

The background of the slide is a photograph of a modern industrial factory. Two large, yellow robotic arms are the central focus, positioned in a way that suggests they are working on a production line. The lighting is dramatic, with a mix of bright yellow and deep blue tones, creating a high-tech atmosphere. The robotic arms are complex, with various joints, cables, and sensors visible. In the background, other industrial equipment and structures are partially visible, though slightly out of focus.

Workforce Transition and Income Inequality in the Age of Automation

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Workforce Transition and Income Inequality in the Age of Automation

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Preface

This report is a final product of almost a year-long research at Delft University of Technology. It is intended to inform anyone who is interested in the impact of digital disruption on income inequality, macroeconomic indicators in the perspective of various stakeholders. This report also indicates that my two years of master education journey at Delft University of Technology will be ended.

Firstly, I want to thank the members of my graduation committee for their support, understanding, motivation and inspiration during the conduct of my research. In particular, I want to thank Dr Servaas Storm for being my mentor since my first year at the EPA programme. My interest in Economics and Finance was sparked by his guidance with the first year EPA course, and have been consolidated thanks to the courses I followed under his supervision in my second year. He did not only supervise my thesis, but also cared about my health more than me. I am also very thankful for my second supervisor, Dr.ir. Bert Enserink, who gave valuable criticism for my research and his guidance for the EPA programme. My chair, Prof.dr. CP (Cees) van Beers has been very helpful and understanding about my health-related problems.

Of course, I want to extend my thanks to everybody from the Engineering and Policy Analysis Program and Technology, Policy and Management Faculty who were with me during these intense two years. Daan, Rizky, Smitesh, Freek, Shajee, Michael, Merih, and Arushi, a big thank you for spending time with me not only in the faculty but also social activities such as Hotpot, annual birthday in Amsterdam and King's days. In particular, I would like to thank Guru, Quinn, Ashwin and Kunal for not only shared amazing memories not only as a roommate but also very close friend. I want to emphasize the contribution of Quinn and Ashwin for helping proofread my research. I also want to thank Tarik, Dogus and Deniz their emotional support when I need to talk and help.

Last but not least, I want to thank my family for their support and understanding. I do not think that I can manage to finish my studies without their support and love. I want to thank my mother her care, understanding and support when I needed it. My father who always supported me both moral and material ways. Of course, my little sister Aysu and my fake twin Zafer, I would like to thank your jokes and distractions to relax when I needed it.

Alper Kocaoglu
January 2019

Executive Summary

It is expected that automation and income inequality will have a major impact on the world economy in the 2020's and beyond. A research conducted by Bain (K. Harris, Kimson, & Schwedel, 2018) claimed that the impact of the economic disruption, which could be triggered by the collision of income inequality and automation, might be more dramatic than what was experienced in the past sixty years. On one hand, the adoption of new automation and production technologies, such as recent developments in artificial intelligence (AI) and machine learning, is expected to raise new businesses and investment opportunities. It is also expected that automation will boost productivity which has been declining due to several reasons, including aging population (Bughin et al., 2017).

On the other hand, only a fraction of society (around 25%) will enjoy the benefits of the coming wave of automation (K. Harris et al., 2018) because automation is expected to increase the demand for high-skilled labour while decreasing the demand for the low-skilled labour. Furthermore, the scarcity of the high skill labour may increase the skill premium. Putting it differently, the demand for high-skilled labour will boost their income while depressing the wage of the low-skilled labour. Moreover, the benefits of automation will flow to the owners of capital due to increasing investment along with automation. As a result, automation has the potential to further deepen income inequality, aggravating the existing inequality in the United States (Alvaredo, Chancel, Piketty, Saez, & Zucman, 2018).

This research, therefore, focuses three research gaps to study the impact of automation and digitalization. These gaps are:

- The impact of automation on gross output, the productivity growth, wage, labour share, employment and the structure of the economy in the short run
- The impact of income inequality on aggregate demand and investment of automation and capital
- The role of Main macroeconomic actors and their possible policy actions

As a result, research question formulated as follows:

“How can Automation in the short run be framed to explore its impact on income inequality and macroeconomic variables in the multi-actor arena ?”

To answer the main research question. First a literature review is conducted in order to analyse the impact of income inequality on macroeconomics indicators and actors who can influence income inequality. It is found that income inequality dampens the technological progress due to high price of stagnant products, rent and cost of living. It is also found that the recent income inequality resulted from a paradigm shift in macroeconomic policy. The major actors that influenced income inequality are central banks, the federal state, labour unions, firms and workers.

After analysing income inequality, technological progress is decomposed in order to compare digitalization and automation with other waves of technological progress. The common points of technological progress were then used to develop a frame work. The main dimensions of this framework have been listed as follows:

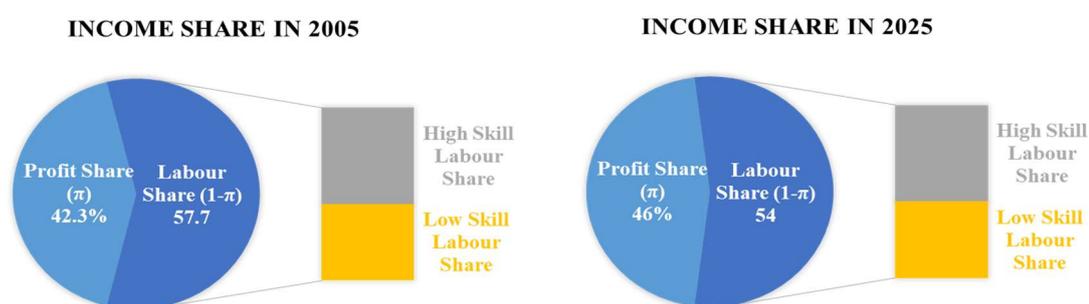
- Growth of Productivity
- Structural Transformation
- Factor Bias
- Income Inequality

This framework is used as a basis to develop a dynamic economic model based on the New Keynesian and Neo-Kaleckian economic models.

Findings

As suggested by other researchers, automation and digitalization increases economic growth and productivity. On the one hand, the high replacement of low skill labour in the dynamic sector boosts productivity and enables to produce 25% more dynamic products compared to the base case scenario. On the other hand, this growth in the dynamic sector comes at a price. The final outputs of the stagnant sectors decrease 22% compared to the base case scenario. This result reflects the importance of the demand growth in production. Automation and digitalization with high replacement rate may provide an additional 8% GDP growth compared to the base case scenario. It is also illustrated that the scenarios with high replacement rate demonstrate higher growth compared scenarios with no replacement. It can be seen that average growth for high replacement is 3%, which is higher than trend growth (2%), while no replacement scenarios are less than 2% growth in average

The demand for high skill labour in dynamic sector increases up to 42% with high replacement rate compared to the base case scenario. The demand for low skill workers in dynamic sector has a trend of decline in general. Therefore, income distribution will be affected negatively regardless of the pace of automation and digitalization.



Automation and digitalization will affect negatively the growth of aggregate demand. While the decline on consumption growth might be compensated by growth in investment growth, the aggregate demand will eventually decline in the later stage of automation and digitalization. Because intermediate firms use their profit to fund their research activities, technological change will slow down due to decreasing aggregate demand and profits.

Policies and Recommendations

Based on the findings of the simulation various policy options and their impacts are analysed:

- **Fiscal Policies:** were ineffective to manage the disruptive impact of automation as long as it does not increase employment in the dynamic sector. Due to consumption preferences of household, most of the transfer income are spent on stagnant sector.
- **Monetary Policies:** might be effective if it boosts investment along with employment. While a low interest rate enables increase employment due to increasing demand for labour, in the long run, it will impact the wages negatively due to capital accumulation and automation.

Therefore, recommendations are listed as follows:

- **Government** can focus on fiscal policies which can boost the employment in the dynamic sector or increasing productivity of the stagnant sector. They can use public policies such as investing in stagnant sector R&D activities and education of low skill labour in order to minimize the disruptive impact of automation in the long run. They can take more interventionist actions to regulate labour market and business environment. For example, government can provide incentives to employers to minimize their cost for employment activities. Governments can also invest in education and retraining activities to address labour market imbalances. Low skilled labour might be trained and prepared for skilled tasks.
- **Central Bank** can minimize the cost of borrowing for households in order to increase consumption, while they can increase interest rates to increase to cost of investment in automation.
- **Labour unions** can help the government to structure education programs in order to provide training for low skill labour. They should look for possible solutions to increase their power in the stagnant sectors.
- **Firms** can collaborate with labour unions and government to minimize the burden of demand constraints due to increasing income inequality. They can educate their low skilled labour in order to increase their complementarity with automation machine.
- **Workers** should collaborate with government training programme and labour unions to increase their employability.

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I

Formulate: Thesis Definition

1

Introduction

One of the grand challenges confronting society today is how to manage the economic, political, and social impacts of the predicted advances in robotics and Artificial Intelligence (AI). Most economists expect that robotization will lead to significant job losses and stagnant wage growth worldwide (at least during a transition period, the duration of which is unknown). It is expected that employment will decline in high-productivity, technologically-dynamic sectors (manufacturing and information), while more people have to find work in low-productivity, “stagnant” sectors (mostly labour-intensive services). There are fears that if there are negative impacts on (stagnant-sector) wages, employment and incomes are large enough to deepen income inequality (which is already high in many countries). Income inequality, in turn, weighs down aggregate demand, economic growth may decline, which would reinforce the negative consequences of robotization. The (policy) challenge is how the predicted disruptive technological change can be managed in ways that minimize the negative impacts (on growth, employment and inequality), while shortening the transition period to a new – and stable – growth trajectory, and achieving more egalitarian distribution of the benefits of robotization. To address the policy challenge a context study of income inequality and technological progress (Automation is considered as a part of technological progress) is undertaken. The context study draws attention to the key elements of income inequality and technological progress. The research gap emphasizes the requirement of a framework and economic model which is built on the key elements of income inequality and technological progress as discussed in section 1.2. Section 1.3 introduces the research questions which are required to address the research gap. Then, section 1.4 gives an overview about the structure of the research project.

1.1 The Collision of Automation and Income Inequality

It is expected that automation and income inequality will have a major impact on the world economy in the 2020s and beyond. A research conducted by Bain (K. Harris, Kimson, & Schwedel, 2018) claimed that the impact of the economic disruption, which could be triggered by the collision of income inequality and automation, might be more dramatic than what was experienced in the past sixty years. On the one hand, the adoption of new automation and production technologies, such as recent developments in artificial intelligence (AI) and machine learning, is expected to raise new businesses and investment opportunities. It is also expected that automation will boost productivity which has been declining due to several reasons, including aging population (Bughin et al., 2017).

On the other hand, only a fraction of society (around 25%) will enjoy the benefits of the coming wave of automation (K. Harris et al., 2018). Because automation is expected to increase the demand for high-skilled labour while decreasing the demand for the low-skilled labour. Furthermore, the scarcity of the high skill labour may increase the skill premium. Putting it differently, the demand for high-skilled labour will boost their income while depressing the wage of the low-skilled labour. Moreover, the benefits of automation will flow to the owners of capital due to increasing investment along with automation. As a result, automation has the potential to further deepen income inequality, aggravating the existing inequality in the United States (Alvaredo, Chancel, Piketty, Saez, & Zucman, 2018).

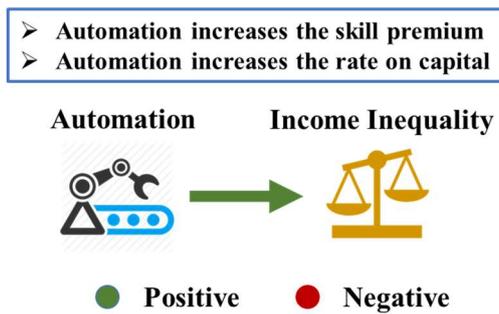


Figure 1.1 The Causal Relationship Between Automation and Income Inequality

1.1.1 The Adoption of Automation Technologies

New technologies and innovation in the area of automation, artificial intelligence, and machine learning algorithms can cause a major transformation in the structure and the dynamics of the world economy. Automation and AI have already created jobs and enabled design of wide range of products. As a consequence, it is expected that automation can provide a rise in the standards of living and material well-being. Besides, it can boost the productivity growth, which has been stagnant since 1980 (Eggertsson, Mehrotra, & Robbins, 2017). However, the increasing productivity will enable firms to produce more with less input, which in this case is labour. Research conducted by McKinsey estimates that 375 million individuals may need to find a new occupation due to the adoption of automation by 2030 (Manyika, Lund, et al., 2017).

Automation or the recent wave of technological progress is not totally different than previous waves of the technological progress which transformed the world economy throughout history. Technological progress has always caused disruption in the world economy. From agricultural economy to manufacturing economy or from manufacturing economy to service economy, each time that technological progress increased productivity, economic prosperity, and economic growth, it disrupted the labour market, which led to deepening income inequality, and caused a shift in the structure of the economy (Manyika, Lund, et al., 2017). In fact, it can be shown that technological progress has several dimensions which are common for all waves of technological progress.

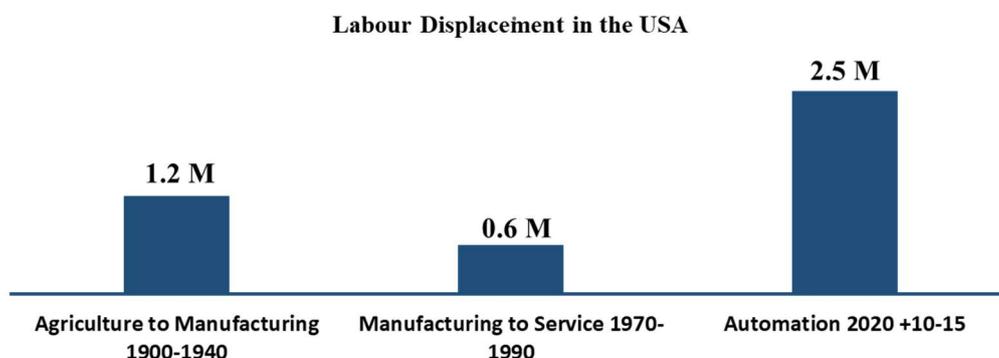


Figure 1.2 Labour Displacement in the USA. Adapted from Labor 2030: The Collision of Demographics, Automation and Inequality by Harris, Kimson, & Schwedel, 2018, Bain. Copyright 2018 by Bain.

Nevertheless, the incoming wave of automation has already led to a shift in structure of the economy. A large proportion of labour force has started to shift from highly productive sectors to low productive or stagnant sectors. Harris, Kimson, & Schwedel (2018) illustrated this phenomenon with an example, between the automobile and healthcare industry in USA. According to their research, the output of the automobile industry increased 128% per unit labour in between 1993 and 2014, while it remained limited to 16% in the healthcare industry in the same time interval. In contrast, employment in the healthcare industry increased 28% while it declined in the automobile industry (K. Harris et al., 2018). This phenomenon intensified by increasing capital investment in the manufacturing industry which boosted the labour productivity in the manufacturing sector, while the capital investment and labour productivity growth were stagnant in the healthcare industry. As a result, there has been unbalanced growth in the economy among highly productive and low productive sectors. The reallocation of labour from the highly productive sectors to low productive sectors was observed by Baumol (1967) who called this transformation and unbalanced growth in the economy as “*Cost disease*”.

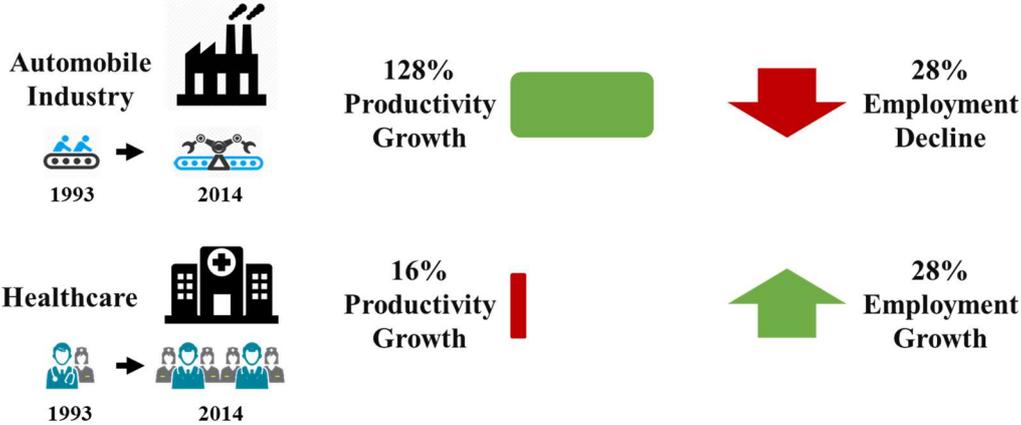


Figure 1.3 Labour Shift in the USA between 1993-2014. Adapted from *Labor 2030: The Collision of Demographics, Automation and Inequality* by Harris, Kimson, & Schwedel, 2018, Bain. Copyright 2018 by Bain.

One might assume that if automation has similarities with the previous wave of technological progress, why is such a furore being created around automation this time? This time, the pace of the transformation and the disruption will be critical to the impact of technological progress

If automation transforms the economy slowly, then, the society might have more time to adjust. Low skill labour that shifted from highly productive sectors to low productive sectors can retrain in order to match with required skills. A slow pace of the transformation might also avoid market volatility and boom-bust cycle in investment (Gillham et al., 2017; K. Harris et al., 2018). However, it is expected that the transformation and disruption will be faster than ever before. It is assumed that the pace of disruption will be three times faster than the historical peak. (K. Harris et al., 2018; Manyika, Lund, et al., 2017). This transformation might be followed by investment cycles which will leave a more disrupted economy with rising income inequality.

