.74%</td>
<td>0.89%</td>
<td>1.04%</td>
<td>1.19%</td>
<td>1.34%</td>
<td>1.49%</td>
<td>1.64%</td>
<td>1.79%</td>
<td>1.94%</td>
</tr>
<tr>
<td>1975</td>
<td>0.19%</td>
<td>0.34%</td>
<td>0.49%</td>
<td>0.64%</td>
<td>0.79%</td>
<td>0.94%</td>
<td>1.09%</td>
<td>1.24%</td>
<td>1.39%</td>
</tr>
<tr>
<td>1976</td>
<td>4.57%</td>
<td>4.72%</td>
<td>4.87%</td>
<td>5.02%</td>
<td>5.17%</td>
<td>5.32%</td>
<td>5.47%</td>
<td>5.62%</td>
<td>5.77%</td>
</tr>
<tr>
<td>1977</td>
<td>2.52%</td>
<td>2.67%</td>
<td>2.82%</td>
<td>2.97%</td>
<td>3.12%</td>
<td>3.27%</td>
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<td>3.57%</td>
<td>3.72%</td>
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<tr>
<td>1978</td>
<td>1.71%</td>
<td>1.86%</td>
<td>2.01%</td>
<td>2.16%</td>
<td>2.31%</td>
<td>2.46%</td>
<td>2.61%</td>
<td>2.76%</td>
<td>2.91%</td>
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<tr>
<td>1979</td>
<td>2.25%</td>
<td>2.40%</td>
<td>2.55%</td>
<td>2.70%</td>
<td>2.85%</td>
<td>3.00%</td>
<td>3.15%</td>
<td>3.30%</td>
<td>3.45%</td>
</tr>
<tr>
<td>1980</td>
<td>-0.41%</td>
<td>-0.26%</td>
<td>-0.11%</td>
<td>0.04%</td>
<td>0.19%</td>
<td>0.34%</td>
<td>0.49%</td>
<td>0.64%</td>
<td>0.79%</td>
</tr>
<tr>
<td>1981</td>
<td>-0.07%</td>
<td>0.08%</td>
<td>0.23%</td>
<td>0.38%</td>
<td>0.53%</td>
<td>0.68%</td>
<td>0.83%</td>
<td>0.98%</td>
<td>1.13%</td>
</tr>
<tr>
<td>1982</td>
<td>-0.14%</td>
<td>0.01%</td>
<td>0.16%</td>
<td>0.31%</td>
<td>0.46%</td>
<td>0.61%</td>
<td>0.76%</td>
<td>0.91%</td>
<td>1.06%</td>
</tr>
<tr>
<td>1983</td>
<td>2.08%</td>
<td>2.23%</td>
<td>2.38%</td>
<td>2.53%</td>
<td>2.68%</td>
<td>2.83%</td>
<td>2.98%</td>
<td>3.13%</td>
<td>3.28%</td>
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<tr>
<td>1984</td>
<td>2.50%</td>
<td>2.65%</td>
<td>2.80%</td>
<td>2.95%</td>
<td>3.10%</td>
<td>3.25%</td>
<td>3.40%</td>
<td>3.55%</td>
<td>3.70%</td>
</tr>
<tr>
<td>1985</td>
<td>1.65%</td>
<td>1.80%</td>
<td>1.95%</td>
<td>2.10%</td>
<td>2.25%</td>
<td>2.40%</td>
<td>2.55%</td>
<td>2.70%</td>
<td>2.85%</td>
</tr>
<tr>
<td>1986</td>
<td>0.52%</td>
<td>0.67%</td>
<td>0.82%</td>
<td>0.97%</td>
<td>1.12%</td>
<td>1.27%</td>
<td>1.42%</td>
<td>1.57%</td>
<td>1.72%</td>
</tr>
<tr>
<td>1987</td>
<td>0.16%</td>
<td>0.31%</td>
<td>0.46%</td>
<td>0.61%</td>
<td>0.76%</td>
<td>0.91%</td>
<td>1.06%</td>
<td>1.21%</td>
<td>1.36%</td>
</tr>
<tr>
<td>1988</td>
<td>2.84%</td>
<td>2.99%</td>
<td>3.14%</td>
<td>3.29%</td>
<td>3.44%</td>
<td>3.59%</td>
<td>3.74%</td>
<td>3.89%</td>
<td>4.04%</td>
</tr>
<tr>
<td>1989</td>
<td>1.99%</td>
<td>2.14%</td>
<td>2.29%</td>
<td>2.44%</td>
<td>2.59%</td>
<td>2.74%</td>
<td>2.89%</td>
<td>3.04%</td>
<td>3.19%</td>
</tr>
<tr>
<td>1990</td>
<td>1.42%</td>
<td>1.57%</td>
<td>1.72%</td>
<td>1.87%</td>
<td>2.02%</td>
<td>2.17%</td>
<td>2.32%</td>
<td>2.47%</td>
<td>2.62%</td>
</tr>
</tbody>
</table>

| TFP avg. | 1.58% | 1.73% | 1.88% | 2.03% | 2.18% | 2.32% | 2.48% | 2.63% | 2.78% |
| (share $\check{Y}$) | (60%) | (66%) | (72%) | (78%) | (84%) | (89%) | (95%) | (101%) | (107%) |
Looking at Table 4.9 first, it can be seen that for a low depreciation rate the net capital stock actually increases and for depreciation rates higher than three per cent it decreases over the whole sample period. Even a difference of only 0.5 per cent in the depreciation rate lead to strong differences in the estimates. In fact, the longer the time period, the stronger are these differences. The last row of Table 4.10 shows the implied average TFP growth rate and the resulting share of technological progress to total economic growth. An increase of 0.5 per cent in the depreciation rate increases the value of the TFP estimates by 0.15 per cent and the contribution of technological progress to total economic growth increases by roughly six per cent. The reason behind this is that the greater the depreciation rate, the smaller is the net capital stock. A small net capital stock implies low capital accumulation. Therefore, more economic growth is traced to technological progress. Thus, it can be concluded that the choice of the depreciation rate influences the results of the Solow (1956) - Swan (1956) estimation strongly.

Besides the depreciation rate there is also a more general problem surrounding the capital stock. It is very hard to measure capital. This was first pointed out by economists of the University of Cambridge and has led to the Cambridge Capital Controversy. The following quote by (Hunt 2002, p. 430) describes the measurement problems associated with capital very well:
"While it is perfectly clear what we mean when we aggregate the amount of labor employed (in order to ascertain its marginal productivity), it is by no means clear what we mean when we aggregate capital. If we say 100 laborers worked for one week, the meaning is unambiguous. But what does it mean to say 100 capitals worked for one week? One hundred factories? Of various sizes? One hundred shovels? Fifty factories and 25 shovels and 25 oil refining plants? This is obviously nonsensical. One piece of capital can be anything ranging from a screwdriver to a gigantic plant that employs tens of thousand of workers."

The quote does not only point out that the size of the capital stock is hard to measure, it also tells that the implication of the size of the capital stock on productivity is ambiguous. One can simply not say that two capital stocks which have the same monetary value are equally productive. Similar, one can also not argue that a capital stock with a higher monetary value is more productive than a capital stock with a lower monetary value.