1.1.2 Rising Income Inequality

The rise in income inequality has been a topic of debate for decades. After years of economic prosperity with full employment in the USA, which is also known as The Golden Age of the Capitalism (Glyn, Hughes, Lipietz, & Singh, 1988), the unit labour cost started to increase more than productivity during the 1970s (Kaldor, 1976). After a series of events such as the collapse of Bretton Woods monetary system¹ in 1971 and the oil crisis, inflation erupted into hyperinflation in the USA. In response, the USA changed its macroeconomic policy targets to fight against hyperinflation. Since then, income inequality has deepened in the USA as shown in Figure 1.4 (Alvaredo et al., 2018). After the economy recovered from recession in the late 1970s, a significant part of the income growth started to go to the families of the wealthiest 10 percent. Interestingly, the income of the bottom 90 percent did not grow after the 2000s.

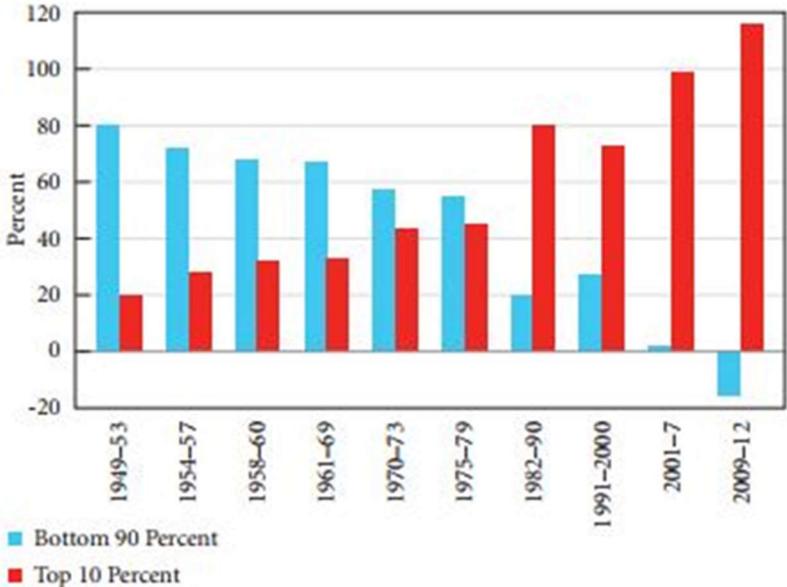


Figure 1.4 Distribution of Average Income Growth during Expansions Reprinted from "When a Rising Tide Sinks Most Boats: Trends in USA Income Inequality" (p.2) by P. V. TCHERNEVA., 2015

On the one hand, since the 1980s, some economists discussed that there have been several factors for rising income inequality, which were not direct control of the policy makers, such as Globalization and Skill-Biased technological change (Antony B. Atkinson, 2015). On the other hand, economists such as Piketty (2014), Alvaredo et al. (2018) and Storm and Nastepad (2012) pointed out the importance of macroeconomic policies. The NAIRU (Non- Accelerating Inflation Rate of Unemployment) policy, for instance, had a major role on the reduction of minimum wage, deregulation of labour rights and worsening of workers’ bargaining position (Storm & Naastepad, 2012).

Nevertheless, income inequality in the USA may be worsened due to disruption of automation. The impact of automation on the labour market – increasing demand for high skill labour, wage polarization

¹ Which is also known as the International payment system pegged to gold.

and investment boom-boost cycle – can lead a concentration of income among people who consume less while saving and investing.

1.1.3 A Challenge for Policy-Makers

Automation along with income inequality might lead to a constraint on aggregate demand and a decline in the consumption growth due to the shift of income from people who consume to people who save more. Such a constraint on aggregate demand might dampen economic growth. It may also cause financial instability, global imbalances, and collapse of globalization (Dabla-Norris, Kochhar, Suphaphiphat, Ricka, & Tsounta, 2015). The financial instability and investment boom-boost cycle in the economy might then lead investors to become less willing to invest. The decrease in investment may dampen technological progress which is significant in the presence of aging population and demographic change (Gillham et al., 2017; Manyika, Lund, et al., 2017).

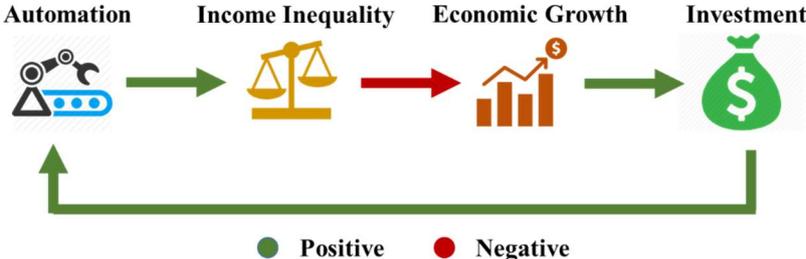


Figure 1.5 The Causal Map of Automation

A wide range of policy actions have been discussed by economists and researchers. These solutions include basic income and robot tax (Guerreiro, Rebelo, & Teles, 2017). However, these policy actions were criticized due to their possible negative impacts on the market and technological progress (R. D. Atkinson, 2018). Some researchers argued that there is a requirement of government involvement and intervention (Gillham et al., 2017; K. Harris et al., 2018; Manyika, Lund, et al., 2017). The rest emphasized the importance of retraining and unemployment benefits (R. D. Atkinson, 2018; D. Autor & Salomons, 2018).

In a nutshell, automation, as a coming wave of technological progress, might not be different than the previous wave of technological progress. However, the pace of transformation will determine its disruptive impact on the economy and society. When demographic changes and income inequality are considered, it seems that the adjustment process might not be easy. Even though several policy solutions have already been offered, their impact on the technological progress, economic growth and their effectiveness are open to question. This brings us to the policy challenge of the coming decade and the issues which will be addressed in the rest of this study:

Automation

- The impact of Automation on the productivity growth and gross output
- The pace of the transformation
- The structural shift in the economy
- The impact of automation on wage, wage share and employment
- The demand for high skill and low skill labour and capital investment

Income Inequality

- Driving factors behind income inequality
- The impact of automation on wage polarization, skill premium and profit share
- The impact of income inequality on aggregate demand and investment

Policy Challenge

- Macroeconomic policy actors and their influence on NAIRU, fiscal and monetary policies
- NAIRU
- The impact of fiscal policies on income inequality, aggregate demand and technological progress
- The impact of monetary policies on income inequality, aggregate demand and technological progress

1.2 Research Gaps

Section 1.1 gives an insight about the policy challenge which policy makers and the society will have to face in the coming decade. This section will point out the research gaps by focusing on the issues under the umbrella of their respective themes.

1.2.1 Automation

Automation and AI are a relatively new research theme among economists and social scientists. There have been several researchers who have studied the impacts of automation on wage, labour share, labour demand gross output and the productivity growth of labour (Acemoglu & Restrepo, 2016, 2017b, 2017a, 2018a; Prettner, 2016; Sachs & Kotlikoff, 2012). Some studies, on the other hand, focused the impacts of automation on labour displacement and wage (Benzell, Kotlikoff, LaGarda, & Sachs, 2015; Hémous & Olsen, 2018; Lankisch, Prettner, & Prskawetz, 2017). However, studies which focused the structural shift in the economy remained limited (Acemoglu & Guerrieri, 2006; Hémous & Olsen, 2018; Mookherjee & Ray, 2017). These studies generally focused on the impacts of Automation in the long run. There has been only one study (Lin & Weise, 2017) which focused short run implications of automation.

Even though the long run implications of automation give an insight on the required policy instruments, the pace of transformation and the shift in the structure of the economy increases the importance of short run implications of automation. Therefore, it is necessary to model and study both long run and short run implication of automation.

Research Gap in Automation

Studying the impact of automation on gross output, the productivity growth, wage, labour share, employment and the structure in *The Short Run*

1.2.2 Income Inequality

Income inequality has been one of the major research topics among economists and social scientists. On the one hand, there are a wide range of studies which focused on the driving factors of income inequality such as skill-biased technological change, globalization and deunionization (Acemoglu, 2000b; Acemoglu & Autor, 2010; Acemoglu, Gancia, & Zilibotti, 2015; Alesina & Perotti, 1993; Card & Dinardo, 2002; Dabla-Norris et al., 2015; International Monetary Fund, 2007; Juhn, Murphy, & Pierce, 1993; Lindert & Williamson, 2001). Several researchers studied the impact of income inequality on growth and investment. Their findings are both positive (Barro, 1999; Benabou, 1996; Forbes, 2000; Kuznets, 1955, 1966; Okun & Summers, 2015) and negative (Alesina & Perotti, 1993; Alvaredo et al., 2018; Barro, 1999; Carvalho & Rezai, 2016; Perotti, 1996; Piketty & Saez, 2006; Rajan & Zingales, 1998).

On the other hand, income inequality has not been studied extensively in the context of automation. Although there have been several attempts to study the impact of income inequality on skill premium and wage polarization (Acemoglu & Restrepo, 2017a; Hémous & Olsen, 2018; Lankisch et al., 2017; Mookherjee & Ray, 2017), they did not study its impact on aggregate demand and investment. Their study focused primarily on the production advantage of automation and investment based on factor prices. Hence, it is important to study the impact of income inequality on aggregate demand and investment, which might hamper technological progress and growth effect of automation.

Research Gap in Income Inequality

- Studying the impact of automation on *labour and profit share* and skill premium
- Studying the impact of income inequality on *aggregate demand and investment* of automation and capital

1.2.3 Policy Challenge

In macroeconomic studies, central banks, government, labour unions, firms, and workers are the main actors whose impacts on macroeconomic policies have been researched (Card, Lemieux, & Riddell, 2003, 2004; Epstein & Schor, 1988; Iversen, 1998; Meltzer, 1998, 2005; Mishkin, 2000; Perotti, 1996;

Verma & Kochan, 2004). These studies generally narrowed down their focus only one actor. Storm and Nastepad (2012), however, focused on factors such as productivity and labour union bargaining power to study NAIRU policies. These factors depend on several actors including labour unions, central bank, government, and firms².

In the context of automation, on the other hand, there have been several research which focused on the fiscal policies (Benzell et al., 2015; Gasteiger & Prettnner, 2017; Guerreiro et al., 2017; Hémous & Olsen, 2018). However, there has not been any research regarding the implication of monetary policies in the context of automation. If it is considered that automation will lead labour displacement, a structural shift, a rise in unemployment, and a more volatile market, the importance of both fiscal and monetary policies increases. Thus, it is necessary to understand the role of macroeconomic actors in NAIRU policies and to study the impacts of monetary and fiscal policies on automation, growth, and investment.

Research Gap in Policy Challenge

- Understanding *the role of the main macroeconomic actors in NAIRU* policies
- Studying *the impacts of monetary and fiscal policies* on automation, growth and investment

1.3 Research Questions

The research gaps regarding automation and income inequality along with policy challenge are addressed based on a preliminary literature and context study in section 1.2. In this section, these research gaps will be translated to a main research question and sub-questions to address the main one. The main research question is:

Main Research Question

“How can Automation in the short run be framed to explore its impact on income inequality and macroeconomic variables in the multi-actor arena ?”

Noting that, notions such as aggregate demand, gross output, employment labour share and productivity are called macroeconomic variables to eliminate redundancy. The main research question is broken down into sub-questions as follows:

² Productivity, for instance, depends on firm’s investment decision, government actions (fiscal stimulus).

1. What is the impact of deepened income inequality on macroeconomic variables and technological progress?

- a) What is the impact of income inequality throughout history?
- b) How did NAIRU policy affect income inequality?
- c) What were the roles of actors which were part of the NAIRU policy?
 - i) What was the role of Central Bank?
 - ii) What was the role of Government?
 - iii) What was the role of Labour unions?
 - iv) What was the role of Firms?
 - v) What was the role of workers?

2. How can technological progress be conceptualised?

- a) What is the distinction between automation and the previous wave of technological progress?
- b) What are the dimensions of technological progress?
- c) How is automation in accordance with the dimensions of technological progress?

3. How can automation of jobs be framed?

- a) What is the basic demand-led unbalanced growth model with two sectors?
- b) How can the labour force be diversified in this model?
- c) What is the production function of this model with exogenous technological change?
- d) How can the consumption and savings preferences be modelled?

4. What is the impact of automation on income inequality?

- a) How does automation affect the workforce transition between two sectors?
- b) What are the impacts of technological progress on workforce transition and income inequality?

5. What is the impact of automation and income inequality on aggregate demand and investment?

6. How can the innovation and technological change be endogenised?

- a) What is the impact of the automation and aggregate demand on investment?
- b) What is the impact of investment on technological change and automation?

7. What is the impact of the fiscal and monetary policies?

- a) What is the impact of these policies on automation?
- b) What is the impact of these policies on economic growth?
- c) What is the impact of these policies on unemployment?

1.4 Thesis Structure

The rest of the thesis from here onwards is structured to answer these research questions. Therefore, it is organised as follow:

Table I.1 Thesis Structure

Part	Title of the Part	Chapter	Title of the Chapter
<i>I</i>	<i>Formulate: Thesis Definition</i>	1	Introduction
		2	Methodology
<i>II</i>	<i>Design: Framework of Automation and Inequality</i>	3	Inequality in the Twenty-First Century
		4	Automation and Artificial Intelligence
<i>III</i>	<i>Apply: Exploring the Future of Automation and Inequality in the USA</i>	5	A Model of Automation and Artificial Intelligence
		6	Simulation I
		7	Technology and Policy Identification
<i>IV</i>	<i>Synthesise: Conclusion and Reflection</i>	8	Conclusion and Recommendation

As it is shown in Table I.1, the thesis has four parts. The Part I is formulating research in chapter 1 and explain the methodology in chapter 2. The Part II focuses designing a framework of Income inequality and Automation. For this purpose, The chapter 3 and 4 discuss income inequality and automation by using literature review. Based on the results, a framework is developed in chapter 4.

The Part III applies the finding of part 2, develops a dynamic economic model, and simulates it. For this purpose, the chapter 5 merges two different school of thoughts, and explains the model. The chapter 6 explores different scenarios under different pace of automation, and its impact on macroeconomic indicators. The chapter 7, then, extends the model which is described in chapter 5 by identifying policy options.

Finally, the Part IV synthesises all the findings of previous chapters, and makes recommendations. It also makes reflections about the research and findings.

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One This chapter lays down research methods which are used to answer the sub questions and conduct this research. The first step of this research is a literature review which is explained in section 2.2. Based on the Literature review, a framework is developed. Section 2.3 addresses the economic model which is used to develop a conceptual model and its operationalization. Finally, Section 2.4 shows the research flow.

2.1 Research Methods

The sub-questions of this research were answered with different methods. This section describes which methods are followed to answer each sub questions and what the deliverables of these methods are.

Table I.2 Research Methods

Research Questions	Methods	Deliverables
What is the impact of deepened income inequality on macroeconomic variables and technological progress?	Literature Review	Driving force of Income Inequality
How can technological progress be conceptualised?	Literature Review + Framework Development	Framework of Automation
How can automation of jobs be framed?	Literature Review + Conceptual Model Development	A Dynamic Economic Model
What is the impact of automation on income inequality?	Simulation	Impact of Automation on Main Macroeconomic Indicators
What is the impact of automation and income inequality on aggregate demand and investment?		
How can the innovation and technological change be endogenised?	Conceptual Model Development + Simulation	Policy Scenarios and Their Impact on Main Macroeconomic Indicators
What is the impact of the fiscal and monetary policies		

As listed in Table I.2, there are four different methods which are used during the research period. These methods are Literature Review, Framework Development, Conceptual Model Development and Simulation. The first question enables this study to identify the driving forces of income inequality thanks to literature review. The second question provides a framework for building a simulation model. Based on the framework and the findings of the first sub question, A dynamic economic model is developed and simulated to answer the third, fourth and fifth sub questions. The model, then, is extended, and simulated to cover the sixth and seventh sub questions.

2.2 Literature Review

Literature Review is one of the main methods which enables to conduct this research. It is used to answer the first, second and even the third research questions. It is used to gain an insight about the impact of income inequality on several macroeconomic indicators. These indicators are mainly aggregate demand and technological progress. It also used to compare the wave of technological progress and develop a framework.

The literature review methodology is executed in two steps. The first step aims to develop an understanding regarding income inequality and automation. The second step, on the other hand, focuses to develop the dynamic economic model. More than 100 articles and research papers are analysed from The National Bureau of Economic Research (NBER), JSTOR, ScienceDirect and Macroeconomic Policy Institute. The key words which are used during the literature review are listed in Table I.3 and Table I.4.

Table I.3 Key Words of First Literature Review

First Literature Review

- "Income Inequality" AND "USA" OR "Corn Law" OR "KARL MARX" OR "KUZNETS CURVE"
- "TREND OF INCOME INEQUALITY" AND "USA" AND "FACTORS"
- "POST-WAR ERA" AND "USA" AND "INCOME DISTRIBUTION"
- "NAIRU" AND "USA" OR "ECONOMIC POLICY ACTORS" OR "GOVERNMENT ECONOMIC POLICY" OR "FISCAL POLICIES" OR "MONETARY POLICIES" OR "LABOUR UNIONS"
- "INDUSTRIAL REVOLUTION" AND "TECHNOLOGICAL PROGRESS" AND "USA"
- "PRODUCTIVITY" AND "GROWTH" OR "NEW TASK" OR "LABOUR-AUGMENTING" OR "CAPITAL AUGMENTING" OR "CAPITAL ACCUMULATION"
- "STRUCTURAL TRANSFORMATION" AND "USA" OR "KUZNETS" OR "BALANCED GROWTH" OR "UNBALANCED GROWTH" OR "BAUMOL" OR "COST DISEASE"
- "FACTOR BIAS" AND "USA" OR "CAPITAL BIASED" OR "SKILL BIASED"

Second Literature Review

- "NEW KEYNESIAN" OR "NEO-KALECKIAN" OR "PRODUCTION FUNCTION" OR "CES" OR "COBB-DOUGLAS" OR "RETURN THE SCALE"
- "FINAL GOOD" AND "INTERMEDIATE GOOD" AND " TWO SECTOR ECONOMIC MODEL"
- "SKILL HETEROGENEITY" AND " HIGH SKILL" OR "LOW SKILL"
- "PRICE SETTING" AND "MARGINAL COST" OR "CALVO PRICE" OR "STICKY PRICE" OR "WAGE SETTING"
- "INCOME SHARE" AND "NEO-KALECKIAN" OR " CONSUMPTION FUNCTION" OR "INVESTMENT FUNCTION"

2.3 Dynamic Simulation

Based on the literature review, a framework is designed which combines all common elements of technological progress. Taking this framework as a base, a dynamic economic model is developed in order to study the impact of automation and associated income inequality on macroeconomic indicators. In order to achieve this research aim, two different economic school of thoughts are used to conceptualise a dynamic economic model.

To illustrate the impact of automation on macroeconomic indicators such as aggregate demand, productivity growth, change on wage and profit share, and investment growth, a numerical analysis software/package is used. In mainstream economics, Stata is a common powerful statistical analysis software which enables to produce high quality graphs and usage of a wide range of state of the art optimization algorithms for economics and econometric models (Pinzon, 2015). Dynare is another software to simulate economic models, such as overlapping generations (OLG) and dynamic stochastic general models (DSGE) by using rational expectation assumptions (Adjemian et al., 2011). However, these software packages generally focus on optimization. This research, on the other hand, is interested in the dynamic evolution of macroeconomic indicators and economic agents such as consumers, firms, capital owners, and labour. Thus, Vensim is chosen as the numerical analysis software for this research. Vensim, a system dynamics software, enables to visualize the dynamic evolution of every kind of system by allowing interactive tracing of behaviour (Ventana Systems, 2016).

2.4 Research Flow

The research flow diagram is illustrated in **Error! Reference source not found..**

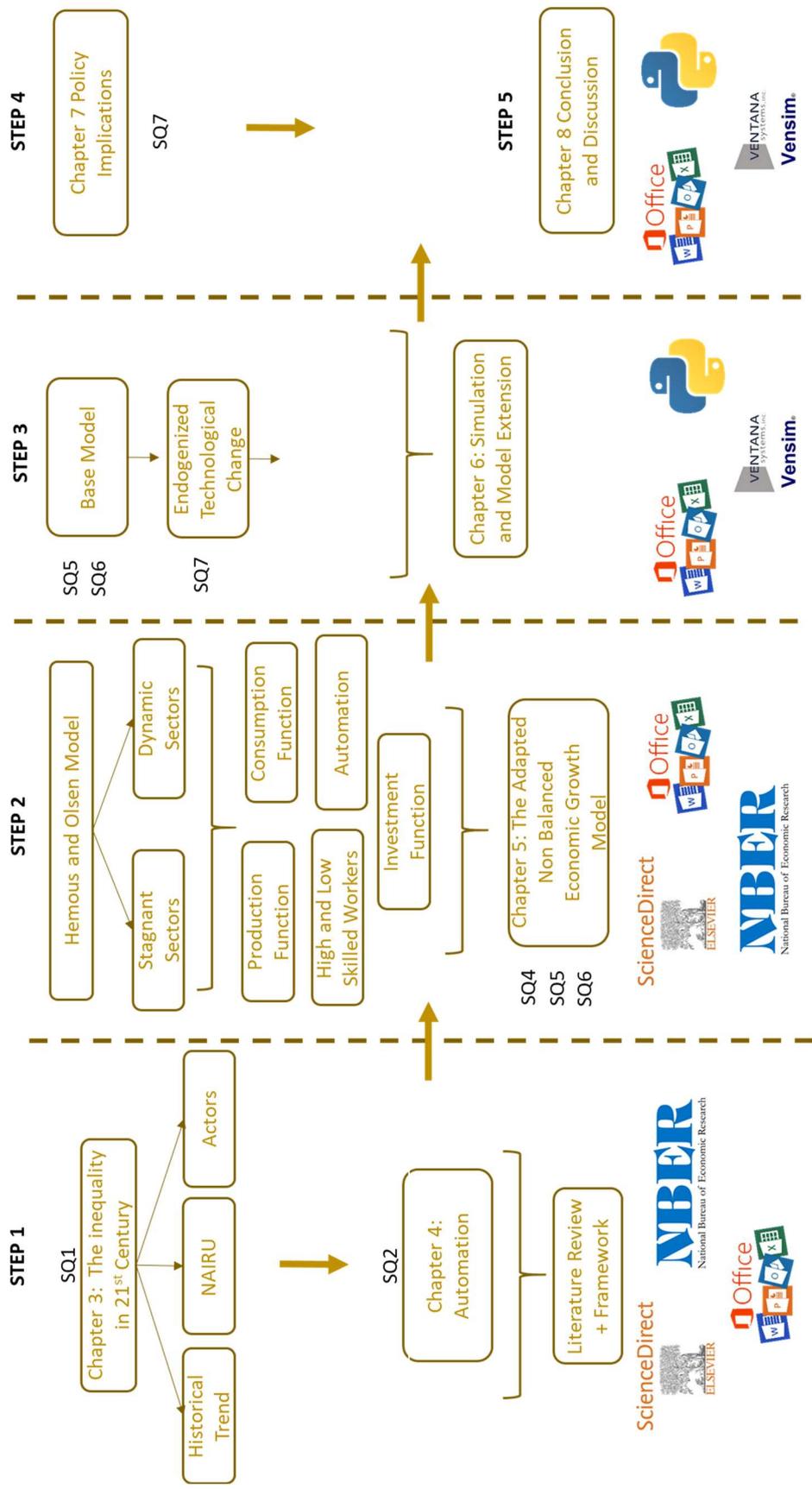


Figure 2.1 Research Flow Diagram

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II

Design: Framework of Automation and Inequality

Inequality In the Twenty-First Century

Income inequality and growing socioeconomic disparities have been at the forefront of public debate since the Great Recession, even though it has risen since the 1970s. It is not merely a topic of discussion in the classroom, but it has permeated the streets and the popular media. Occupy Wall Street, and Arab Spring were tangible evidence of how people have become more aware of the extent of the increasing income inequality (Shelter, 2011). This chapter tries to answer how income inequality has been worsened after the 1970s and which factors affected that by reviewing the literature on income inequality, particularly Capital in the twenty-first century (Piketty, 2014) and Macroeconomics beyond the NAIRU (Storm & Naastepad, 2012). For this purpose, it analyses the historical trends in income inequality in section 3.1. Section 3.2 addresses the relationship between macroeconomic policies and income inequality in the USA after the second World War. Section 3.2.2 decomposes the multi-actor arena of macroeconomic policy and NAIRU. Finally, Section 3.4 summarises the findings.

3.1 Historical Trends in Income Inequality

The issue of income distribution between wage and rent or working class and owner of the capital extends back for a long time. The French Revolution, for instance, is a revolution that arose from inequality (Piketty, 2014). The French revolution started as a clash of economic classes in 1780 (Soboul, 1953). After a long war with the United Kingdom, the monarchy of France was looking for a solution to overcome economic and political instability due to increased debt because of the war. The working class or majority of the population had to carry the heavy burden of the war (White, 1995). However, the working class was already frustrated due to increasing rents and stagnant agricultural wages (Piketty, 2014). According to Piketty (2014), the population of France increased from 20 million to 30 million in the 18th century. This increase resulted in an increase in the demand for land which was the primary source of capital to produce agricultural products. Due to limited supply of land, the price of land or the rent increased. Therefore, majority of the income went to the owners of the land, while the working class had a smaller portion of income due to stagnant agricultural wages.

3.1.1 David Ricardo and Corn Law

A similar phenomenon was also observed in the United Kingdom in the 19th century. During the first industrial revolution, people in the United Kingdom started to relocate from rural areas where they resided in order to execute daily agricultural jobs to larger cities where workforce for the industry was required (Allen, 2004). That caused a workforce transition from agriculture to the more dynamic manufacturing industry. This transition brought a demand for land and capital requirements in urban areas. On the other hand, the rents and the prices of land increased due to “Corn law” (Ricardo, 1815). Corn Law was a trade restriction on imported grains that enforced by the United Kingdom in order to keep the price of grains high and protect domestic food producers against low price of the external market in 1815 (Williamson, 1990). The law increased the price of food and grains in the UK. It increased the rents on lands and profits of grain producers and landowners (Ricardo, 1815).

Ricardo (1817) explained this phenomenon as “law of rent”. In theory, when more land is cultivated, farmers will start to use less productive and free land. However, grains from both lands are sold for the

same price. Therefore, farmers would like to pay more for more productive land. As a result, income from cultivation is taken by the landowner as rent. As stated above, this increase was reflected as an increase in the price of food and grains. Along with the food price, the living costs also increased during this time due to increasing rent for the house and another type of land (Allen, 2004). As a result, workers demanded higher wages. Higher wage expectations and relatively low consumption of manufacturing goods such as clothes and shoes decreased the profitability of manufacturing sector which was more dynamic regarding technological development (Berg, 2004). The low profitability and slowdown in urbanisation, which stemmed from high rent in urban areas and increasing agricultural activity – dampened the industrial revolution (Williamson, 1990).

Ricardo (1817) suggested a tax on rent and free trade as a solution. The tax on the rent of capital should restore the rent of land to its normal price. It should then reduce the cost of living and increase real wages. That caused an increase in relative demand for manufacturing goods and helped enhance the manufacturing sector and the industrial revolution.

Nevertheless, an equal income distribution might not be the main purpose of Ricardo's proposition. However, he addressed a fundamental issue with income inequality. As it was seen in the UK in the 19th century, income inequality might result in low consumption of more dynamic products. This low consumption might discourage investors to invest in this new technology and impede the expansion of dynamic industry. Income inequality, therefore, can cause a stagnant growth for the economy.

3.1.2 Karl Marx and Capital accumulation

After fifty years from Ricardo's *Principles of Political Economy and Taxation* (Ricardo, 1817), Marx (1867) also centred his works on unequal income distribution in his famous book "Das Kapital." However, while Ricardo's work focused on the rent of land, Marx was mainly interested in the capital accumulation and labour conditions (Piketty, 2014).

Even though the structure of the economy started to change with the industrial revolution – a shift from agricultural economy to manufacturing economy – the essential problem of income distribution remained the same. Capital ownership shifted from the owner of the land to the owner of machinery and equipment. The landlords, who gained the majority of the income as rent, became capitalists who gained rents and profits from surplus value of labour (Marx, 1867).

Marx (1867) explained unequal income distribution by his surplus value theory and the capital accumulation. In this theory, capitalists hire workers in order to produce surplus value and make a profit which helps them to accumulate capital. To make a profit, capitalists should keep the working hours in certain length and hire workers at the lowest possible wage. This wage is not more than what it requires to keep workers alive, in other words, enough to feed them and clothe them (Marx, 1867). Indeed, the wage was low and stagnant until the end of the 19th century, while the profits of capitalists were increasing (Piketty, 2014).

3.1.3 Simon Kuznets and Kuznets Curve

Ricardo and Marx centred their thoughts on income distribution problem and the rent which is paid to the owner of the capital. Kuznets, on the other hand, focused on a different perspective on income inequality. Kuznets (1955) stated that the trend that income inequality is “widening in the early phases of economic growth when the transition from the pre-industrial to the industrial civilization was most rapid; becoming stabilised for a while; and then narrowing in the later phase”(p.18). This phenomenon would follow an inverted U-shape, which is called Kuznets curve, as inequality rises with the transition and falls again when income per capita increases after a threshold.

The idea behind of his theory is that in the early phase of industrialisation process, only a small minority was in a position to take advantage of this process. This minority, then, used their savings and capitals to yield a much larger share of income. Besides, the income per capita in urban areas is higher than income per capita in rural areas due to industrialisation. Therefore, these factors caused income inequality in the early phase of industrialisation. However, the trend of income distribution reversed later in an advanced phase of industrialisation.

This trend, indeed, was observed in the USA based on the data from US federal income tax returns and Kuznets’s calculations (Piketty, 2014). According to this data and Kuznets’s theory, US completed its industrial development at the end of 19th century. Besides, the distributional gap for income has started to narrow between 1913 and 1948.

3.1.4 The trend of Income Inequality in the US

As Kuznets (1955) suggested, income inequality started to decline in the first half of the 20th century, especially after the 1930s in the USA. In particular, as shown in figure 1 which is based on the data of World Inequality Database³, the income share of top 10% earners⁴ stabilised around 35% between 1950 and 1970. However, this trend started to reverse in favour of the top 10% earners since the 1980s. Income inequality in the USA started to increase and reached the level of the beginning of the 20th century (Piketty, 2014). The labour income share for the bottom 80% of the population has dropped from 60% to 50% in USA (Congressional Budget Office, 2011). In particular, it has worsened after Great Recession. The additional income which is created in 2010 was gained by top 1% of the population of the US (Stiglitz, 2012).

³ <http://wid.world/country/usa/>

⁴ People who earn 10% of total income.



Figure 3.1 Income Inequality in the USA between 1913-2014 World Inequality Database

Based on Kuznets's theory (1955), one can argue that income inequality would have reduced. But then how can the trend of income inequality over the last 30 years be explained?

Mainstream economists have argued several factors to explain this trend of income inequality in the USA. Atkinson (2015) listed some of these factors as follows:

- Globalization,
- Technological change,
- Financial service growth,
- Deunionization of labour unions,
- Changing pay norms (rising salaries of CEOs) (p.82)

The relationship between income inequality and technological change, for instance, is based on marginal productivity and skill-biased technological change (Card & Dinardo, 2002). According to this theory, workers get paid based on their marginal product. The marginal product of high-skilled workers has increased due to technological change because the technological change was skill-biased (Card & Dinardo, 2002). That caused an increase in the demand for high-skilled workers. Therefore, their wage also increased in parallel with this demand. The degree in which high-skilled workers' wages exceeded low-skilled workers' wages were called as "wage premium" (Antony B. Atkinson, 2015). In essence, the skill-biased technological change caused an increase in wage premiums which worsened income inequality in the USA.

The relationship between globalisation and income inequality, on the other hand, is based on the phenomenon of shifting manufacturing jobs where Unit Labour Cost (ULC) or wage is relatively low (D. Autor, Dorn, & Hanson, 2013a). The recent technological developments of communication and transportation technologies enabled the firms to outsource their production lines to countries where ULC is relatively low, more particularly in Asian countries (International Monetary Fund, 2007). As a result, job opportunities and wages for low-skilled workers decreased. That worsened income inequality in the USA

In addition to technological change and globalisation, impacts of other factors on income inequality have also been studied in depth (Podgursky, 1983; Juhn, Murphy, & Pierce, 1993; Card, Lemieux, & Riddell, 2004; Piketty & Saez, 2006; Autor & Dorn, 2009; Acemoglu, 2011; Autor et al., 2013a; Autor, Dorn, & Hanson, 2013b; Acemoglu, Gancia, & Zilibotti, 2015; Ahlquist, 2017; Autor, Dorn, Katz, Patterson, & Van Reenen, 2017). Indeed, these factors have influenced income inequality not only in the USA but also in other advanced economies. However, one might get an impression that income inequality has deepened due to factors which they do not have a direct influence. Indeed, these factors have been driven by actions of various stakeholders including the Federal Government in the USA, the Federal Reserve in the USA, labour Unions, firms and workers (Antony B. Atkinson, 2015). Actions of these actors, on the other hand, have been influenced by policy actions of government and external shocks such as war and economic crisis (Piketty, 2014). If the trend of income inequality in Figure 1 is analysed, two turning points – which are shown with blue dots in figure 1 – draw attention. These turning points address dramatic policy changes and economic crises due to war and shifts in politics.

3.2 Income Inequality, Fiscal and Monetary Policies

As mentioned in the previous section, the trend of income inequality in the USA has seen two turning points between 1913 and 2014. These turning points have several characteristics in common. They resulted from a dramatic change in the combination of fiscal and monetary policies. The first turning point, on one hand, was seen around the 1930s. During the Great Depression, while the nationalisation policies and World Wars were depressing the USA economy and capital accumulation (physical and human), the Federal Government in the USA increased its control on the economy and put a combination of new fiscal policies⁵ after the Second World War (Alvaredo et al., 2018). These factors led to the decline of income inequality in the USA.