Despite the capital controversy, the Solow (1956) - Swan (1956) analysis conducted in this paper treats capital accumulation equally. For example, with a capital share of 0.30 and without any changes in technology and labour, a five percent increase
in capital stock would lead to an increase of 1.5 per cent in economic growth. An increase in capital stock of two per cent would lead to economic growth of 0.6 per cent. No distinction is made concerning the composition of the added capital. Only the size of the capital stock matters. As the Capital Controversy points out this is likely to be wrong. Therefore, the quality of the TFP estimations is affected.

4.3.7.2 Labour stock

There are not only problems concerning the capital stock but there is also at least one that concerns the labour stock. This thesis has used the number of total employed persons to derive the labour stock. Normally it would be preferred to use the number of total hours worked. This is especially true for the case of Germany, because there was a rapid increase in part-time employment in the 1990s implying that the number of total employed persons overweights the actual labour contribution (European Commission 2002). However, it was decided to use total employment in persons, because deriving the amount of total hours worked is time consuming and complex and therefore beyond the scope of this thesis.

Nevertheless it should be noted that because of the high share of part time work in the German economy, the estimations in this thesis are likely to overstate the share of labour accumulation to economic growth. This concerns especially the second time period. Consequently, technological progress is likely to be understated.
4.3.7.3 Factor shares

The Solow-Swan estimation has been reported to be highly sensitive to the choice of the factor shares (Dowling and Summers 1998). Based on findings in the literature, this thesis used a capital share of 0.3. Table 4.11 points out how TFP estimations would differ using other capital shares:
Table 4.11: Sensitivity of TFP Estimation to factor shares, West Germany 1971-1990

<table>
<thead>
<tr>
<th>Year</th>
<th>$TFP_{\alpha = 0.20}$</th>
<th>$TFP_{\alpha = 0.25}$</th>
<th>$TFP_{\alpha = 0.30}$</th>
<th>$TFP_{\alpha = 0.35}$</th>
<th>$TFP_{\alpha = 0.40}$</th>
<th>$TFP_{\alpha = 0.45}$</th>
<th>$TFP_{\alpha = 0.50}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>2.36%</td>
<td>2.27%</td>
<td>2.17%</td>
<td>2.08%</td>
<td>1.99%</td>
<td>1.89%</td>
<td>1.80%</td>
</tr>
<tr>
<td>1972</td>
<td>3.55%</td>
<td>3.46%</td>
<td>3.37%</td>
<td>3.28%</td>
<td>3.19%</td>
<td>3.10%</td>
<td>3.01%</td>
</tr>
<tr>
<td>1973</td>
<td>3.54%</td>
<td>3.50%</td>
<td>3.45%</td>
<td>3.41%</td>
<td>3.36%</td>
<td>3.32%</td>
<td>3.27%</td>
</tr>
<tr>
<td>1974</td>
<td>1.59%</td>
<td>1.47%</td>
<td>1.34%</td>
<td>1.21%</td>
<td>1.08%</td>
<td>0.95%</td>
<td>0.82%</td>
</tr>
<tr>
<td>1975</td>
<td>1.13%</td>
<td>0.96%</td>
<td>0.79%</td>
<td>0.62%</td>
<td>0.45%</td>
<td>0.28%</td>
<td>0.11%</td>
</tr>
<tr>
<td>1976</td>
<td>5.27%</td>
<td>5.22%</td>
<td>5.17%</td>
<td>5.12%</td>
<td>5.06%</td>
<td>5.01%</td>
<td>4.96%</td>
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<tr>
<td>1977</td>
<td>3.15%</td>
<td>3.13%</td>
<td>3.12%</td>
<td>3.10%</td>
<td>3.08%</td>
<td>3.07%</td>
<td>3.05%</td>
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<tr>
<td>1978</td>
<td>2.27%</td>
<td>2.29%</td>
<td>2.31%</td>
<td>2.32%</td>
<td>2.34%</td>
<td>2.36%</td>
<td>2.38%</td>
</tr>
<tr>
<td>1979</td>
<td>2.73%</td>
<td>2.79%</td>
<td>2.85%</td>
<td>2.91%</td>
<td>2.96%</td>
<td>3.02%</td>
<td>3.08%</td>
</tr>
<tr>
<td>1980</td>
<td>0.09%</td>
<td>0.14%</td>
<td>0.19%</td>
<td>0.25%</td>
<td>0.30%</td>
<td>0.35%</td>
<td>0.40%</td>
</tr>
<tr>
<td>1981</td>
<td>0.56%</td>
<td>0.55%</td>
<td>0.53%</td>
<td>0.51%</td>
<td>0.50%</td>
<td>0.48%</td>
<td>0.47%</td>
</tr>
<tr>
<td>1982</td>
<td>0.55%</td>
<td>0.50%</td>
<td>0.46%</td>
<td>0.41%</td>
<td>0.36%</td>
<td>0.31%</td>
<td>0.26%</td>
</tr>
<tr>
<td>1983</td>
<td>2.78%</td>
<td>2.73%</td>
<td>2.68%</td>
<td>2.62%</td>
<td>2.57%</td>
<td>2.52%</td>
<td>2.47%</td>
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<tr>
<td>1984</td>
<td>3.07%</td>
<td>3.08%</td>
<td>3.10%</td>
<td>3.11%</td>
<td>3.13%</td>
<td>3.14%</td>
<td>3.16%</td>
</tr>
<tr>
<td>1985</td>
<td>2.15%</td>
<td>2.20%</td>
<td>2.25%</td>
<td>2.30%</td>
<td>2.35%</td>
<td>2.40%</td>
<td>2.45%</td>
</tr>
<tr>
<td>1986</td>
<td>0.86%</td>
<td>0.99%</td>
<td>1.12%</td>
<td>1.25%</td>
<td>1.38%</td>
<td>1.51%</td>
<td>1.64%</td>
</tr>
<tr>
<td>1987</td>
<td>0.58%</td>
<td>0.67%</td>
<td>0.76%</td>
<td>0.86%</td>
<td>0.95%</td>
<td>1.04%</td>
<td>1.14%</td>
</tr>
<tr>
<td>1988</td>
<td>3.31%</td>
<td>3.37%</td>
<td>3.44%</td>
<td>3.50%</td>
<td>3.57%</td>
<td>3.63%</td>
<td>3.70%</td>
</tr>
<tr>
<td>1989</td>
<td>2.33%</td>
<td>2.46%</td>
<td>2.59%</td>
<td>2.72%</td>
<td>2.85%</td>
<td>2.99%</td>
<td>3.12%</td>
</tr>
<tr>
<td>1990</td>
<td>1.51%</td>
<td>1.77%</td>
<td>2.02%</td>
<td>2.28%</td>
<td>2.54%</td>
<td>2.79%</td>
<td>3.05%</td>
</tr>
</tbody>
</table>
From Table 4.11 it can be seen that especially during years in which there was a strong movement in factor accumulation, TFP estimations were very sensitive to the choice of capital share. For example, for the year of 1975 a capital share of 0.20 would imply TFP growth of 1.13 per cent and a capital share 0.50 would imply a TFP growth of only 0.11 per cent. In contrast, for the year of 1990 the trend is increasing. A capital share of 0.20 would imply TFP growth of 1.51 per cent and a capital share of 0.50 would imply a TFP growth of 3.05 per cent.

In conclusion, besides the choice of the depreciation rate, the choice of the factor shares also has important effects on the estimation results.