The second turning point, on the other hand, was seen in the 1970s. Along with the inflationary shock, which included the commodity price increase and oil crisis, the shift in politics and economic policies with the election of Ronald Reagan led to deregulations and deunionization of labour unions in USA (Piketty, 2014). These factors, in parallel with the globalisation and skill-biased technological changes, caused the rise of income inequality in the USA.

Nevertheless, after a period of declining income inequality, which Alvaredo et al. (2018) called as “relatively egalitarian phase” (p.41), the trend of income inequality started to rise in the USA after the 1970s. To understand the driving forces behind the inflationary shock and shift in politics and economic policies were, it is imperative to analyse the dynamics of the US and World economy after the Second World War.

3.2.1 A Shift in Macroeconomic Policies: NAIRU

The prosperity of the post-war era did not last long. After reaching its historical peak in 1969, the federal minimum wage has become stagnant (Alvaredo et al., 2018). From this point on, the income gap between bottom 50 % and top 10% has started to increase again. There were several external and domestic factors that caused the stagnation of the federal minimum wage in the USA.

⁵ These Fiscal Policies include social security, education, labour policies and taxation.

One of the external factors was increasing the competitiveness of Germany, Japan and other European countries' manufacturing sector (Bureau of International Information Programs, 2012). After losing its capital and infrastructure, countries such as Japan and Germany started to accumulate capital and followed and export-led economic growth in the Post-war era thanks to international cooperation including Marshall Plan, IMF and World Bank (Baldwin, Baldwin, & Robert, 1984; Epstein & Schor, 1988; Glyn et al., 1988). As a consequence, the US manufacturing industry became less willing to agree on high minimum wage and social rights which could negatively impact their competitiveness in the market. (Bureau of International Information Programs, 2012). In addition, while the US share of world output decreased, the trade deficit of US increased in parallel with increasing competitiveness of Japan and German Output (Eichengreen, 2004). That increased the desirability of gold over US dollars, and the gold reserve of the Federal Reserve declined (Meltzer, 1991).

Inflation, on the other hand, was another major issue during this time. Along with the decline of US share of world output, external shocks such as Oil crisis in 1973 and 1979 caused a rise of the inflation rate from 2% in 1962 to 15% in 1979 in the USA (M. Bordo & Eichengreen, 2013). To control inflation and reduce the pressure on the federal reserve of the USA, President Nixon announced the end of convertibility of US Dollars to Gold, which was fixed 35\$ for an ounce, and a 90-day freeze on wages and prices (Meltzer, 1991). However, these attempts were insufficient to reduce the inflation (Meltzer, 2005).

Milestones of Economic Policy Events After the 1970s

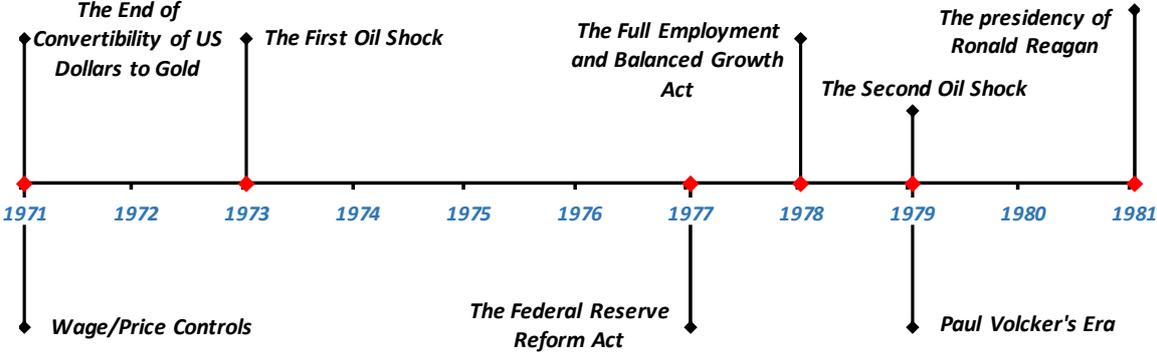


Figure 3.2 Milestones After the 1970s

By the end of the 1970s, the inflation led to a shift in not only in politics but also macroeconomic policy targets of the US Federal Government. The shift started with The Federal Reserve Reform Act in 1977, which set the price stability as primary national policy target and increased the transparency and the accountability of the Federal Reserve (Meltzer, 2009). It was followed by the Full Employment and Balanced Growth Act in 1978 which was the amendment to the Employment Act of 1946 by setting new policy objectives, including less than 3% unemployment and less than 3% inflation rate (Meltzer, 2009).

These acts, notably the Federal Reserve Reform Act, commissioned the Federal Reserve to follow the dual mandate which is to promote the maximum employment, price stabilisation and moderate interest rate (Steelman, 2011). However, there was a dilemma to achieve both objectives of the dual mandate. After nominated as the chairman of the Federal Reserve, Paul Volcker decided to put reining in inflation

as the top priority of the Federal Reserve and increased the interest rates (Meltzer, 2009). While these measures reduced the inflation rate from 13% in 1980 to 3% in 1983, the unemployment rate rose from 7% to 10% during this period (Steelman, 2011). This unfavourable environment for workers continued with the election of Ronald Reagan as the president of the USA in 1981 (Meltzer, 2009). As a supporter of the reduced role of the government, president Reagan reduced government spending, cut taxes, and increased deregulation (Meltzer, 1998).

Overall, increased competitiveness, the great inflation, increased unemployment and deregulations gave damage to workers and the bargaining power of labour unions. The membership of labour unions dropped from one-third of the workforce at the beginning of a post-war era to 20% in 1983 (Bureau of International Information Programs, 2012). As a result, income inequality has started to increase in parallel with a stagnant wage.

Labour unions and workers were blamed as a cause of inflation due to their bargaining power and targeted by both the Federal Reserve and administrations (Meltzer, 2005). Therefore, labour market deregulation was seen as a solution in the trade-off between inflation and unemployment. However, there are other parameters such as labour productivity and aggregate demand, which will increase labour productivity thanks to capital deepening that affects the natural rate of unemployment⁶ (Storm & Naastepad, 2012). The relationship between these factors and unemployment, and how these factors affected by fiscal and Monetary policies are analysed in next section.

3.2.2 Post-War Era: Towards to Egalitarian Income Distribution

The post-war era, which is also known as the Golden Age of Capitalism (Glyn et al., 1988), witnessed a tremendous economic growth with international cooperation. Although early wartime studies assumed that there would have been crucial macroeconomic issues regarding employment, distribution of income, and consumption (Hansen, 1943; Samuelson, 1943; Slichter, 1943), the US economy experienced rapid economic growth and prosperity thanks to several factors after the Second World War. These factors include pent-up consumer demand⁷ and international financing which was used to rebuild infrastructures and accumulate capitals in devastated European and Asian Countries, more particularly Germany and Japan (Gilchrist & Williams, 2004; Kochan, 2015). However, these factors could not be sufficient to secure a smooth transition from a wartime economy to a peacetime economy in the absence of a development plan under the guidance of the Federal Government in the USA with supportive fiscal policies regarding education and labour markets (Hansen, 1943; Kochan, 2015).

If figure 2 is projected on to figure 1, it can be seen that the first turning point and decline of income inequality have started with the Social Security Act and the Fair Labour Standards Act. While Social Security Act provided retirement and unemployment rights, the Fair Labour Standards Act aimed to regulate minimum wages and weekly working hours which can be seen as a part of the modern welfare state (Dadkhah, 2009; Kochan, 2015). These policies were followed by the G.I. Bill and the Employment Act. The Employment Act, for instance, focused on providing job opportunities for US citizens in the presence of increasing workforce with US soldiers who returned home (Bailey, 1950). Therefore, it can

⁶ The unemployment rate which do not cause a rise in the inflation rate

⁷ A demand boom for consumer goods after a period when consumers' demand was restricted due to War

be concluded that they took a vital role in the transition from the wartime economy to the peacetime economy and establishment of the welfare state (Dadkhah, 2009).

Milestones of Economic Policy Events of Post-War Era

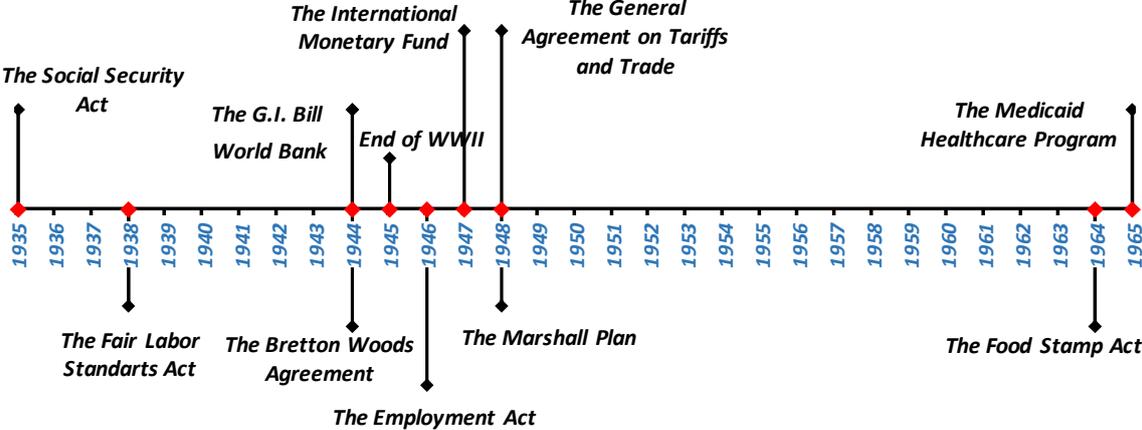


Figure 3.3 Milestones of Post-War Era

The Bretton Woods Conference, on the other hand, consolidated the impacts of fiscal policies by setting the ground for building international cooperation including the creation of a system of convertible currency, World Bank and International Money Fund (Dadkhah, 2009; Kochan, 2015; Meltzer, 1991).

Overall, the income distinction between the top 10% earners and the bottom 50% started to blur as a consequence of the minimum wage increase during this era (Alvaredo et al., 2018). However, this distinction started to become clearer again after the 1970s as a result of the shift in macroeconomic policies.

3.3 NAIRU: A Policy Tool of Multi-Actor Arena

The motive behind the Non-Accelerating Inflation Rate Of Unemployment (NAIRU) policies started with the great inflation and the shift in macroeconomic policies during the 1970s. The central point of the shift in macroeconomics was managing the aggregate demand by using fiscal and monetary policies in order to promote new macroeconomic policy targets such as maximum employment and price stabilization, which introduced by the Federal Reserve Reform Act and by the Full Employment and Balanced Growth Act (Glyn et al., 1988; Steelman, 2011). However, policymakers started to face the unavoidable truth about the relationship between the dual mandate. Maximising employment drove the interest rate higher while securing price stabilisation led to higher unemployment.

This trade-off between unemployment and inflation was observed by Philips (1958) and called as “the Phillips Curve”. Policymakers, especially the Federal Reserve, chased the Phillips Curve in order to forecast inflation and execute their dual mandate, however, Phelps (1967) stated that the Phillips Curve shifts upward gradually when participants of the production learn how to expect inflation. In other words, the inflation rate continues to rate due to high inflation expectation of labour and labour unions. Indeed, the future inflation expectation plays a key role in the determination of wage and price (Taylor, 1979; Storm & Naastepad, 2012).

Storm (Storm & Naastepad, 2012) explained the wage setting process of standard NAIRU model as follow:

$$\widehat{\mathcal{W}} - \widehat{p}^e = a_0 - a_1u + a_2\hat{\lambda} + a_3z, \quad a_0, a_1, a_3 > 0; 0 < a_2 < 1 \quad (3.1)$$

where $\widehat{\mathcal{W}}$ is wage growth, \widehat{p}^e is expected future inflation increase, u is the rate of unemployment, $\hat{\lambda}$ is labour productivity increase and z is a variable which comprises factors such as minimum wage and labour unions' bargaining power (p.4). If it is assumed that the real wage increase equals to productivity increase ($\widehat{w} = \hat{\lambda}$), and inflation expectation equals to actual inflation ($\widehat{p}^e = \hat{p}$), then Non-Accelerating Inflation Rate Of Unemployment can be written as follows:

$$u^* = \frac{a_0 - (1 - a_2)\hat{\lambda} + a_3z}{a_1} \quad (3.2)$$

where equilibrium rate of unemployment is used for as a discipline tool in order to stabilise price (Storm & Naastepad, 2012). As a consequence, claims for wage increase of workers decreased in parallel with the increase of unemployment rate. Their wage increase expectations even worsened with the election of Ronald Reagan who introduced deregulations and government spending cuts (Meltzer, 1998). While deregulations affected the z variable negatively, decreasing government spending would have an impact on the productivity variable.

In fact, there are several actors and institutions that play roles in the wage setting process. All these actors and institutions have diverse objectives, which sometimes contradict each other. Among them, the Federal Government, Federal Reserve (Central Bank), Labour Unions, Firms and Workers are the main actors in the wage setting arena (Iversen, 1998; Mishkin, 2000; Irmen & Wigger, 2002).

3.3.1 The Role of Federal Government

The Federal Government is one of the major actors in the wage setting process of NAIRU. As shown in table 1, The Federal Government has four main macroeconomic objectives, which order of importance may change based on several factors such as the ideology of governing political party and external shocks (Hibbs, 1977). To achieve these objectives, they use Fiscal Policies, Tax Policies, Trade Policies and Regulation of Financial Institutions.

The impact of these policy instruments, on the other hand, depends on the action of Federal Reserve. Even though a fiscal stimulus boosts the economy and decreases the actual unemployment rate, the Federal Reserve increases the interest rate ⁸as a Monetary Policy Rule (MPR) and crowds out the impact of this fiscal stimulus in the Standard NAIRU Model (Storm & Naastepad, 2012). In other words, the actual unemployment rate (u_a) will decrease, while the NAIRU unemployment rate (u_n) do not change. Therefore, fiscal policies are perceived to be ineffective to achieve the macroeconomic targets of the government. On the other hand, the Federal Government can deregulate Labour Market which promotes the deunionization of Labour Unions (Kochan, 2015). That will reduce the z variable and the equilibrium rate of unemployment in the equation 1.1.

⁸ It was assumed that Federal Reserve is independent from other government institutions for its decision.

Nevertheless, Servaas (2012) found that the standard NAIRU model does not capture the impact of productivity increase of the fiscal stimulus. Federal Government can promote productivity increase via capital deepening and innovation thanks to policy instruments such as fiscal and education policies. The productivity increase, then, reduces the equilibrium rate of unemployment. Any monetary policy which will dampen the impact of a fiscal stimulus will affect this cycle negatively. Therefore, Federal Government actions are limited by Federal Reserve.

Table II.1 Actor Scan of Federal Government

Actors	Interest	Objectives	Means
<i>Federal Government</i>	Economic Development	Full Employment	Fiscal Policies
	Technological Progress	Price Stabilization	Privatisation and Deregulation
	Job Creation	Production Growth	Tax Policies
	Infrastructure and Capital Development	The balance of Budget and Trade	Trade Policies
	Higher Education		Education Policies
			Regulation of Institutions

3.3.2 *The Role of Federal Reserve (Central Bank)*

The Federal Reserve Reform Act determined Federal Reserve's objectives in 1977 (Meltzer, 2009). These objectives are maximum employment, Price stabilisation and Moderate Interest Rate as shown in table 2. The first objectives are called the dual mandate of Federal Reserve (Steelman, 2011). To achieve these objectives, Federal Reserve uses Monetary Policies (interest rate change) and Money Supply.

Table II.2 Actor Scan of Federal Reserve

Actors	Interest	Objectives	Means
<i>Federal Reserve</i>	Economic Development	Maximum Employment	Monetary Policies
	Independence	Price Stabilization	Money Supply
	Credibility	Moderate Interest Rate	Lender of Last Resort
	Reputation		Managing Gold Reserve
			Managing Foreign Exchange
			Supervision and Regulation of Banks

These policy instruments of Federal Reserve actually do not have a direct impact on the variables of the equation 1.1. However, Federal Reserve can manipulate the unemployment rate by MPR to rein in inflation. While this diminishes the impact of the fiscal stimulus in the standard NAIRU model, it might even dampen future productivity growth due to decreasing capital deepening, investment and innovation (Storm & Naastepad, 2012).

3.3.3 The Role of Labour Unions

Labour Unions have a significant impact on the wage setting process of Standard NAIRU. As shown in table 3, they want to promote a more equitable distribution of income between wage and profits, fair employment opportunities and welfare of their members (Verma & Kochan, 2004). By lobbying and collective bargaining, they can influence the variable z in the equation 1.1. While an increase on z increases the equilibrium rate of unemployment in the standard NAIRU model, factors such as better working conditions, which are parameters to measure z , can promote higher labour productivity and reduce the equilibrium rate of unemployment (Storm & Naastepad, 2012).

Table II.3 Actor Scan of Labour Unions

Actors	Interest	Objectives	Means
<i>Labour Unions</i>	More Equitable Distribution of Income	Higher Minimum Wage	Lobbying
	Fair Employment Opportunities	Better Working Conditions	Bargaining Power
	Social Welfare of its members	Lower Working Hours	
	Community-wide interest (Woman rights)		

Even though they have a significant role in the wage setting process, their actions have been restricted since the 1970s. The higher unemployment rate, increasing competitiveness of the European countries and deregulations of President Reagan led to decrease of Union membership and deunionization (Verma & Kochan, 2004; Bureau of International Information Programs, 2012; Kochan, 2015). Therefore, Labour unions in the USA have lost their bargaining power.

3.3.4 The Role of Firms

In the pursuit of higher profits, firms use policy instruments such as investment, renting capital and labour and innovation to achieve the higher profit and higher market share. Therefore, an increase in z variable leads to a profit squeeze for companies, because they lose the higher profit share of income (Marglin & Bhaduri, 1988). On the other hand, a higher value of the z variable may push firms to innovate for labour-capital substitution, which increases the productivity.

Table II.4 Actor Scan of Firms

Actors	Interest	Objectives	Means
<i>Firms</i>	Higher Profit Share	Economic Profit	Investment
	Free Market Economy	Reduced Labour Cost	Renting Capital and Labour
	Competitiveness in International Market	Higher Market Share	Innovation
		Reduced Unit Cost	Lobbying

3.3.5 The Role of Workers

Workers' interest and objectives are in parallel with Labour unions (Verma & Kochan, 2004; Kochan, 2015). However, they have limited power without collective action.

Table II.5 Actor Scan of Workers

Actors	Interest	Objectives	Means
<i>Workers</i>	Higher Wealth	Higher Income	Voting
	Prosperity	Better Working Conditions	
	Welfare	Lower Working Hours	
	Community-wide interest (Woman rights)		

3.4 Summary: Income Inequality as Grand Challenge

The overall conclusion is that income inequality has been a challenge for centuries. Its impact on the society can be seen since the French Revolution. Even though recent literature suggest that there are several factors such as directed technological change and globalisation which has driven income inequality higher, it has been negatively influenced by policies and institutions since the Corn Law (Ricardo, 1815; Atkinson, 2015; Alvaredo et al., 2018). In the pursuit of achieving macroeconomic objectives, the Federal Government and The Federal Reserve of the USA caused a rise in income inequality in the USA. However, Income inequality might have a devastating impact on the US economy. These impacts include decreasing aggregate demand, a slowdown in technological progress and productivity (Williamson, 1990; Baily & Montalbano, 2016; Gordon, 2016). Moreover, based on research conducted by IMF, the inequality may affect economic growth drivers and dampen investments. It may cause financial instability, global imbalances, and the collapse of globalisation (Dabla-Norris et al., 2015). Therefore, it is required to analyse how income inequality will affect the future of the US economy.

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Automation and Artificial Intelligence

The trend of income inequality, which has worsened in the twenty-first century, faces a new challenge. Recent technological changes including developments in automation and artificial intelligence are expected to cause a major transformation not only in the US economy but also in the global economy. This chapter aims to identify this challenge and analyse its impact on production, aggregate demand, wages, and unemployment. Therefore, in section 3.1., automation and artificial intelligence will be compared with previous waves of technological progress. In section 3.2 a framework will be built based on similarities of technological progress and will be enriched through a literature review of automation and previous waves of technological progress. In section 3.3, the impact of automation and artificial intelligence will be analysed by addressing the elements of the framework. Section 3.4 will assess the existing economic models regarding automation and artificial intelligence by addressing the elements of the framework. The last section will summarise the chapter and emphasise the impacts of automation and digital disruption on macroeconomic trends.

4.1 A New Wave of Technological Progress

Self-driving cars, high-frequency trading algorithms which replace traders and brokers, online banking services with machine learning techniques are a few examples of how the world of work has been going under a rapid change for a decade. Automation – a term which will be used to define developments in the area of artificial intelligence, robotics, and other new technologies – is expected to disrupt the economy, established business practices, jobs, tasks, and required skills (Muro, Liu, Whiton, & Kulkarni, 2017). On the other hand, it is expected to increase productivity, product and service varieties, aggregate demand and economic growth (Bughin et al., 2017).

The debate for the disruptive impact of Automation and productivity gains dates back in 18th century when the first industrial revolution started. The first industrial revolution, which was pictured as increasing utilisation of steam engines in production rather than traditional methods such as manual labour force, was protested by textile workers in the 19th century (Manyika, Lund, et al., 2017). President John F. Kennedy was looking for solutions to maintain full-employment at the time of second industrial revolution which included the adoption of electricity in production to enable economies of scale (R. D. Atkinson, 2018; Bruckner, LaFleur, & Pitterle, 2017).

In fact, Automation, as the fourth wave of industrial revolution, has several characteristics in common with other waves of the industrial revolutions. Essentially, all these revolutions are part of technological progress⁹. Technological progress is one of the main drivers for the growth of productivity and total output, as a result it increases the income and consumption. (Bruckner et al., 2017). It is actually an incremental change in the inputs and techniques of production. However, there have been occasional dramatic changes in technology which led the major transformations in the economy, institutions and

⁹ It is also referred as Technological Change in literature

society (Freeman et al., 1988). When these transformations are analysed, in other words industrial revolutions, three elements of them stand out.

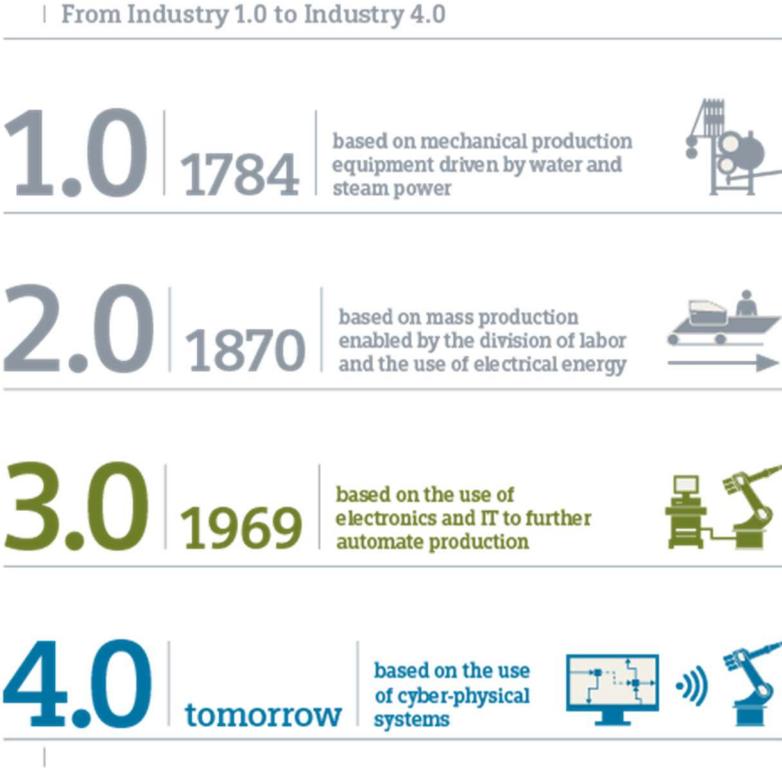


Figure 4.1 Industrial Revolutions Reprinted from Siemens Annual Report, 2013. Retrieved May 17, 2018, from <https://www.siemens.com/annual/13/en/company-report/report-industry-solutions/strategic-context/>

Growth of Productivity: The progress in production technology is one of the significant elements of the transformation, which is accompanied by all waves of technological progress. It involves not only a rise efficiency in the usage of the inputs in order to produce a product, but also in creating new jobs and tasks which help to increase total output by using same amount of input (Acemoglu, 2009). In return, it promotes economic growth, development and increase in consumption (Bruckner et al., 2017). As income and aggregate demand increase , more technological progress are stimulated (Manyika, Lund, et al., 2017). As shown in figure 3.2, the gross domestic product per capita increased in the previous wave of technological progress.

However, technological progress was disruptive for established businesses and jobs. The adoption of new technology led to wage polarization, displacement of labour and the sectoral shift (Manyika, Lund, et al., 2017).

Structural Transformation: The structural transformation of economy addresses the change in the employment share of three main sectors: agriculture, manufacturing, and service. During the first industrial revolution, the agricultural employment in the USA decreased from 70% at the end of 19th century to 5% in the 1970s (Bruckner et al., 2017; Manyika, Lund, et al., 2017). The third industrial revolution, on the other hand, accelerated the shift from manufacturing to service sector (Bruckner et al., 2017).

GDP per capita growth in the United Kingdom and the United States, PPP basis, annual average in each period 1701-2010

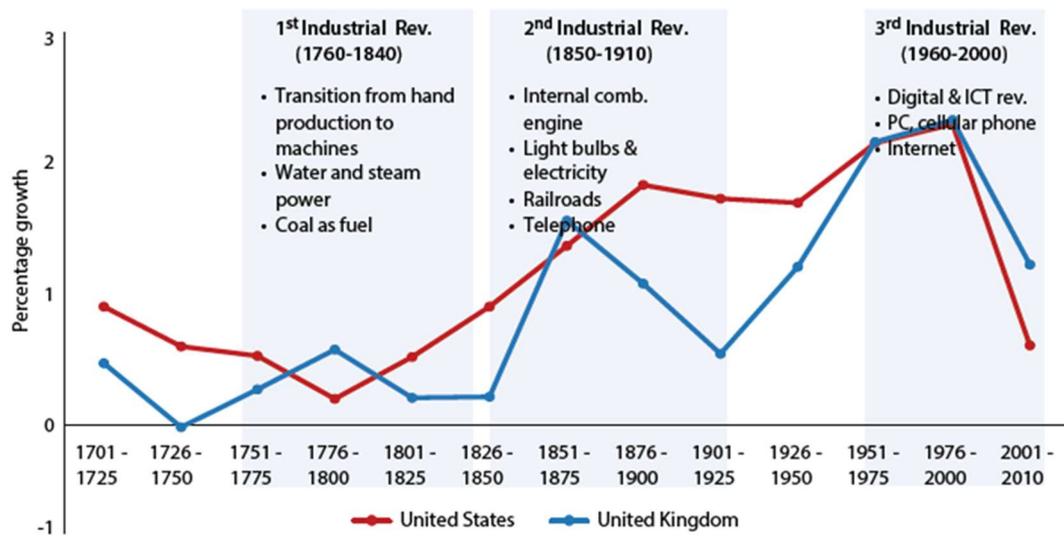


Figure 4.2 GDP Growth in USA and UK Reprinted from The impact of the technological revolution on labour markets and income distribution (p.9) by Bruckner et al., 2017, United Nations. Copyright 2017 by United Nations.

The structural transformation in the economy and employment, on the other hand, was a signal for disintegrating labour productivity and technological progress. The labour share in more productive sectors decreased. This decrease is followed by a decreasing labour productivity growth in US economy. As illustrated in figure 3.3, labour productivity has been decreasing since the second industrial revolution, even though there was a slight increase during the third industrial revolution.

Factor Bias: Factor bias is the last element of the transformation. It addresses the direction of technological change. Along with structural transformation, factor bias, especially the skill-biased technological change, was an essential factor for decreasing labour productivity. While skilled workers employed in highly productive and technological based industries, low- skilled labour had shifted to the less productive service industry (Bruckner et al., 2017; Manyika, Lund, et al., 2017).

In conclusion, Automation is not poles apart from the previous waves of technological progress. It is expected to share all three elements of technological progress (R. D. Atkinson, 2018; Bruckner et al., 2017; K. Harris et al., 2018; Manyika, Lund, et al., 2017). On the other hand, it might have a more disruptive impact on the economy, society and institutions due to its pace of adoption and transformation (K. Harris et al., 2018; Manyika, Lund, et al., 2017).

Labour productivity growth and output per hour worked, average annual growth during each period, 1821-2016

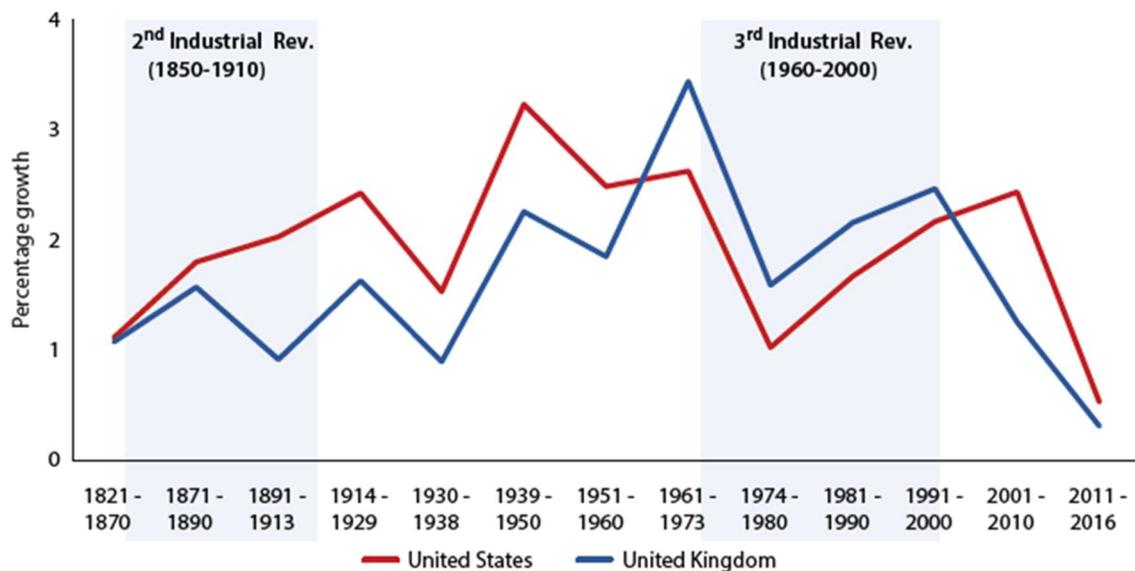


Figure 4.3 Labour Productivity Growth in the USA Reprinted from The impact of the technological revolution on labour markets and income distribution (p.9) by Bruckner et al., 2017, United Nations. Copyright 2017 by United Nations.

4.2 Dimensions of Technological Progress

As it was illustrated in section 4.1, technological progress has led to major transformation in economy and society. The transformation has been built on three elements which are technological progress, structural change and factor bias. In this section, a framework will be developed based on the analysis on section 4.1 in order to structure technological progress and model automation. Along with three elements, income inequality will be the fourth dimension of this framework. This framework begins with analysing previous economic models and frameworks regarding technological progress, structural change, economic growth, productivity growth and income inequality. Mainly, Romer (Romer, 1990), Aghion (1990), Jones and Vollrath (Jones, 2015; Jones & Vollrath, 2013), and Acemoglu and Restrepo (Acemoglu, 2002, 2009; Acemoglu & Restrepo, 2018a) The findings will be used to enrich the framework.

4.2.1 Growth of Productivity

Productivity growth encapsulates all the factors which enable to enhance productivity, maximise efficiency, and promote economic growth. These factors also referred as Total Factor Productivity or Multi-Factor Productivity in literature (Acemoglu, 2009; Jones & Vollrath, 2013). In fact, there are several types of the parameter to determine productivity growth including labour productivity and capital productivity (Acemoglu, 2009). In this section, primary types of production growth are listed as follows:

I. New Idea and Task Creation: Creation of new ideas and tasks enables efficient utilisation of resources including labour and capital. This idea was introduced by Schumpeter (1942) and referred to as “Creative Destruction”. In essence, creative destruction symbolises the replacement of old products,

methods, and techniques with more efficient and new ones (Aghion & Howitt, 1990). Romer (Romer, 1990), Jones and Volltrah (Jones, 2015; Jones & Vollrath, 2013), and Acemoglu and Restrepo (Acemoglu & Restrepo, 2018a) also showed its importance for productivity and economic growth.

II. Labour-Augmenting Technological Progress : In mainstream macroeconomics theory, output Y is defined as a function of capital K and labour L , put it differently $Y = F[K, AL]$ (Cobb & Douglas, 1928). Then an increase in technology or A will be labour-augmenting (Solow, 1967). In other words, it enables to increase the productivity of labour. Education, innovation and learning by doing could enhance the productivity of labour (Anthony B. Atkinson & Stiglitz, 1969; Jones & Vollrath, 2013). Recent studies (Acemoglu, 2000a; Jones, 2004; Kortum, 1997; Samuelson, 1965) suggested that technological progress is labour-augmented in the long term.

III. Capital-Augmenting Technological Progress: In comparison with labour-augmenting technological progress, capital-augmenting technological progress is represented as an increase of A technology if output Y is defined as a function of capital K and labour L or $Y = F[AK, L]$ (Acemoglu, 2009). It is also referred as “*Capital Deepening*” and comprises marginal productivity gains through R&D and learning by doing (Acemoglu, 2000a; Acemoglu & Guerrieri, 2006; Corrado, Hulten, & Sichel, 2006)

IV. Capital Accumulation : Capital accumulation is described as an increase in capital-output ratio or capital-labour ratio in economy (Kaldor, 1961). The productivity gain from capital accumulation depends on the elasticity of substitution between labour and capital and productivity advantage of capital over labour, which is related to capital-augmenting technological change (Acemoglu & Guerrieri, 2006). If elasticity of substitution between capital and labour is higher than unity, which means labour can be substituted by capital, labour will be displaced by more productive capital (Acemoglu & Restrepo, 2016).