4.4 Application of the Kaldor model

The application of Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) growth framework to Germany is of particular interest in light of the findings in Chapter 3 that the German capital stock has been decreasing in size, especially during the period from 1992 to 2011. For the very same time period the application of the Solow (1956) - Swan (1956) growth framework which was conducted in Section 4.3 has found that technological progress was significantly lower than it was during the time period from 1971 to 1990. The Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model argues that technological progress is found
in new capital investment. Accordingly, the lower capital investment during the period from 1992 to 2011 could explain the lower TFP growth during that time period.

In estimating Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962) economic growth model, this thesis will closely follow the approach outlined in Taylor (2007). First, the technical progress function of Kaldor and Mirrlees (1962) will be estimated. Then, the employment elasticity will be determined for both time periods. This is useful in order to learn more about the capital intensity of the production (Taylor 2007). Lastly, Kaldor’s (1966) three growth laws will be tested on the German growth experience from 1992 to 2011.

4.4.1 Literature Review

An extensive search of the literature did not result in any findings of an estimation of the technical progress function of Kaldor and Mirrlees (1962) on Germany. In regards to Kaldor’s (1966) growth propositions, Kaldor (1966) himself conducted a study where he used a cross section of twelve countries including West Germany to test his propositions. For the sample period of 1953-4 to 1963-4 Kaldor (1966) found supporting evidence: First, Kaldor (1966) estimated that manufacturing growth has a strong effect on overall economic growth. Kaldor (1966) also high-
lighted that high economic growth rates require the growth of the manufacturing sector to be far greater than overall output growth. Kaldor (1966) confirmed that manufacturing output growth and manufacturing productivity growth have a strong correlation. Lastly, Kaldor (1966) showed that overall productivity growth and employment in the manufacturing sector is positively related.

Before testing Kaldor’s (1966) three growth laws on the recent German growth experience, the next section employs the technical progress function of Kaldor and Mirrlees (1962) to test the relationship between technical progress and economic growth following the approach outlined by Taylor (2007).

### 4.4.2 Estimation of the technical progress function of Kaldor and Mirrlees

As the second chapter has outlined, the technical progress function of Kaldor and Mirrlees (1962) can be specified as:

\[
\frac{\dot{p}_t}{p_t} = f\left(\frac{\dot{i}_t}{i_t}\right),
\]

where \(\frac{\dot{p}_t}{p_t}\) denotes the rate of growth of productivity and \(f\left(\frac{\dot{i}_t}{i_t}\right)\) denotes a function of the rate of growth of investment per worker (Kaldor and Mirrlees 1962). Thus, the stronger investment, the higher technological progress.
The technical progress function of Kaldor and Mirrlees (1962) is estimated using
the following approach outlined by Taylor (2007):

\[ \log y = \alpha + \beta \log k + u_t, \]  

(4.17)

where \( \beta \) is expected to be greater than zero, \( u_t = p_1 u_{t-1} + p_2 u_{t-2} + \epsilon_b \), \( y \) is RGDP divided by total employment and \( k \) is capital stock divided by total employment.

Putting \( y \) and \( k \) into the log form has the handy feature that this allows regression results to be interpreted as percentage change rates.

The estimation of Equation 4.17 did not yield statistically robust results. Both AR(1) and AR(2) delivered estimations with \( \beta \) being statistically insignificant. Therefore, Equation 4.17 was adjusted as follows:

\[ \log y = \alpha + \beta \log k + \gamma \text{ time-trend} + u_t \]  

(4.18)

The inclusion of a time trend reduces autocorrelation and this led to statistically more robust estimation results as Table 4.12 shows:
Table 4.12: Estimation of the technical progress function of Kaldor and Mirrlees (1962), West Germany 1971-1990 and Germany 1992-2011


Exact AR(2) Newton-Raphson Iterative Method converged after 3 iterations

<table>
<thead>
<tr>
<th>Constant (α)</th>
<th>Coefficient (β)</th>
<th>Time trend (γ)</th>
<th>R-Bar²</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.06*</td>
<td>0.44 [0.001]*</td>
<td>0.02 [0.000]*</td>
<td>0.99</td>
<td>1.91</td>
</tr>
<tr>
<td>(1.31)</td>
<td>(0.11)</td>
<td>(0.00)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Exact AR(1) Inverse Interpolation Method Converged after 5 iterations

<table>
<thead>
<tr>
<th>Constant (α)</th>
<th>Coefficient (β)</th>
<th>Time trend (γ)</th>
<th>R-Bar²</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.11*</td>
<td>0.68 [0.001]*</td>
<td>0.02 [0.000]*</td>
<td>0.94</td>
<td>1.77</td>
</tr>
<tr>
<td>(2.05)</td>
<td>(0.16)</td>
<td>(0.00)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.10 \) and \( d_u = 1.54 \) (Gujarati and Porter 2010).

As shown by Table 4.12, an increase in capital per worker contributed 0.44 to every 1 per cent increase in output per worker during the time period from 1971 to 1990. The \( R-Bar^2 \) value of 0.99 indicates that this relationship is very strong and there are also no signs of autocorrelation. Therefore, the application of Kaldor’s (Kaldor and Mirrlees 1962; Kaldor 1966) growth model suggests that capital accumulation was very important for West Germany’s economic growth.
The results of the estimation for the second time period indicate that the contribution of capital accumulation to economic growth increased. In particular, an increase in capital per worker contributed 0.68 to every one per cent increase in RGDP per worker. Following Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962) analysis this means that Germany’s technological progress in the second period was higher than in the first one. Nevertheless, the relationship between RGDP per worker and capital per worker was a little bit less strong in the second period then in it was in the first one as indicated by $R-bar^2$ being 94 per cent.

Taylor (2007) pointed out that technological progress in the sense of the technological progress function of Kaldor and Mirrlees (1962) does not only depend on investment, but also on the division of capital and labour. In particular, technological progress leads to labour saving production techniques. To what extent Germany’s production techniques are labour saving can be analysed by estimating the elasticity of employment for both time periods. If labour saving did occur then the employment elasticity of the second period is lower. The labour elasticity is estimated using the following equation (Taylor 2007):

$$\log Y_{GDP} = \alpha + \beta \log e + u_t,$$  \hspace{1cm} (4.19)
where $\beta$ is expected to be greater than zero, $Y_{GDP}$ denotes total real GDP and e denotes total employment. The results of the estimation are illustrated in Table 4.13:

Table 4.13: Estimation of the labour elasticity, West Germany 1971-1990 and Germany 1992-2011

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Likelihood Estimation: Fixed Initial Values of Disturbances Error TERM: AR(1) converged after 4 iterations</td>
</tr>
<tr>
<td>$\text{Constant (}\alpha\text{)}$</td>
</tr>
<tr>
<td>12.46*</td>
</tr>
<tr>
<td>(3.70)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Likelihood Estimation: Fixed Initial Values of Disturbances Error TERM: Restricted AR(2) converged after 5 iterations</td>
</tr>
<tr>
<td>$\text{Constant (}\alpha\text{)}$</td>
</tr>
<tr>
<td>10.23</td>
</tr>
<tr>
<td>(2.05)</td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. **Significant at 10 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of $d_l$ and $d_u$ at 5 per cent significance level: $d_l = 1.20$ and $d_u = 1.41$ (Gujarati and Porter 2010).

Table 4.13 shows that labour elasticity was actually slightly higher in the second time period compared to the first one. Nevertheless, the results confirm that the German economy is a very capital intensive one, where labour accumulation does not play a crucial role. In the first time period, an increase in employment of one
percent only led to an increase in RGDP of 0.92 per cent. For the second time period an increase in employment would increase RGDP by 1.04 per cent. This shows that adding labour does not have strong effects on output growth.