Figure 4.4 Growth of Productivity Chart

4.2.2 Structural Transformation

Structural Transformation represents the shift in main activity in the economy. In the literature, there are two significant theories based on structural transformation. Kuznets (1966) suggested that technological progress leads to a shift in industrial structure by allocating resources where new products, processes, or methods to use raw materials are invented. This cycle enables to further growth in productivity. Technological progress has led to a major shift of labours and capital first from agriculture to manufacturing, then manufacturing to the service sector (Herrendorf, Rogerson, & Valentinyi, 2013). In literature, structural transformation is studied in two different perspective as follows:

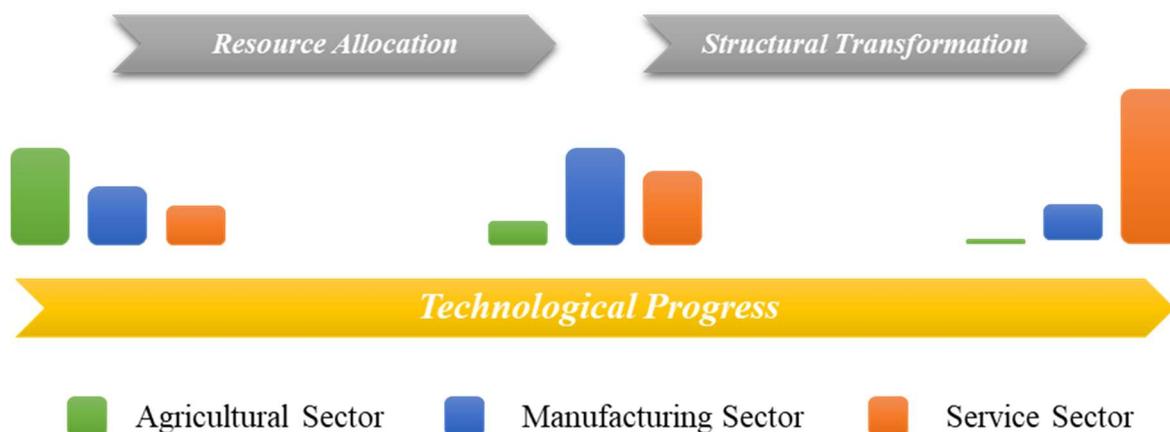


Figure 4.5 Kuznets Technological Progress and Structural Transformation

I. Unbalanced Growth Path : In unbalanced growth path, the supply side of the economy consists of dynamic sector, which productivity grows over time, and stagnant sector, which productivity growth is slow or stagnant. (Baumol, 1967). The divergence between productivity causes a change in factor prices and capital accumulation in the dynamic sector (Acemoglu & Guerrieri, 2006). That results in an excess of labour which is directed to stagnant sector. Such a rise in labour share in stagnant sector could lead slow-down for growth of productivity, aggregate demand and technological progress in the absence of the guidance of policies and institutions (McMillan & Rodrik, 2011). On the other hand, Kongsamut, Rebelo and Xie (2001) developed another argument from the demand side of the economy. Basically, Agricultural products have low income elasticity which means that when income of household increase, the fraction of spending on agricultural products declines (Kongsamut et al., 2001).

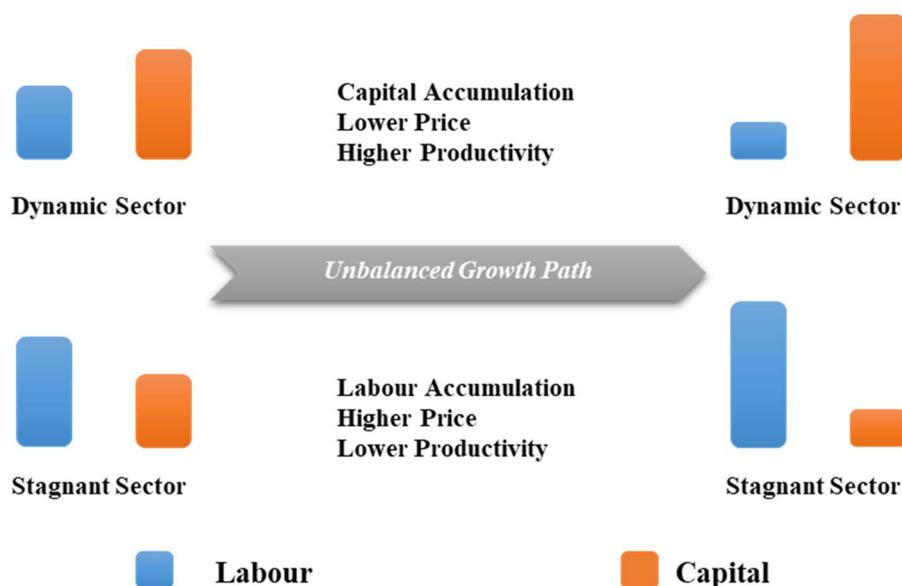


Figure 4.6 Unbalanced Growth Path

II. Balanced Growth Path : Acemoglu (2009) defined balanced growth as “a path where, while output per capita increases, the capital-output ratio, the interest rate, and the distribution of income between capital and labor remain roughly constant” (p.66). In other words, the growth path should be consistent with Kaldor’s Facts (Kaldor, 1961). One can argue that there is a clash between Kaldor’s facts

and Kuznets' technological progress theory. Indeed, if technological progress of two sectors are the same then a balanced growth of capital and labour will not be achieved (Acemoglu, 2009). However, Kongsamut, Rebelo and Xie (2001), Acemoglu (2009) and Jurgen (1999) suggested that although there is an unbalanced growth in sectoral level, in aggregate level capital-output ratio, capital-labour ratio and interest rates are constant, which they called Constant Growth Path (Acemoglu, 2009) or Generalized Balanced Growth Path (Jürgen, 1999; Kongsamut et al., 2001).

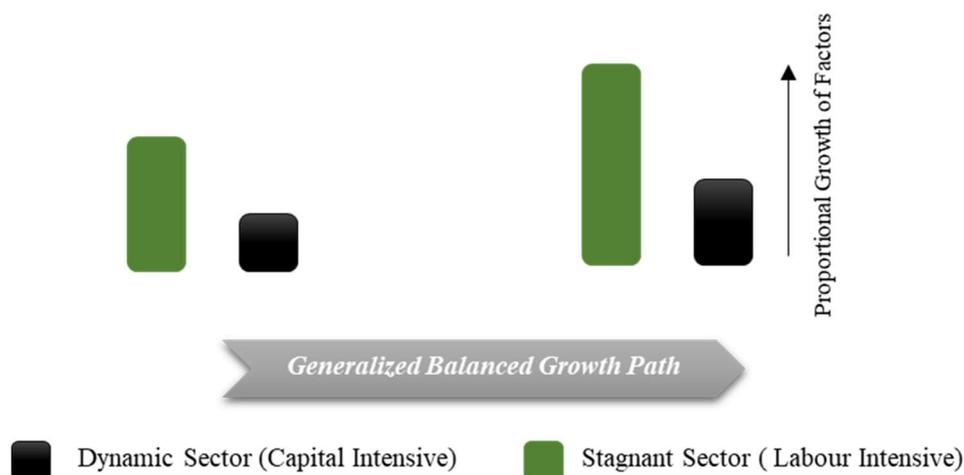


Figure 4.7 Balanced Growth Path

4.2.3 Factor Bias

Acemoglu (2005) stated that the impact of technological progress on the structure of wage and rent demonstrated that technological progress is not neutral. Factor Bias is a term which is used to describe the direction of technological progress. Hicks (1963) stated that a change in relative price of factors of production leads to innovation, which is biased to expensive factor in order to reduce its relative price. Therefore, an increase in relative price promotes not only technological progress, but also the direction of it. However, Acemoglu (2009) argued that the market size effect¹⁰ dominates the price effect. Nevertheless it can be assumed that there are two factors which are used in production in the macro level : Capital and Labour. On the other hand, Labour can be studied as Skill-Biased Technological Change and Unskill-Biased Technological Change as it is shown in figure 3.6.

¹⁰ Acemoglu (2005) developed a theorem which includes two different Bias : Weak Equilibrium Bias and Strong Equilibrium Bias. Weak equilibrium Bias is defined as an increase of relative supply of a factor cause technological progress in the direction of this factor. On the other hand, Strong Equilibrium occurs when elasticity of substitution between factors are large enough, an increase of relative supply of a factor induces technological development biased itself.



Figure 4.8 Factor Bias

I. Capital-Biased Technological Progress: Capital-Biased Technological Progress indicates a technological progress which enables an increase of productivity of capital over labour as it is discussed in the section 4.2.1. Studies (Acemoglu, 2000a, 2009; Jones & Vollrath, 2013) showed that if elasticity of the substitution is more than unity, economic growth and technological progress promote capital accumulation and capital-biased technological change.

II. Labour-Biased Technological Progress: Labour-Biased Technological Progress can be defined as technological progress which enables an increase in the productivity of labour over the capital as discussed in the section. Acemoglu (Acemoglu, 2002, 2005) claimed that technological progress had been labour augmenting. When the elasticity of substitution between labour and capital is less than unity, capital accumulation causes an increase in the price of labour and profit of labour-augmenting technology. Recent Studies (Krusell, Ohanian, Rios-Rull, & Violante, 2000; Nadiri, 1970; Nerlove, 1967) showed that the elasticity between labour and capital has been less than unity.

a. Unskilled-Biased Technological Progress: Unskilled-Biased Technological Progress promotes the demand for unskilled labour for production. Mokyr (1990) and Acemoglu (2009) stated that technological progress during the 19th century was biased towards unskilled workers. Acemoglu (2005, 2009) explained this bias with weak equilibrium bias theory. According to this theory, an increase in unskilled labour during first industrial revolution promoted technological progress biased towards unskilled labour (Acemoglu, 2005).

b. Skill-Biased Technological Progress: Skill-Biased technological Progress causes an increase in the demand for skilled labour. The technological progress in the second half of 20th century has been skill-biased (Acemoglu & Autor, 2010). Acemoglu (2005) argued that the relative increase of the supply of skilled workers after 1950 has led the direction of technological progress towards skilled workers.

4.2.4 Income Inequality

Income inequality has been a side effect of technological progress. In particular, Kuznets (1966) stated that in the absence of adequate institutions and policies, technological progress worsens income inequality. There are several channels in which technological progress affects income distribution negatively. These channels are as follows:

I. The Growth of Productivity: The growth of productivity enables an increase in total output, aggregate demand, and national income as mentioned in section 4.2.1. However, it can also create income inequality, especially in the adoption process (Bruckner et al., 2017). For instance, Kuznets (1966) suggested that new products and tasks required new skills and institutions. Therefore, established

business owners or labour, who have skills related to outdated technology or products, suffer due to the absence of required skills or resources to take advantage of new tasks and products. Moreover, technological progress might be capital-augmenting. In this case, capital accumulation leads displacement of labour with machines (Acemoglu, 2000a). Therefore, the share of capital income in the national income will increase as well (Piketty, 2014).

II. *Structural Transformation:* The impact of structural transformation on income inequality is closely related to factors of growth of productivity. People, who do not possess the required skills and resources accumulate in outdated or low productivity sectors (Baumol, 1967). Their share of the total national income decreases, while the share of people who possess adequate skills and resources increases.

III. *Factor Bias:* In fact, the term Factor Bias gives a hint that the direction of technological progress might be biased towards a specific factor or group. While capital-biased technological progress promotes a rise of the income share of capital owners, skill-biased technological progress causes an increase in the demand and income for high-skilled workers (Acemoglu, 2000b; Acemoglu & Autor, 2010). According to the World Inequality Report (Alvaredo et al., 2018), while income inequality was a side product of skill-biased technological change from the 1970s to 2000s, capital-biased technological change has been a more dominant factor on income inequality since the 2000s.

4.3 Automation and Dimensions of Technological Progress

This section aims to adopt the framework, which was developed in section 4.2, for automation and artificial intelligence. Put differently; this section will assess the coming wave of technological progress in term of elements of dimensions of technological progress. Therefore, a literature review will be executed in order to understand the similarities and differences between automation and previous wave of technological progress.

4.3.1 Growth of Productivity

There are several studies (Bughin et al., 2017; K. Harris et al., 2018; Manyika, Lund, et al., 2017) regarding how automation will enhance productivity, enable the creation of new jobs and products.

I. *New Idea and Task Creation:* Driverless cars, robots on automated assembly lines, and AI chatbot customer service agents are a few examples of products which artificial intelligence and automation have brought in its wake (Gillham et al., 2017; Purdy & Daugherty, 2016). In a report published by McKinsey (Manyika, Lund, et al., 2017), it was estimated that increasing income due to automation might enable 250 million jobs globally.

II. *Labour-Augmenting Technological Progress:* According to a report published by PWC (Gillham et al., 2017), labour productivity will increase more than 50% in the USA.

III. *Capital-Augmenting Technological Progress:* It is estimated that automation and artificial intelligence increase productivity of capital by around 16% (Purdy & Daugherty, 2016).

IV. Capital Accumulation: The productivity increase due to the replacement of old capital and labour are expected to be around 6% (Gillham et al., 2017).

4.3.2 Structural Transformation

Even though increasing income and demand will promote job creation, it is estimated that 166 million workers in the USA will have to find new jobs (Manyika, Lund, et al., 2017). According to a report published by McKinsey (Manyika, Lund, et al., 2017), while automation will reduce the share of labour in manufacturing, transportation, and accommodation sector, it will increase employment in construction and healthcare. These findings are in parallel with Baumol's (Baumol, 1967) unbalanced growth. The workforce of high productive sectors such as manufacturing will shift to low productive sectors such as construction and healthcare.

4.3.3 Factor Bias

Automation and Artificial Intelligence are expected to be towards high-skilled workers as it was the case for the previous wave of technological progress (Acemoglu, 2000b; Author, 2015). According to a report published by Bain (K. Harris et al., 2018), the benefits of automation and artificial intelligence will flow to high-skilled workers, while low-skilled workers will suffer from the decreasing demand for low-skilled workers. Besides, it was estimated that automation and artificial intelligence annually would displace 2.5 million workers, while it was around 1 million annually for a first and second wave of automation (K. Harris et al., 2018). On the other hand, Krugman (2012) claimed that robots and artificial intelligence would be capital biased. Therefore, the capital owners will take advantage of automation and the fourth wave of technological progress while the share of labour in total income decrease.

4.4 Assessing The Existing Economic Model Literature

This section will try to assess the economic models regarding automation and artificial intelligence. The topic of Automation and artificial intelligence has been at the forefront of research agenda of several economists and research institutes. Acemoglu and Restrepo (2016, 2017b, 2017a, 2018a, 2018b), Hémous and Olsen (2018), Author and Salamons (2018) Jones, Aghion and Jones (2017), and Klaus (2016) studied the impact of automation by developing a framework.

Acemoglu and Restrepo (2016), for instance, developed a task-based framework by combining Zeira (1998) model and Acemoglu's (2002) directed technological change to study the impact of automation on employment and wages. In their model, there are two different technological changes, which are automation of existing task and creation of new products and task (Acemoglu & Restrepo, 2016). Acemoglu and Restrepo (2018a) extended their studies by including the productivity gains through deepening of automation and capital accumulation and endogenise technological progress. In their model, the creation of new tasks stands as a countervailing effect against the capital accumulation and automation (2018a). Therefore, the economy can follow a balanced growth path.

Jones, Aghion and Jones (2017) developed a similar framework of Acemoglu and Restrepo (2016). However, their framework used Cobb-Douglass production function instead of Constant elasticity of substitution for intermediate goods while a final good used a constant elasticity of substitution function.

Jones, Aghion and Jones (2017) discussed that “Cost Disease” (Baumol, 1967) will constrain the growth of automation and artificial intelligence.

Hémous and Olsen (2018), on the other hand, used a framework similar to Jones, Aghion and Jones (2017). They developed a constant elasticity of substitution function with two sectors: automated and non-automated (Hémous & Olsen, 2018). Also, they introduced both low-skilled labour and high-skilled labour, and endogenise technological progress. However, their static model does not reflect the bias of technological change which causes an unbalanced growth (Hémous & Olsen, 2018).

4.5 Summary

Automation and Artificial Intelligence is leading a major transformation for workforce and economy. Even though it has several advantages like productivity gains and increasing income, it might worsen the income inequality. In this chapter, it is illustrated that automation and artificial intelligence is a part of technological progress which has continued over the course of many years. A framework is developed based on the common characteristics of the previous waves of technological progress. This framework has four characteristics which causes transformation of the economy. Then, the coming wave of technological progress assessed by this framework in order to understand which characteristics do automation and the previous waves of technological progress share. Finally, the recent studies, which focused on modelling of automation and artificial intelligence, were assessed by pointing on the element of the framework.

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III

Exploring the Future of Automation and Inequality in the USA

5

A Model Of Automation and Artificial Intelligence

Based on the findings in Chapter 3 and the framework in Chapter 4, this chapter builds a theoretical economic model. The framework of Hémous and Olsen (Hémous & Olsen, 2018) gives a basic understanding on the impact of automation on wage structure and the nature of structural transformation of the economy. Therefore, their model is used as a base model and extended in parallel with the framework which was developed in chapter 4. The rest of this chapter is as follow: section 5.1 introduces the basic environment, section 5.2 introduces the production side of the economy based on New Keynesian models. Section 5.3 focuses the demand side of the economy which is built on Neo-Kaleckian models. Finally, Section 5.4 summarize the findings.

5.1 Basic Environment

In the core of this research, it is aimed to study the driving force behind income inequality in USA, analyse the transformative impact of automation and artificial intelligence on the US economy, and investigate how effective are fiscal and monetary policies in order to minimize the negative impacts of automation and income inequality. In line with these objectives, the second chapter studies the role of fiscal and monetary policies, notably NAIRU, for rising income inequality in the USA. On the other hand, the chapter 3 analyses the impact of automation and artificial intelligence as a fourth wave of technological progress. This chapter conceptualizes a theoretical economic model by operationalizing the dimensions of technological progress framework and the findings regarding income inequality in chapter 2. This theoretical model enables this research to study the impact of automation on productivity, skill premium, and workforce transition, and the impact of income inequality on aggregate demand and future technological progress.

The framework of Hémous and Olsen (2018) is taken as a basis to build the theoretical model. In their model, Hémous and Olsen (2018) introduced two horizontal innovation and automation of existing task of low skill labour. This structure matched with three element of the framework which is developed in chapter 3. These elements are te creation of new task and idea, capital accumulation and capital augmenting technological progress. While horizontal innovation increases all wages, automation causes a constrain on low skill labour wage and demand for them. They divided production side of the economy as automated and non-automated (Hémous & Olsen, 2018). When the wage of low skill labour increases, the unit cost of non-automated sector increases. That provides incentives for firms to automate existing tasks and displace low skill labour with machines and robots. Even though there is horizontal innovation which increases the demand for both low skill and high skill workers, it does not prevent unbalanced growth (Hémous & Olsen, 2018)

Hémous and Olsen (2018) developed a rich economic model which comprised of factors such as skill-biased technological change and income distribution in the USA for last 50 years. They also addressed structural transformation superficially by splitting the economy into automated and non-automated

production. However, they assume that firms produce an identical product which use same available technology. In fact, it has been observed that the pace of technological diffusion between ICT and Service Sector was slow (Andrews, Criscuolo, & Gal, 2016; OECD, 2018). To put it differently, there are productivity differences between dynamic and stagnant sectors which were not included in the model of Hémous and Olsen. Besides, Hémous and Olsen (2018) emphasized the skill-biased technological change and the rising skill premium. However, it might not be adequate to address rising income inequality in the USA since 2000. The World Inequality report (Alvaredo et al., 2018) stated that income inequality has been driven by capital income since the 2000s. Within this context, robot and machine ownership has become one of the primary concerns of automation and artificial intelligence.

Therefore in this section, the model of Hémous and Olsen (2018) improved by modelling the supply and the demand side separately as shown in Figure 5.1 . The supply side of the economy is identical to new Keynesian models (Sims, 2016) with two different productive sectors. The new Keynesian models allow the study of business cycles and rigidities in the short term (Galí, 2015; Sims, 2016; Smets & Wouters, 2007) .On the other hand, the demand side of the economy is modelled based on the neo Kaleckian growth model (Dutt, Dutt, & Amitava, 1984; Marglin & Bhaduri, 1988; Storm & Naastepad, 2012; L. Taylor, 1983, 2004). Neo Kaleckian models, in particular, the model of Marglin and Bhaduri (1990), provides a rich understanding on income distribution and its impact on aggregate demand and productivity. Therefore, the neo Kaleckian model of the demand side enable to model not only skill-premium, but also robot and capital ownership

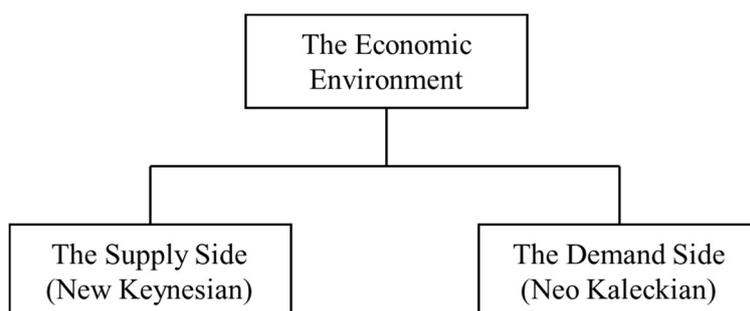


Figure 5.1 The Economic Environment

In contrast to the model of Hémous and Olsen (2018), this improvement will enable to track the impact of automation and increasing income inequality on aggregate demand. Conversely, it is also possible to track the impact of aggregate demand investment for technology and capital (automation) because this research identifies a different incentive mechanism for investment. In the model of Hémous and Olsen, investment for automation is driven by cost difference and market competition between automated and non-automated firms. On the other hand, this research introduces a mechanism which is a function of aggregate demand and profit share of firms. The price and wage mechanism will be similar to the model of Hémous and Olsen (2018). However, every sector will have its own price. A relative decrease on the price of the dynamic sector due to capital accumulation will be reflected as an increase in demand for this sectors' goods. Technological progress will be exogenous for the basic model, but it is endogenized in the chapter 7. Table III.1 shows a comparison of factors with the model of Hémous and Olsen and the model which is built in this chapter.

Table III.1 Factors Comparison of Theoretical Economic Models

Factors	Hémous and Olsen	This Research
Supply Side		
Growth of Productivity		
New Idea and Task Creation	N	N_S and N_D
Labour Augmenting Tech. Prog.	-	$\gamma_{z,l}$ and $\gamma_{z,h}$
Capital Augmenting Tech. Prog.	Φ	γ_a
Capital Accumulation	X	K_S, K_D and A
Structural Transformation		
Unbalanced Growth Path	<i>Automated, Non Automated</i>	<i>Dynamic , Stagnant</i>
Factor Bias		
	<i>Skill-Biased and Capital Biased</i>	<i>Skill-Biased and Capital Biased</i>
Price		
	P, W_L and W_H	P_S, P_D, W_L and W_H
Demand Side		
Income		
	<i>Low Skill , High Skill Income and Profit</i>	<i>Low Skill, High Skill and Capital Income, and Profit</i>
Savings		
	-	S_H, S_{CO}
Consumptions		
	C	C_S and C_D
Investment		
Unbalanced Growth Path	X	K_S, K_D and A

5.2 The Supply Side of the Economy

In this section, the supply side of the economy is elaborated by extending the model of Hémous and Olsen (2018), as mentioned in section 5.1. One of the main arguments regarding automation is its impact in short term. However, the model of Hémous and Olsen (2018) was built on Neoclassical economic foundations, which ignores rigidities on price, fluctuations on productivity and focus on resource allocation in the long run (Galí, 2015; Garín, Lester, & Sims, 2018). Hence, the model of Hémous and Olsen (2018) is improved by following the new Keynesian models.

The supply side of the economy is divided into four sub-sections. These sub sections are production, which introduces the production functions and factors, price and wage setting process, which describes price setting process based on the factor prices and profit, and technology, which specifies technological progress function.

5.2.1 Production

The economy consists of dynamic and stagnant sectors which produce two unique final goods D and S , respectively. This structure of the economy is in parallel with unbalanced growth study of Baumol (1967). All tasks and the final goods are produced by using four production factors: high skill workers denoted by H , low skill workers denoted by L , capitals, which include vintage machines, assembly lines and other forms of capital, denoted by K and automation machine in the form of artificial intelligence, machine learning and robots denoted by A , as it is shown in Figure 5.2.

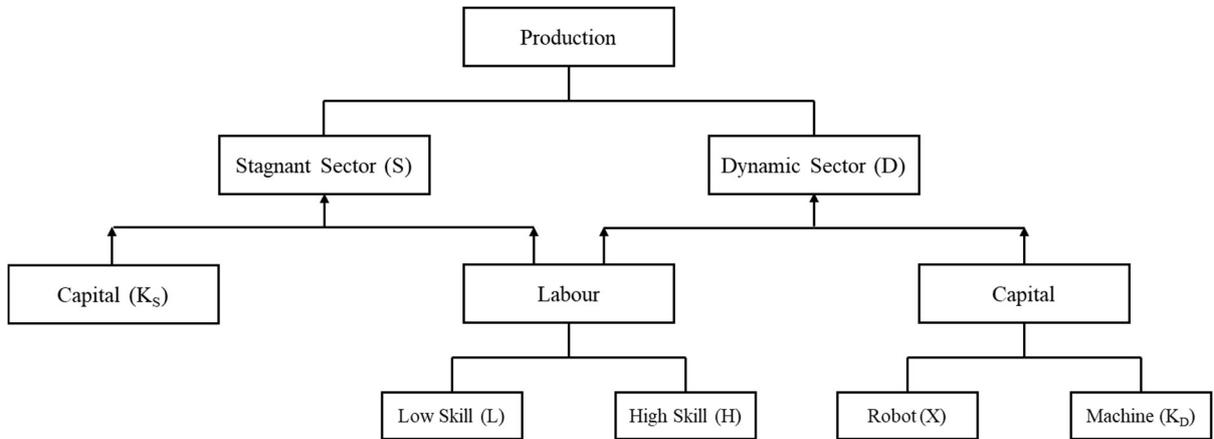


Figure 5.2 Production Tree

The final goods of both the dynamic and stagnant sectors are produced competitively by combining a set of respective intermediate goods $j \in [0, N_{u,t}]$ and $u, Y \in \{S, D\}$, where the subscript u denotes the respective sectors (stagnant and dynamic), according to the following Constant Elasticity of Substitutions (CES) aggregator:

$$Y_t = \left(\int_0^{N_{u,t}} y_t(j)^{\frac{\sigma_u - 1}{\sigma_u}} dj \right)^{\frac{\sigma_u}{\sigma_u - 1}} \quad (5.1)$$

where Y_t ¹¹ denotes the aggregate output at time t , y_t ¹² is the intermediate good j at time t , and $N_{u,t}$ symbolizes technological progress. σ_u , on the other hand, is the elasticity of substitution among these intermediate goods and, is assumed to be more than unity ($\sigma_u > 1$). The intermediate goods are imperfect substitutes in the production of the final goods if the elasticity of the substitution among intermediate

¹¹ To eliminate redundancy Y_t is used to address the final goods of the dynamic sector D_t and the final good of the stagnant sector S_t at time t .

¹² $y_t(j)$ represents the intermediate goods of the dynamic sector $d_t(j)$ and the intermediate goods of the stagnant sector $s_t(j)$.

goods are less than infinity ($\sigma_u < \infty$). As long as $\sigma_u < \infty$, the intermediate good firms will have market power.

Each intermediate good $y_t(j)$ is produced by monopoly firms using the Cobb-Douglas production function (Cobb & Douglas, 1928) :

$$y_t(j) = (m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u})^{\Upsilon_u} \quad (5.2)$$

where $m_{u,t}(j)$ denotes the composite workforce and $k_{u,t}(j)$ is traditional capital such as assembly line or vintage machine as it is mentioned above. The parameter β_u determines the share of workforce in the production function in each respective sector. It is assumed that the workforce share of the dynamic sector (β_d) is less than the workforce share of the stagnant sector (β_s) as in Baumol (1967), Acemoglu and Guerrieri (2006) and Jochen (2013).

$$\beta_s > \beta_d \quad (5.3)$$

Following Hornstein (1993), Devereux, Head and Laphan (1996) and Kim (1997), the parameter Υ_u (upsilon) determines the degree of returns to scale. There are three different states for the degree of returns to scale. If Υ_u is greater than unity ($\Upsilon_u > 1$), the production function of the firm has an increasing returns to scale. In other words, the production technology of the firm features additional output. In contrast, the production function features diminishing returns to scale if Υ_u is less than unity ($\Upsilon_u < 1$). The final state, on the other hand, is called constant returns the scale which Υ_u equals to unity ($\Upsilon_u = 1$).

In the rest of the research, it is assumed that the dynamic sectors have increasing returns to scale, while the stagnant sectors demonstrate diminishing returns to scale¹³. This assumption is in parallel with Canning (1988) and Hornstein (1993).

Nevertheless, the composite workforce is written as an aggregated product of low skill labour $l_{u,t}(j)$, high skill labour $h_{u,t}(j)$ and automation machine¹⁴ $a_t(j)$ with the elasticity of substitution between low-skill (automation machine) and high-skill labour (ϵ_u), using the CES function:

$$m_{u,t}(j) = \left[\Phi_u^{\frac{1}{\epsilon_u}} (\gamma_{u,h}(j) h_{u,t}(j))^{\frac{\epsilon_u-1}{\epsilon_u}} + (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a(j) \alpha(j) a_t(j) + \gamma_{u,l}(j) l_{u,t}(j))^{\frac{\epsilon_u-1}{\epsilon_u}} \right]^{\frac{\epsilon_u}{\epsilon_u-1}} \quad (5.4)$$

where $\gamma_{u,h}(j)$, $\gamma_{u,l}(j)$ and $\gamma_a(j)$ (gamma) denotes the productivity of low skill labour, high skill labour and automation machine in intermediate good j , respectively¹⁵. It is assumed that the productivity of low skill labour, high skill labour and automation machine are identical across producers of intermediate

¹³ The reason behind this assumption is that the modern dynamic sectors are knowledge based capital intensive industries which enable mass production. As a result, the outputs of the dynamic industries will increase. On the other hand, the stagnant sectors are mostly regional based and workforce intensive industries such as service and retail. Therefore their outputs diminish due to regional limitations and demand constraint.

¹⁴ This term refers to automation, artificial intelligence, robots and machine learning techniques.

¹⁵ Acemoglu and Restrepo (2016, 2017, 2018) used productivity advantage to model productivity advantage of labour in tasks which have high indices. In their task-based framework, new tasks were introduced with high index values. Therefore, while robots and machines have productivity advantage for old tasks which have low index or routine, labour has productivity advantage for new tasks. As a result, robots and machines replace labour for tasks which have low index values. In addition, Harada (2018) developed a model which has both an exogenous TFP parameter and an endogenous labour productivity parameter. This labour productivity parameter increases as a function of R&D spending.

goods. The parameter Φ_u represents high skill labour share in the composite workforce. The parameter $\alpha(j) \in \{0, 1\}$ (alpha), on the other hand, is a multiplier for the intermediate goods firms. The multiplier $\alpha(j)$ equals to unity ($\alpha = 1$) for the intermediate goods firms in the dynamic sector, zero ($\alpha = 0$) otherwise. Because, only the intermediate goods firms in the dynamic sector have access to automation machine technology as it is shown in the Figure 5.2. It is assumed that automation machine is a perfect substitute of low skill labour¹⁶. Thus, the intermediate good firms of the dynamic sector can employ low skill labour $l_t(j)$ or automation machine $a_t(j)$ for production in contrast with the stagnant sector. Lankisch, Prettnner, & Prskawetz (2017) also developed a similar production function in their framework which study the impact of automation on skill premium. In their framework, Lankisch, Prettnner, & Prskawetz (2017) assumed that automation technology is perfect substitute for low skill workers while imperfect substitute for high skill workers.

Using Equations 5.2 and Equation 5.4, the intermediate good production function can be written as follows:

$$y_t(j) = \left(\left[\Phi_u^{\frac{1}{\epsilon_u}} (\gamma_{u,h}(j) h_{u,t}(j))^{\frac{\epsilon_u-1}{\epsilon_u}} + (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_\alpha(j) \alpha(j) a_t(j) + \gamma_{u,l}(j) l_{u,t}(j))^{\frac{\epsilon_u-1}{\epsilon_u}} \right]^{\frac{\beta_u \epsilon_u}{\epsilon_u-1}} k_{u,t}(j)^{1-\beta_u} \right)^{\gamma_u} \quad (5.5)$$

Nonetheless, it is assumed that all final good firms in the dynamic sector are symmetric and, behave identically. To put it in another way, since the final good firms are produced in a perfectly competitive market, all firms face the same marginal cost and the same demand. Therefore, they will determine same price for their final products. In turn, they will hire the same number of workers and produce the same amount of output. Consequently, taking technological progress¹⁷ as given, the aggregate output can be rewritten as follows:

$$Y_t = N_{u,t}^{\frac{\sigma_u}{\sigma_u-1} \gamma_u} \times \left(\left[(\Phi_u)^{\frac{1}{\epsilon_u}} (\Gamma_{u,h} H_{u,t})^{\frac{\epsilon_u-1}{\epsilon_u}} + (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\Gamma_{u,l} L_{u,t} + \Gamma_\alpha A_t)^{\frac{\epsilon_u-1}{\epsilon_u}} \right]^{\frac{\epsilon_u \beta_u}{\epsilon_u-1}} K_{u,t}^{1-\beta_u} \right)^{\gamma_u} \quad (5.6)$$

while

$$H_u = \int_0^{N_u} h_u(j) dj, \quad L_u = \int_0^{N_u} l_u(j) dj, \quad A = \int_0^{N_u} a(j) dj, \quad K_u = \int_0^{N_u} k_u(j) dj \quad (5.7)$$

¹⁶ This assumption enables this research to explore the employment dynamic which was one of the main concerns regarding automation. Another approach can be a CES production function which allows various degrees of elasticity of substitution between low-skill labour and automation machine. Hémous and Olsen (2018) and Lin & Weise (2017), for instance, explored several types of elasticity of substitution between low skill labour and automation machine in their studies.