The higher labour elasticity in the second time period is most likely as result of the reunification. The East German economy was not as capital intense as the West German one and therefore the importance of labour for Germany from 1992-2011 is higher than it was for West Germany from 1971-1990.

It can be concluded that according to Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962) model, Germany experienced stronger technological progress in the second period than in the first period. However, production in the first period was slightly more capital intense than it was compared to the second period.

4.4.3 Estimation of Kaldor’s growth propositions

As outlined above Kaldor (1966) confirmed his growth propositions using a cross section of countries including West Germany from 1953-4 to 1963-4. The following tests his growth propositions for Germany from 1992 to 2011 using the methodology outlined by Taylor (2007). Unfortunately, it was not possible to extend this analysis to West Germany because of data limitations.
4.4.3.1 **Estimation of Kaldor’s first proposition**

Kaldor’s (1966) first growth proposition states that there is a strong correlation between total output growth and output growth in the manufacturing sector. In fact, the manufacturing sector is the engine of economic growth. Kaldor’s (1966) first growth proposition can be tested using the following equation (Taylor 2007):

\[ \log Y_{GDP} = \alpha + \beta M + u \quad (4.20) \]

where \( \beta \) is expected to be between zero and one, \( Y_{GDP} \) refers to real GDP and \( M \) refers to gross value added by the manufacturing sector (Taylor 2007).

The estimation results are shown in Table 4.14:

**Table 4.14: Estimation of Kaldor’s (1966) first proposition, Germany 1992-2011**

<table>
<thead>
<tr>
<th>Constant (( \alpha ))</th>
<th>Coefficient (( \beta ))</th>
<th>( R-Bar^2 )</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.84* ( [0.000]^* )</td>
<td>0.28 ( [0.000]^* )</td>
<td>0.98</td>
<td>1.51</td>
</tr>
</tbody>
</table>

(0.13) \( (0.13) \)

*Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.20 \) and \( d_u = 1.41 \) (Gujarati and Porter 2010).

The results shown in Table 4.14 indicate a very strong correlation between total
output growth and manufacturing output growth of 98 per cent. As the coefficient of 0.28 is significantly below unity this means that strong economic growth rates can only be accomplished when the growth of the manufacturing sector is significantly greater than overall economic growth. However, Taylor (2007) points out that a further estimation is required, because the estimation results are likely to be affected by the fact that manufacturing output is a large part of total GDP. Therefore, a second estimation analyses the relationship between non-manufacturing output and manufacturing output:

\[
\log GDP^* = \alpha + \beta \log M + u
\]  

(4.21)

where \(\beta\) is again expected to be between zero and one and \(GDP^*\) refers to real GDP without manufacturing output. If the manufacturing output is the driver of economic growth then the estimation of Equation 4.21 should also indicate a very strong correlation. The results of this estimation are shown in Table 4.15:
The results in Table 4.15 show that there is a very strong correlation of 98 per cent between non-manufacturing output and manufacturing output. In addition, the coefficient is well below unity. This confirms the previous estimation and it can be concluded that Kaldor’s (1966) first growth proposition is right and that the manufacturing sector is the engine of Germany’s economic growth.

**4.4.3.2 Estimation of Kaldor’s second proposition**

Kaldor’s (1966) second proposition states that the growth of labour productivity in the manufacturing sector and the growth of manufacturing output are positively related. In addition, the growth rate of manufacturing output is equal to the sum of its productivity growth and its employment growth. The relationship between manufacturing labour productivity and the manufacturing output growth
is analysed with the following equation (Taylor 2007):

\[ \log p = \alpha + \beta M + u \] (4.22)

where \( \beta \) is expected to be greater than zero and \( P \) equals manufacturing output divided by employment in the manufacturing sector. The results in Table 4.16 confirm the positive relation between growth of labour productivity and manufacturing output:

Table 4.16: Estimation of Kaldor’s (1966) second proposition, Germany 1992-2011

<table>
<thead>
<tr>
<th>Constant (( \alpha ))</th>
<th>Coefficient (( \beta ))</th>
<th>( R-Bar^2 )</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12.94*</td>
<td>0.88 [0.000]*</td>
<td>0.99</td>
<td>1.59</td>
</tr>
<tr>
<td>(1.19)</td>
<td>(0.04)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.20 \) and \( d_u = 1.41 \) (Gujarati and Porter 2010).

The \( R-Bar^2 \) of 99 per cent indicates that the correlation is very strong. To test whether the growth rate of manufacturing output is equal to the sum of its productivity growth and its employment growth a second estimation is conducted.

\[ \log e_m = \alpha + \beta \log M + u \] (4.23)
where \( \beta \) is expected to be greater than zero. The above equation shows that the estimation regresses total employment in the manufacturing sector on the manufacturing output growth. The results are illustrated in Table 4.17:

**Table 4.17: Second estimation of Kaldor’s (1966) second proposition, Germany 1992-2011**

<table>
<thead>
<tr>
<th>Constant (( \alpha ))</th>
<th>Coefficient (( \beta ))</th>
<th>( R-\text{Bar}^2 )</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.93*</td>
<td>0.12 [0.018]</td>
<td>0.95</td>
<td>1.59</td>
</tr>
<tr>
<td>(1.19)</td>
<td>(0.04)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.20 \) and \( d_u = 1.41 \) (Gujarati and Porter 2010).

Looking at both Table 4.16 and 4.17 is can be seen that the constants of Equations 4.22 and 4.23 do almost add up to zero. The constant of the former equation is -12.94 and the one of the later is 12.93. In addition the coefficients are 0.88 and 0.12, which adds up to one. This means that a one per cent increase in manufacturing output would result in a 0.88 per cent increase in productivity in manufacturing labour and a 0.12 per cent increase in employment. Nevertheless, Kaldor’s (1966) second proposition has to be rejected, because as indicated by Table 4.17 the coefficient of the second estimation is statistically not significant and therefore the estimates are not reliable. In conclusion, the second proposition is rejected.
4.4.3.3 Estimation of Kaldor’s third proposition

The third proposition states that productivity growth of the total economy is positively correlated with employment growth in the manufacturing sector and negatively correlated with growth in the non-manufacturing sector. This can be estimated in the following way (Taylor 2007):

\[
\log p_{\text{GDP}} = \alpha + \beta \log e_m + \gamma \log e_{nm} + u
\]  

(4.24)

where \( \beta \) is expected to be greater than zero and \( \gamma \) is expected to be smaller than zero, \( p \) denotes real GDP divided by total employment and \( e_{nm} \) is the employment in the non-manufacturing sector. The estimation of the third proposition was not successful, because the coefficient were statistically not significant as shown by Table 4.18:

Table 4.18: Estimation of Kaldor’s (1966) third proposition, Germany 1992-2011

<table>
<thead>
<tr>
<th>Constant (( \alpha ))</th>
<th>Coefficient (( \beta ))</th>
<th>Coefficient (( \gamma ))</th>
<th>R-Bar(^2)</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.55</td>
<td>-0.22 [0.191]</td>
<td>0.64 [0.072]</td>
<td>0.88</td>
<td>1.59</td>
</tr>
<tr>
<td>(7.52)</td>
<td>(0.16)</td>
<td>(0.33)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.10 \) and \( d_u = 1.54 \) (Gujarati and Porter 2010).
Applying the AR(2) method or including a time-trend did also not yield in usable regression results. Even though the estimates in Table 4.18 cannot be trusted it should still be noted that the coefficients also have the opposite signs of what Kaldor (1966) predicted. In conclusion Kaldor’s (1966) third growth proposition is also rejected.

4.4.4 Policy implications

Based on Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) analysis, a large proportion of Germany’s economic growth is the result of capital accumulation. Therefore, economic growth can be increased by increasing capital investments. As suggested previously investments can be increased by offering tax cuts or subsidies for investments.

The findings of this chapter have also pointed out that the manufacturing sector, with its possibilities for increasing returns to scale, is the driver of German economic growth. But Chapter 3 has shown that especially during the second time period the growth of the industry sector, which comprises the manufacturing sector, was very weak. Accordingly, the German government should pursue policies that support growth of the manufacturing sector. Here, policy makers can choose from a wide range of policy measures, e.g. decreasing regulation or providing
incentives for improving machinery. Following the logic put forward by Kaldor (1966), promoting the growth of the manufacturing sector would lead to stronger growth of the overall economy.

### 4.4.5 Limitations

The applicability of the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model has several limitations. First of all, the same issues as for the Solow (1956) - Swan (1956) model apply in terms of data input.

A crucial limitation of the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) growth model itself is that it is not as applicable as for example the Solow (1956) - Swan (1956) model. While it is possible to estimate the technical progress function of Kaldor and Mirrlees (1962) using econometric methods, this estimation only sheds light into the role of capital accumulation, but it does not explain the contribution of other factors. The applicability of Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model would be much greater if it was possible to put it into a production function, like it is possible for the Solow (1956) - Swan (1956) model. It was suggested to Kaldor to express his model using the Cobb-Douglas production function as $Y = Ae^{at}K^\beta$. However, Kaldor rejected this suggestion (Hahn 1989). Its inability to be expressed in a production function
may also explain why the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model is so rarely applied.

Besides the inability to be expressed as a production function, the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model also suffers from general theoretical weaknesses. Rothschild (1959) for example has pointed out that the Kaldor (1957) model is based on many assumptions which do hold in the short-run, but not in the long-run. For example, the fact that employment fluctuates and that investment is affected by wage-profit relationships, makes it impossible that there is a unique relationship between capital growth and output growth. Nevertheless, this is what Kaldor’s (1957) technical progress function suggests\(^2\) (Rothschild 1959).

Kaldor’s (1966) growth propositions have also been subject to numerous criticisms. In regards to the first growth proposition Wolfe (1968) pointed out that since both the manufacturing and the services sector have a strong correlation with output growth it is not really evident that it is manufacturing which is the driver of growth, because it could also be the services sector. There is also no clear evidence whether there are increasing returns in manufacturing (Wolfe 1968).

\(^{2}\)This also applies to the technical progress function of Kaldor and Mirrlees (1962)
4.5 Application of the Romer model

The last model to be estimated is Romer’s (1986) endogenous growth model. Similar to the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model, the Romer (1986) model embodies technological progress into capital. But in contrast to Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966), technological progress is not a result from investment, but from knowledge. The creation of new knowledge allows the creation of superior capital stock. Unfortunately, Romer (1986) did not provide any details of what he actually refers to as knowledge. Therefore, to test how knowledge affects technological progress and capital accumulation, one has to experiment with different proxies for knowledge. The following section will try patents, research and development (R&D) expenditure and R&D personnel. Because of data limitations, estimations using patents will cover the period from 1992 to 2010, estimations using R&D expenditure will cover the period from 1992-2009 and estimations using R&D personnel covers the period 1996-2010.

4.5.1 Literature Review

In order to assess endogenous growth theories, including Romer (1986), Jones (1995) has investigated the influence of the number of scientists and engineers en-
gaged in R&D on TFP growth. According to Romer (1986) one would expect that the higher the number of scientists and engineers engaged in R&D, the higher the knowledge accumulation. Accordingly, it is expected that with a higher number of scientists and engineers engaged in R&D, technological progress as measured by TFP growth is increasing. However, Jones (1995) could not confirm this expectation. For a number of sample countries including Germany, Jones (1995) found that while the number of scientists and engineers engaged in R&D increased strongly, TFP growth did not show a growth trend. Therefore, Jones (1995) rejected Romer’s (1986) model because no relationship between knowledge and TFP growth can be found.

4.5.2 Estimations

This section will experiment with three different statistics as proxies for knowledge. For each regression, two estimations will be run. The first one will use technological progress as a dependent variable and the second one will use capital as a dependent variable.

4.5.2.1 Technological progress and patents

The first attempt uses the number of patent grants. The thinking behind using patent grants as a proxy for knowledge is that new patents capture the amount of knowledge being created as a result from R&D activities of enterprises. The
influence of knowledge on technical progress will be estimated using the following
equation:

\[ TFP = \alpha + \beta P + u \]  \hspace{1cm} (4.25)

where \( \beta \) is expected to be positive, TFP is the percentage growth of TFP and \( P \)
denotes the percentage growth of patents granted. Since Romer (1986) embodied
technological progress into capital, the effects of patents on capital will also be
analysed:

\[ K = \alpha + \beta P + u \]  \hspace{1cm} (4.26)

where \( \beta \) is expected to be positive, \( K \) is the percentage change in capital stock.

Table 4.19 shows the results of the two estimations:
Table 4.19: Estimation of Romer’s (1986) growth model using patents, Germany 1992-2010

1. Estimation: TFP as dependent variable

Exact AR(2) Newton-Raphson Iterative Method converged after 6 iterations

<table>
<thead>
<tr>
<th>Constant ($\alpha$)</th>
<th>Coefficient ($\beta$)</th>
<th>$R$-Bar$^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95*</td>
<td>0.67 [0.130]</td>
<td>0.06</td>
<td>1.85</td>
</tr>
<tr>
<td>(0.04)</td>
<td>(0.04)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Estimation: Capital as dependent variable

Exact AR(2) Newton-Raphson Iterative Method converged after 11 iterations

<table>
<thead>
<tr>
<th>Constant ($\alpha$)</th>
<th>Coefficient ($\beta$)</th>
<th>$R$-Bar$^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99*</td>
<td>-0.00 [0.854]</td>
<td>0.90</td>
<td>1.94</td>
</tr>
<tr>
<td>(0.00)</td>
<td>(0.00)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of $d_l$ and $d_u$ at 5 per cent significance level: $d_l = 1.18$ and $d_u = 1.40$ (Gujarati and Porter 2010).

It can be seen that neither estimation provided statistically robust results, because both coefficients were statistically not significant. Using the AR(1) method or including a time trend did also not yield usable regression output. Therefore, another proxy is tried.

4.5.2.2 Technological progress and R&D expenditure

Another possible proxy for knowledge is total R&D expenditure. The size of R&D expenditure indicates the amount of resources being invested in knowledge
The following equations will be estimated:

\[ TFP = \alpha + \beta R\&Dexp + u \quad (4.27) \]

\[ K = \alpha + \beta R\&Dexp + u \quad (4.28) \]

where \( \beta \) is expected to be positive in both estimations and \( R\&Dexp \) stands for the change rate of total R\&D expenditure. Table 4.20 shows that the usage of R\&D expenditure also did not provide statistically significant results:

Table 4.20: Estimation of Romer’s (1986) growth model using R\&D expenditure, Germany 1992-2010

<table>
<thead>
<tr>
<th>1. Estimation: TFP as dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact AR(2) Newton-Raphson Iterative Method converged after 14 iterations</td>
</tr>
<tr>
<td>( Constant (\alpha) )</td>
</tr>
<tr>
<td>0.79*</td>
</tr>
<tr>
<td>(0.18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Estimation: Capital as dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact AR(2) Newton-Raphson Iterative Method converged after 41 iterations</td>
</tr>
<tr>
<td>( Constant (\alpha) )</td>
</tr>
<tr>
<td>0.97*</td>
</tr>
<tr>
<td>(0.01)</td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthsis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.18 \) and \( d_u = 1.40 \) (Gujarati and Porter 2010).
Accordingly, another proxy for knowledge has to be tried.

4.5.2.3 Technological progress and R&D staff

The last attempt employs the amount of people conducting R&D work as a proxy for knowledge. This is very similar to the approach of Jones (1995). As people working in R&D create knowledge it would be expected that there is a relationship between the amount of R&D staff and TFP growth or the capital stock. Thus, the following equations are estimated:

\[
\text{TFP} = \alpha + \beta \text{R&D-empl} + u \quad (4.29)
\]

\[
K = \alpha + \beta \text{R&D-empl} + u \quad (4.30)
\]

where \( \beta \) is expected to be positive in both cases and R&D-empl refers to the change rate of total R&D staff. Because of data limitations these estimations will only cover the period from 1996 to 2010. Unfortunately, the estimations were again unusable as Table 4.21 demonstrates:
Table 4.21: Estimation of Romer’s (1986) growth model using R&D employment, Germany 1996-2010

1. Estimation: TFP as dependent variable

<table>
<thead>
<tr>
<th>Constant (α)</th>
<th>Coefficient (β)</th>
<th>R-Bar²</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01</td>
<td>0.01 [0.983]</td>
<td>-0.15</td>
<td>1.99</td>
</tr>
<tr>
<td>(0.31)</td>
<td>(0.31)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Estimation: Capital as dependent variable

<table>
<thead>
<tr>
<th>Constant (α)</th>
<th>Coefficient (β)</th>
<th>R-Bar²</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99*</td>
<td>-0.00 [0.827]</td>
<td>0.77</td>
<td>1.78</td>
</tr>
<tr>
<td>(0.02)</td>
<td>(0.02)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *Significant at 5 per cent level. P-value in square brackets. Standard error in parenthesis. Durbin-Watson d Statistic: Significance points of \( d_l \) and \( d_u \) at 5 per cent significance level: \( d_l = 1.08 \) and \( d_u = 1.36 \) (Gujarati and Porter 2010).

Both times the independent variable was insignificant. Therefore, using total R&D personnel as a proxy for knowledge does not work either.

It can be concluded that the attempts to estimate the Romer (1986) model were unsuccessful. None of the used proxies showed a relationship with TFP growth or capital growth. This confirms earlier findings by Jones (1995). It can be concluded that knowledge accumulation does not influence technological progress or capital
accumulation in Germany. Therefore the Romer (1986) model is rejected.

4.6 Conclusion

This chapter applied the three growth models empirically. For the Solow (1956) - Swan (1956) growth model this thesis found higher TFP estimates than previous studies like Young (1994); Burda and Hunt (2001) or European Commission (2002). Using the Solow (1956) - Swan (1956) model it was also shown that the rate of Germany’s technological progress from 1992 to 2011 was lower than the one of West Germany from 1971 to 1990. Further, it was shown that Germany’s business cycles can be explained by the RBC Theory. It was also pointed out that the results of the application of the Solow (1956) - Swan (1956) growth framework are highly sensitive to the choice of the capital stock’s depreciation rate and to the choice of the capital share.

The application of Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) growth model yielded different results to Solow (1956) - Swan (1956). The estimation how the technical progress function of Kaldor and Mirrlees (1962) showed that Germany experienced higher technical progress during the period from 1992 to 2011 than West Germany had experienced during the period from 1971 to 1990. However, by determining the labour elasticity it was found that the economy’s pro-
duction process during the second period was slightly less capital intensive than it had been during the first period. Thus, West Germany’s stance of technology from 1971 to 1990 was likely to be higher the one of Germany from 1992 to 2011. In testing Kaldor’s (1966) growth propositions it was confirmed that the manufacturing sector was the driver of Germany’s economic growth from 1992 to 2011. But Kaldor’s (1966) second and third growth proposition could not been confirmed.

Romer’s (1966) growth model could not be estimated. Neither patent grants, nor R&D expenditure of R&D personnel demonstrated a relationship with TFP growth or capital growth. Therefore the Romer (1986) model was rejected in explaining the growth experience of Germany.
Chapter 5: Findings and Conclusion

The aim of this thesis was to analyse Germany’s economic growth based on the Solow (1956) - Swan (1956), the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) and the Romer (1986) model. Looking at the political and economic development of post-war Germany, it was outlined that during the years of division West Germany was a capitalist and wealthy country whereas East Germany was socialist and relatively poor. Both countries reunited in 1990 and adopted West Germany’s constitution and economic system. As the unification implied severe economic changes it was decided to break the empirical analysis into two time periods. The first time period is from 1971 to 1990 and includes West Germany only. The second one is from 1992 to 2011 and looks at the reunited Germany. The year of 1991 was excluded from the analysis for various reasons, including problems concerning the estimation of the capital stock and because the strong changes in labour stock could bias the estimation.

The economic performance of West Germany from 1971 to 1990 was found to be
strong. The economy grew by 2.61 per cent on average, even though West Germany was suffering from two recessions resulting from the oil crises during this time period. The application of the Solow (1956) - Swan (1956) model found that roughly four fifths of the economic growth could be traced to technological progress. Labour accumulation only played a minor role, as it contributed 0.34 per cent growth to the 2.61 per cent growth. Capital accumulation was even less important and contributed 0.10 per cent. Therefore, technological progress was the main driver behind West Germany’s economic growth and it was argued that this made West Germany’s growth very sustainable because unlike factor accumulation technological progress is not subject to marginal diminishing productivity.

In contrast, the overall economic performance of Germany after the reunification was weak. The economy grew by only 1.33 per cent on average, which is significantly lower than the growth of West Germany from 1971 to 1990. Applying the Solow (1956) - Swan (1956) it was shown that technological progress contributed 1.48 per cent to technological growth, capital accumulation contributed -0.26 per cent and labour accumulation 0.11 per cent. Therefore, factor accumulation was negative. While technological progress increased its relative importance for overall economic growth after the reunification, the rate of technological progress during the time period from 1992 to 2011 was significantly lower than during the time
period from 1971 to 1990. Therefore, less technological progress is one of the reasons why Germany experienced low economic growth. Consequently, it was argued that in order to achieve higher economic growth rates, German policy makers have to promote innovation in order to increase technological progress. In addition, investments could be promoted in order to raise growth coming from capital accumulation.

It was also shown that for both time periods fluctuations in the business cycle can be explained by technological fluctuations. This provides evidence to the Real Business Cycle Theory.

The results of the Solow (1956) - Swan (1956) model were found to be very sensitive to the choice of the depreciation rate and the capital share. However, it is a difficult task to find a perfect depreciation rate or a perfect capital share and the choice of these values will always dependent on a few assumptions. Therefore, with the results of the Solow (1956) - Swan (1956) application being so dependent on the ambiguous choice of the depreciation rate and the capital share it was argued that the numbers derived in this thesis can only serve as a point of reference.

The application of the Kaldor (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 203
1966) model yielded different results to the one of Solow (1956) - Swan (1956). Estimating the technical progress function of Kaldor and Mirrlees (1962) it was found that technological progress during the second time period was significantly stronger than during the first one. The reason behind this is that Kaldor’s (Kaldor 1957; Kaldor and Mirrlees 1962; Kaldor 1966) model embodies technological progress into capital replacement. In particular, it was found that from 1971 to 1990 capital replacement contributed 0.44 of every one per cent increased in real GDP. From 1992 to 2011 capital replacement contributed 0.68 of every one per cent increased in real GDP, making capital replacement significantly more important than in the time period before. This suggests that the lower TFP growth rates of the time period from 1992 to 2011 as compared to the ones of the time period from 1971 to 1990 are a result of the significantly lower rate of capital investments during the later time period. Based on estimations of the labour elasticity, it was found that the production of West Germany from 1971 to 1990 was slightly more capital intensive than Germany’s production from 1992 to 2011. Therefore, while technological progress during the time period from 1992 to 2011 was higher than during the time period from 1971 to 1990, the stance of technology was likely to be lower than during the previous time period, because the production was less capital intensive. This is most likely the result of the integration of the backward East German economy.
Analysing the German growth experience from 1992 to 2011 in respect to Kaldor’s (1966) growth propositions, only his first law was confirmed. It was shown that output growth in the manufacturing sector is the engine of overall output growth. The second and the third growth proposition were rejected because the econometric analysis did not provide statistically robust results.

Attempts to estimate the Romer (1986) model were not successful. This thesis tested the influence of knowledge accumulation on technological progress and on capital accumulation. Experimenting with the number of patent grants, R&D expenditure and employment in R&D as proxies for knowledge accumulation, no relationship was found with technological progress or capital accumulation. Therefore, the Romer (1986) growth model was rejected for Germany.

There are a few limitations associated with the approach pursued in this thesis. For example, there is no reliable data for the gross capital stock of the years from 2009 to 2011 available. Therefore, the values of the net capital stock for 2009 to 2011 were estimated using the moving average of the net capital stock. The quality of these estimates is unknown. In addition, all net capital stock estimates were derived using a depreciation rate of three percent. This depreciation rate
was suggested by the literature, but this choice is again ambiguous. As the estimates of the net capital stock used in this thesis had a major impact on all the empirical results, the derived conclusions depend heavily on the quality of these estimates. However, the quality of the estimates could not be assessed for this thesis.

Another limitation concerns the labour input. Like the capital input, the labour input has a major influence on the results of the empirical estimations in this thesis. However, because of limited time and resources this thesis used total employment as a proxy for labour input, but working hours is normally the preferred choice for a proxy.

A limitation concerning the application of the Solow (1956) - Swan (1956) growth framework is that the selected factor shares, which were estimated by Bernanke and Gürkaynak (2002), were determined for West Germany for the period from 1980 to 1995. It is possible that factor shares changed after the reunification and therefore the results of the Solow (1956) - Swan (1956) estimation for the time period from 1992 to 2011 could be based on a wrong factor share. If this is the case, TFP growth estimations could be biased downwards or upwards.

Future research could address the shortcomings of this thesis by improving the
data which was used for the net capital stock. Furthermore, future research could also repeat the empirical estimations conducted in this thesis by using total working hours instead of total employment. Implementing these suggestions would lead to more robust results.
Appendix A: The curvature of a production function

The curvature of a production function can be strictly concave or strictly convex.

To determine the curvature of a production function one has to determine the second derivative of the production function. If the second derivative is negative, the production function is strictly concave and if the second derivative is positive, the production function is strictly convex (Chiang 1984).

Table A.1 and Figure A.1 reproduce how Chiang (1984) illustrated the concept of the curvature of a function:
Table A.1: The curvature of a production function

<table>
<thead>
<tr>
<th>If at</th>
<th>The derivative signs are</th>
<th>We can illustrate by</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x = x_1$</td>
<td>$f'(x_1) &gt; 0$ $f''(x_1) &lt; 0$</td>
<td>point A</td>
</tr>
<tr>
<td>$x = x_2$</td>
<td>$f'(x_2) = 0$ $f''(x_2) &lt; 0$</td>
<td>point B</td>
</tr>
<tr>
<td>$x = x_3$</td>
<td>$f'(x_3) &lt; 0$ $f''(x_3) &lt; 0$</td>
<td>point C</td>
</tr>
<tr>
<td>$x = x_4$</td>
<td>$g'(x_4) &lt; 0$ $g''(x_4) &gt; 0$</td>
<td>point D</td>
</tr>
<tr>
<td>$x = x_5$</td>
<td>$g'(x_5) = 0$ $g''(x_5) &gt; 0$</td>
<td>point E</td>
</tr>
<tr>
<td>$x = x_6$</td>
<td>$g'(x_6) &gt; 0$ $g''(x_6) &gt; 0$</td>
<td>point F</td>
</tr>
</tbody>
</table>

Source: Chiang (1984), p. 242

Figure A.1: The curvature of a production function

Source: Chiang (1984), p. 243

Figure A.1(a) illustrates a strictly concave function, because its second derivative is always negative. In contrast, Figure A.1(b) demonstrates a strictly convex function, because its second derivative is always positive.
Appendix B: Data
<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Capital Stock, 2000 prices, in mio. $\mathcal{E}(K_t)$</th>
<th>Inflation Rate ($i_t$)</th>
<th>Inflation Index 2000 ($\check{P}_t$)</th>
<th>Gross Capital Stock current prices in mio. $\mathcal{E}(K^*_t)$</th>
<th>Inflation Index 2005 ($\check{P}_t$)</th>
<th>Gross Capital Stock 2005 prices in mio. $\mathcal{E}(\check{K}_t)$</th>
<th>Net Capital Stock change rate $\dot{K}_t$</th>
<th>Net Capital Stock $K_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
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<td>4,097,573</td>
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<td>100.0000</td>
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<td>1972</td>
<td>4,206,985</td>
<td>0.05485</td>
<td>0.41191</td>
<td>1,732,903</td>
<td>0.38184</td>
<td>4,538,279</td>
<td>0.02198</td>
<td>104.5309</td>
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<tr>
<td>1973</td>
<td>4,415,120</td>
<td>0.07032</td>
<td>0.44088</td>
<td>1,946,523</td>
<td>0.40869</td>
<td>4,762,805</td>
<td>0.01947</td>
<td>106.5665</td>
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<tr>
<td>1974</td>
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<td>0.06986</td>
<td>0.47168</td>
<td>2,173,186</td>
<td>0.43725</td>
<td>4,970,173</td>
<td>0.01354</td>
<td>108.0093</td>
</tr>
<tr>
<td>1975</td>
<td>4,778,865</td>
<td>0.05910</td>
<td>0.49956</td>
<td>2,387,309</td>
<td>0.46309</td>
<td>5,155,194</td>
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<td>108.7898</td>
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<tr>
<td>1976</td>
<td>4,945,825</td>
<td>0.04247</td>
<td>0.52077</td>
<td>2,575,637</td>
<td>0.48275</td>
<td>5,335,302</td>
<td>0.00494</td>
<td>109.3269</td>
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<tr>
<td>1977</td>
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<td>0.03734</td>
<td>0.54022</td>
<td>2,764,425</td>
<td>0.50078</td>
<td>5,520,232</td>
<td>0.00466</td>
<td>109.8366</td>
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<tr>
<td>1978</td>
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<td>0.02719</td>
<td>0.55490</td>
<td>2,937,522</td>
<td>0.51440</td>
<td>5,710,631</td>
<td>0.00449</td>
<td>110.3298</td>
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<tr>
<td>1979</td>
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<td>0.04044</td>
<td>0.57734</td>
<td>3,162,913</td>
<td>0.53520</td>
<td>5,909,827</td>
<td>0.00488</td>
<td>110.8684</td>
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<tr>
<td>1980</td>
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<td>0.05441</td>
<td>0.60875</td>
<td>3,451,239</td>
<td>0.56432</td>
<td>6,115,793</td>
<td>0.00485</td>
<td>111.4063</td>
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<tr>
<td>1981</td>
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<td>0.64738</td>
<td>3,788,392</td>
<td>0.60012</td>
<td>6,312,751</td>
<td>0.00220</td>
<td>111.6519</td>
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<tr>
<td>1982</td>
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<td>0.05241</td>
<td>0.68131</td>
<td>4,099,365</td>
<td>0.63157</td>
<td>6,490,755</td>
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<tr>
<td>1983</td>
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<td>0.70374</td>
<td>4,345,344</td>
<td>0.65237</td>
<td>6,660,858</td>
<td>-0.00379</td>
<td>111.0279</td>
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<tr>
<td>1984</td>
<td>6,330,295</td>
<td>0.02406</td>
<td>0.72067</td>
<td>4,562,078</td>
<td>0.66806</td>
<td>6,828,797</td>
<td>-0.00479</td>
<td>110.4964</td>
</tr>
<tr>
<td>1985</td>
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<td>0.02066</td>
<td>0.73556</td>
<td>4,767,228</td>
<td>0.68187</td>
<td>6,991,419</td>
<td>-0.00619</td>
<td>109.8129</td>
</tr>
<tr>
<td>1986</td>
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<td>0.73461</td>
<td>4,872,231</td>
<td>0.68099</td>
<td>7,154,671</td>
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<td>109.0827</td>
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<td>5,181,123</td>
<td>0.69139</td>
<td>7,493,819</td>
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<td>0.02781</td>
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<td>0.72977</td>
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<tr>
<td>Year</td>
<td>Gross Capital Stock, 2000 prices, in mio. $\mathcal{E}(\hat{K}_t)$</td>
<td>Inflation Rate ($i_t$)</td>
<td>Inflation Index 2000 ($\hat{P}_t$)</td>
<td>Gross Capital Stock current prices in mio. $\mathcal{E}(\hat{K}_t^*)$</td>
<td>Inflation Index 2005 ($\hat{P}_t$)</td>
<td>Gross Capital Stock 2005 prices in mio. $\mathcal{E}(\hat{K}_t)$</td>
<td>Net Capital Stock change rate ($\dot{K}_t$)</td>
<td>Net Capital Stock ($K_t$)</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------</td>
<td>------------------</td>
<td>-------------------------------</td>
<td>---------------------------------</td>
<td>------------------</td>
<td>-----------------------------</td>
<td>-------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1991</td>
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<td>0.81877</td>
<td>6,708,242</td>
<td>0.75900</td>
<td>8,838,263</td>
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<td>100.0000</td>
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<td>1992</td>
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<td>0.86084</td>
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<td>9,117,055</td>
<td>0.00154</td>
<td>100.1544</td>
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<tr>
<td>1993</td>
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<td>0.89860</td>
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<td>9,384,445</td>
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<td>1994</td>
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<td>1995</td>
<td>9,167,815</td>
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<td>0.87100</td>
<td>9,889,768</td>
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<td>1996</td>
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<tr>
<td>1997</td>
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<td>10,363,080</td>
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<td>98.1433</td>
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<td>0.90900</td>
<td>10,596,963</td>
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<td>0.00550</td>
<td>0.98598</td>
<td>9,904,896</td>
<td>0.91400</td>
<td>10,836,866</td>
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<td>10,274,600</td>
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<td>10,274,600</td>
<td>0.92700</td>
<td>11,083,711</td>
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<td>95.9986</td>
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<td>1.01942</td>
<td>10,697,889</td>
<td>0.94500</td>
<td>11,320,518</td>
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<td>2002</td>
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<td>1.03452</td>
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<td>0.95900</td>
<td>11,520,766</td>
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<td>93.9981</td>
</tr>
<tr>
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<td>11,700,205</td>
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<td>92.6422</td>
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<tr>
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<td>1.06257</td>
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<td>0.98500</td>
<td>11,876,548</td>
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<td>1.15415</td>
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<td>1.06990</td>
<td>12,712,880</td>
<td>-0.00991</td>
<td>86.6609</td>
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</table>
Table B.3: First estimation of the Net Capital Stock, Germany 2009-2011

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross fixed capital formation in mio. $\mathcal{E}(I_t)$</th>
<th>Gross capital stock in mio. $\mathcal{E}(K_t)$</th>
<th>Change in Net Capital Stock ($\dot{K}$)</th>
<th>Net Capital Stock ($K_t$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>12,712,880</td>
<td></td>
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<td>86.66090</td>
</tr>
<tr>
<td>2009</td>
<td>390255.2</td>
<td>13,103,136</td>
<td>0.000697622</td>
<td>86.72136</td>
</tr>
<tr>
<td>2010</td>
<td>413322.2</td>
<td>13,516,458</td>
<td>0.001543763</td>
<td>86.85523</td>
</tr>
<tr>
<td>2011</td>
<td>438811.2</td>
<td>13,955,269</td>
<td>0.002464956</td>
<td>87.06933</td>
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</table>

Table B.4: Second estimation of the Net Capital Stock, Germany 2009-2011

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<thead>
<tr>
<th>Year</th>
<th>Gross Capital Stock current prices in mio. $\mathcal{E}(K^*_t)$</th>
<th>Change Rate Gross Capital Stock ($\dot{K}^*_t$)</th>
<th>Inflation Index 2005 ($P_t$)</th>
<th>Gross Capital Stock 2005 prices in mio. $\mathcal{E}(K_t)$</th>
<th>Net Capital Stock change rate ($\dot{K}$)</th>
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</thead>
<tbody>
<tr>
<td>2005</td>
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<tr>
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<td>1.04280</td>
<td>11,951,030</td>
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</tr>
<tr>
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<td>12,712,880</td>
<td>0.02009</td>
<td>1.06990</td>
<td>11,882,320</td>
<td>-0.03399</td>
</tr>
<tr>
<td>2009</td>
<td>12,942,927</td>
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<td>12,052,114</td>
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</tr>
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<td>2010</td>
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<td>1.08596</td>
<td>12,143,466</td>
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</tr>
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<td>2011</td>
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<td>1.11105</td>
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Table B.5: Third estimation of the Net Capital Stock, Germany 2009-2011

<table>
<thead>
<tr>
<th>Year</th>
<th>Change in Net Capital Stock ($\dot{K}$)</th>
<th>Net Capital Stock ($K_t$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>-1.4257%</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>-1.1544%</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>-0.9912%</td>
<td>86.6609</td>
</tr>
<tr>
<td>2009</td>
<td>-1.1904%</td>
<td>85.6293</td>
</tr>
<tr>
<td>2010</td>
<td>-1.1120%</td>
<td>84.6770</td>
</tr>
<tr>
<td>2011</td>
<td>-1.0979%</td>
<td>83.7474</td>
</tr>
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</table>
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