¹⁷ Here it can be assumed that technological progress is the available number of intermediate goods.

and

$$\begin{aligned}
 H &= \int_0^{N_d} h_d(j) dj + \int_0^{N_s} h_s(j) dj, & L &= \int_0^{N_d} l_d(j) dj + \int_0^{N_s} l_s(j) dj, \\
 K &= \int_0^{N_d} k_d(j) dj + \int_0^{N_s} k_s(j) dj,
 \end{aligned} \tag{5.8}$$

where $L_{u,t}$ and $H_{u,t}$ are the total mass of low skill and high skill labour while $K_{u,t}$ and A_t represents the total mass of traditional capital and automation machine which are rented to produce the final goods. $\Gamma_{u,h}$, $\Gamma_{u,l}$ and Γ_a represents the aggregate productivity of high skill labour, low skill labour, and automation machine, respectively. $N_{u,t}^{\frac{\sigma_u}{\sigma_u-1}} \Upsilon_u$, on the other hand, is the total factor productivity (TFP) parameter and an indicator for technological progress. These parameters are elaborated in Section 5.2.2

5.2.2 Technological Progress

As mentioned in chapter 4, Technological progress has a key role in terms of economic development and growth. In this section, the framework, which is developed in chapter 4, is operationalized in terms of the supply side of the economy and production function. Even though all elements of the framework are addressed and discussed, they are not included in the model and simulation due to the complexity of the model and their limited contribution to the analysis.

In section 5.2.2.1, technological change and several elements of the framework such as new idea and task creation and structural change are introduced. In section **Error! Reference source not found.**, topics such as factor bias and productivity advantage of the production factors are discussed. While technological progress is modelled as an exogenous variable in this section, the model is extended by endogenizing technological progress in chapter 7.

5.2.2.1 Technological Change

Following Romer (1990), Technological change takes the form of an expansion of a variety of intermediate goods j , which are available at time t . It is represented by parameter $N_{u,t}$ in Equation 3.2. Therefore, an increase in $N_{u,t}$ can be seen as a source of technological progress. This approach of modelling technological progress is named as “*horizontal innovation*” (Gancia & Zilibotti, 2005; Hémous & Olsen, 2018) because a new task and idea do not replace the existing technological knowledge.¹⁸

In this research, technological change causes unbalanced growth and diversification between the stagnant and dynamic sectors. Due to slowdown of technological change in the stagnant sectors such as business service, education, and healthcare, product varieties in stagnant sectors remained at 1980s

¹⁸ The alternative way to model technological progress is quality increases in the production methods and techniques which can be called as “*vertical innovation*”. This type of technological progress is named as “*Creative Destruction*” by Schumpeter (1942). Grossman and Helpman (1991) and Aghion and Howitt (1992) also studied vertical innovation.

levels (Manyika, Remes, Mischke, & Krishnan, 2017). Therefore, the growth of product variety in stagnant sector \hat{N}_s is written as follows¹⁹:

$$\hat{N}_s \cong 0 \quad (5.9)$$

On the other hand, technological change in the dynamic sectors increases over time due to knowledge accumulation and innovation. In the short term, it is assumed that the product variety in the dynamic sectors $N_{d,t}$ follows the stochastic process²⁰:

$$\log N_{d,t} = (1 - \omega_d) \log \tilde{N}_{d,t} + \omega_d \log N_{d,t-1} + \sigma_d \varepsilon_{d,t} \quad (5.10)$$

where $\omega_d \in (-1, 1)$ measures the persistence, σ_d denotes the standard deviation and $\varepsilon_{d,t}$ is an n IID standard normal process. \tilde{N}_d , on the other hand, represents the steady state value of the product variety in the dynamic sectors and grows at a rate that depends on the exogenous variable g_{N_d} for some $g_{N_d} > 0$:

$$\tilde{N}_{d,t} = g_{N_d} \tilde{N}_{d,t-1} \quad (5.11)$$

5.2.2.2 Productivity

The notion of productivity is used to describe productivity of the production factors in the production function and denoted by parameters $\gamma_{u,h}$, $\gamma_{u,l}$ and γ_x in equation 5.4. Following Storm & Naastepad (2012), the growth processes of these efficiencies are written as follows:

$$\hat{\gamma}_{u,l}(j) = \hat{\gamma}_{u,l} \equiv b_{0,l} + b_{1,l}\hat{\gamma}_u + b_{2,l}\hat{w}_t + b_{3,l}z_{u,l} \quad (5.12)$$

$$\hat{\gamma}_{u,h}(j) = \hat{\gamma}_{u,h} \equiv b_{0,h} + b_{1,h}\hat{\gamma}_u + b_{2,h}\hat{v}_t + b_{3,h}z_{u,h} \quad (5.13)$$

$$\hat{\gamma}_a(j) = \hat{\gamma}_r \equiv b_{0,a} + b_{1,a}\hat{\gamma}_u \quad (5.14)$$

where $\hat{\gamma}_u$ denotes the increase in the product of intermediate products. Coefficients $z_{u,l}$ and $z_{u,h}$ reflect the low-skill and high skill labour's bargaining power of labour unions in respective sectors, which increases productivity of workers because $b_{3,l}, b_{3,h} > 0$. $b_{0,l}$ and $b_{0,h}$, on the other hand, are exogenous parameters and are comprised of other factors which affect productivity of production factors²¹. Finally,

¹⁹ In fact, there are technology diffusion across sectors. However, several factors such as market structure, knowledge barriers and institutions minimise the impact of technology diffusion. As a result, technological change in stagnant sectors has remained at 1980s levels (Manyika, Remes, et al., 2017).

²⁰ Following Romer (1990) and Hémous and Olsen (2018), technological change in dynamic sectors has a simple dynamic growth. Therefore, the increase on a variety of intermediate products $N_{d,t}$ do not give any information regarding the nature of the new product. In other words, new product is born with similar manufacturability with automation machine and labour. On the other hand, Acemoglu & Restrepo (2017b, 2018a) built task based innovation which enables to model manufacturability of the new task by different a production factor based on their price and productivity advantage.

²¹ In fact, modelling the individual production advantage based on industry enables this research to describe phenomenon like labour augmenting technical change or directed technical change, which increases by increasing product variety. The exogenous variables $b_{0,l}$ and $b_{0,h}$, on the other hand, enable to analyse them in the basic level.

\hat{w}_t and \hat{v}_t represent the growth of wages of low skill and high skill labour, which are described in sections 5.2.3 and 5.2.4. The index (j) of high skill labour productivity $\hat{\gamma}_{u,h}(j)$, the low skill labour productivity $\hat{\gamma}_{u,l}(j)$ and the automation machine productivity $\hat{\gamma}_a(j)$ are dropped because they are identical across sectors.

By using equation 5.12, the aggregated sum of productivity of production factors are written as follows:

$$\Gamma_{u,l} = \int_0^{N_u} \gamma_{u,l}(j) dj \equiv N_u(b_{0,l} + b_{1,l}\hat{y}_u + b_{2,l}\hat{w}_t + b_{3,l}z_{u,l}) \quad (5.15)$$

$$\Gamma_{u,h} = \int_0^{N_u} \gamma_{u,h}(j) dj \equiv N_u(b_{0,h} + b_{1,h}\hat{y}_u + b_{2,h}\hat{v}_t + b_{3,h}z_{u,h}) \quad (5.16)$$

and

$$\Gamma_a = \int_0^{N_u} \gamma_u(j) dj \equiv N_u(b_{0,a} + b_{1,a}\hat{y}_u) \quad (5.17)$$

5.2.3 Price Setting Process

In this section, the price setting process of the stagnant and the dynamic sector is introduced. It is assumed that prices are sticky. Essentially, sticky prices are used to address the nominal rigidity of the prices. To model price-stickiness, it is required to assume that firms are price-setters. In fact, the intermediate firms were introduced as monopolists who can set their own price in section 5.2.3.2 while the final good firms operate in perfectly competitive markets²². As a result, the profit maximization process of the final good firms causes a downward sloping demand curve for intermediate goods.

The staggered price setting model of Calvo (1983) is used as a base to model price-stickiness. Calvo (1983) assumed that there is a fixed probability that a firm can change its price each period. The price setting process is elaborated in the level of final good firms and in the level of intermediate good firms. To eliminate redundancy, a generalized price setting and wage setting mechanism are introduced rather than introducing them separately for each sector.

5.2.3.1 Final Good Firms

The final good firms want to maximize their profit. They buy the intermediate goods to produce the final goods. Therefore the objective function can be written in nominal terms as:

$$\max_{y_t(j)} P_{u,t} Y_t - \int_0^{N_{u,t}} p_{u,t}(j) y_t(j) dj \quad (5.18)$$

²² In perfectly competitive market, firms sell differentiated products and have some pricing power. However, they cannot earn any economic profit in the long run due to entry and exit. Economic profit considers the total profit which include opportunity cost of the investment. In monopolistic market, firms have market power to set their own price.

Profit equals to the difference between total revenue and total cost. The total revenue of the final good firms is the price of the final goods $P_{u,t}$ times the amount of the final goods Y_t . The total cost, on the other hand, is the sum of all the intermediate goods of respective sector $y_t(j)$, which are used in the production, times their respective price $p_{u,t}(j)$.²³ If the production function of the final good is plugged in, the objective function of the price maximization of the final good producers can be rewritten as follows:

$$\max_{y_t(j)} P_{u,t} \left(\int_0^{N_{u,t}} y_t(j)^{\frac{\sigma_u-1}{\sigma_u}} dj \right)^{\frac{\sigma_u}{\sigma_u-1}} - \int_0^{N_{u,t}} p_{u,t}(j) y_t(j) dj \quad (5.19)$$

Then the demand for each intermediate goods:

$$y_t(j) = \left(\frac{p_{u,t}(j)}{P_{u,t}} \right)^{-\sigma_u} Y_t \quad (5.20)$$

The final good firms operate in perfectly competitive market. Therefore their profit will be zero, which implies that:

$$P_{u,t} Y_t = \int_0^{N_{u,t}} p_{u,t}(j) y_t(j) dj \quad (5.21)$$

If the demand function for intermediate goods is plugged in, the price for the final good can be solved as follows:

$$P_{u,t} Y_t = \int_0^{N_{u,t}} p_{u,t}(j) \left(\frac{p_{u,t}(j)}{P_{u,t}} \right)^{-\sigma_u} Y_t dj \quad (5.22)$$

and

$$P_{u,t} = \left(\int_0^{N_{u,t}} p_{u,t}(j)^{1-\sigma_u} dj \right)^{\frac{1}{1-\sigma_u}} \quad (5.23)$$

Then, the aggregate price index is:

$$P_t = \frac{P_{s,t} S_t + P_{d,t} D_t}{S_t + D_t} \quad (5.24)$$

Given the aggregate price index, the aggregate inflation index can be written as follow:

$$1 + \tau_{t+1} = \frac{P_{t+1}}{P_t} \quad (5.25)$$

²³ $y_t(j)$ represents the intermediate goods of the dynamic sector $d_t(j)$ and the intermediate goods of the stagnant sector $s_t(j)$. $p_{u,t}(j)$, on the other hand, denotes the price of the intermediate goods of respective sectors. In other words, it can be thought as $p_{d,t}(j)$ for the dynamic sector and $p_{s,t}(j)$ for the stagnant sector.

5.2.3.2 Intermediate Good Firms

The problem of profit maximization of intermediate good firms have two dimensions. They have to optimize not only their price but also their cost. As a price taker in factor market²⁴, the intermediate good firms take the wage as given. Since they can set the price due to their monopolistic power, they produce as much output as demanded at a given price. However, they may not be able to adjust their price in order to maximize their profit as Calvo (1983) assumed in his staggered price setting model. On the other hand, they can minimize their costs in each period which is in turn equivalent to maximizing profits. Following Sims (2016), the cost minimization problem of the intermediate good firms is:

$$\min_{l_{u,t}(j), h_{u,t}(j), k_{u,t}(j), \alpha a_t(j)} W_t l_{u,t}(j) + V_t h_{u,t}(j) + R_{k,t} k_{u,t}(j) + \alpha R_{a,t} a_t(j), \quad (5.26)$$

subject to the constraint of producing enough to meet demand:

$$\left(m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u} \right)^{\gamma_u} \geq \left(\frac{p_{u,t}(j)}{P_{u,t}} \right)^{-\sigma_u} Y_t \quad (5.27)$$

where $\alpha \in \{0, 1\}$ is a multiplier for the intermediate good firms in dynamic sector. Thus, it is equal to one ($\alpha = 1$) for the intermediate goods firms in the dynamic sector, zero ($\alpha = 0$) otherwise. $W_t, V_t, R_{k,t}, R_{a,t}$ are the nominal wage for low skill labour, the nominal wage for high labour, the nominal capital rents and the nominal rents of automation machine which firms take as given. Therefore, the nominal wage of low skill labour and high skill labour, the rent of capital and the rent of automation machine is common for all firms not only in their respective sector, but also whole economy.

A standard Lagrangian can be written as follows:

$$\begin{aligned} \mathcal{L} = & -W_t l_{u,t}(j) - V_t h_{u,t}(j) - R_{k,t} k_{u,t}(j) - \alpha R_{a,t} a_t(j) \\ & + \varphi_{u,t}(j) \left(\left(m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u} \right)^{\gamma_u} - \left(\frac{p_{u,t}(j)}{P_{u,t}} \right)^{-\sigma_u} Y_t \right) \end{aligned} \quad (5.28)$$

and it can be rewritten based on the equation 5.5:

$$\begin{aligned} \mathcal{L} = & -W_t l_{u,t}(j) - V_t h_{u,t}(j) - R_{k,t} k_{u,t}(j) - \alpha R_{a,t} a_t(j) \\ & + \varphi_{u,t}(j) \left(\left(\left[\Phi_u^{\frac{1}{\epsilon_u}} \left(\gamma_{u,h}(j) h_{u,t}(j) \right)^{\frac{\epsilon_u-1}{\epsilon_u}} \right. \right. \right. \\ & \left. \left. \left. + (1 - \Phi_u)^{\frac{1}{\epsilon_u}} \left(\gamma_a(j) \alpha(j) a_t(j) + \gamma_{u,l}(j) l_{u,t}(j) \right)^{\frac{\epsilon_u-1}{\epsilon_u}} \right]^{\frac{\epsilon_u \beta_u}{\epsilon_u-1}} k_{u,t}(j)^{1-\beta_u} \right)^{\gamma_u} \right. \\ & \left. - \left(\frac{p_{u,t}(j)}{P_{u,t}} \right)^{-\sigma_u} Y_t \right) \end{aligned} \quad (5.29)$$

²⁴ Factor market is a term to define a market where factors of production are bought and sold. For instance, intermediate good firms hire labour and rent in order to product intermediate goods. They sell their product in the good markets.

where the Lagrange multiplier $\varphi_{u,t}(j)$ can be interpreted as nominal marginal cost in period t ²⁵ $MC_{u,t}(j)$.

The first order conditions are:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial l_{u,t}} = 0 \Leftrightarrow W_t = & Y_u \beta_u \gamma_{u,l}(j) (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a(j) \alpha(j) a_t(j) \\ & + \gamma_{u,t}(j) l_{u,t}(j))^{\frac{-1}{\epsilon_u}} m_{u,t}(j)^{\frac{1-\epsilon_u}{\epsilon_u}} MC_{u,t}(j) \left((m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u})^{Y_u} \right) \end{aligned} \quad (5.30)$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial h_{u,t}} = 0 \Leftrightarrow V_t \\ = Y_u \beta_u \gamma_{u,h}(j) (\Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_{u,h}(j) h_{u,t}(j))^{\frac{-1}{\epsilon_u}} m_{u,t}(j)^{\frac{1-\epsilon_u}{\epsilon_u}} MC_{u,t}(j) \left((m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u})^{Y_u} \right) \end{aligned} \quad (5.31)$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial a_t} = 0 \Leftrightarrow R_{a,t} = & Y_u \beta_u \gamma_a(j) (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a(j) \alpha(j) a_t(j) \\ & + \gamma_{u,t}(j) l_{u,t}(j))^{\frac{-1}{\epsilon_u}} m_{u,t}(j)^{\frac{1-\epsilon_u}{\epsilon_u}} MC_{u,t}(j) \left((m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u})^{Y_u} \right) \end{aligned} \quad (5.32)$$

$$\frac{\partial \mathcal{L}}{\partial k_{u,t}} = 0 \Leftrightarrow R_{k,t} = Y_u (1 - \beta_u) (k_{u,t}(j))^{-1} MC_{u,t}(j) \left((m_{u,t}(j)^{\beta_u} k_{u,t}(j)^{1-\beta_u})^{Y_u} \right) \quad (5.33)$$

Here, if it is assumed that the factor markets are competitive and the intermediate good firms face the same prices for the production factors, they will hire high skill and low skill labour or rent capital in the same ratio. As a result, they have the same marginal cost in their respective sectors²⁶. If the price of production factors, which are derived from the equations 5.30, 5.31, 5.32 and 5.33, are plugged in the cost function, and the index (j) of the marginal cost function $MC_{u,t}(j)$ is dropped, it results to:

$$W_t l_{u,t}(j) + V_t h_{u,t}(j) + R_{k,t} k_{u,t}(j) + \alpha R_{a,t} a_t(j) = MC_{u,t} y_t(j) \quad (5.34)$$

If the equation 5.34 is rearranged based in the equation 5.5 :

²⁵ The nominal marginal cost is a function, which measure how much the nominal cost change when the firm produces one more unit of its good.

²⁶ The dynamic sector and the stagnant sector have different marginal cost functions. Because the dynamic sector can access in automation technology.

$$\begin{aligned}
MC_{u,t} = & (\gamma_u)^{-1} (y_t(j))^{\frac{1-\gamma_u}{\gamma_u}} \beta_u^{-\beta_u} (1-\beta_u)^{-(1-\beta_u)} \left[\Phi_u \left(\frac{V_t}{\gamma_{u,h}} \right)^{1-\epsilon_u} \right. \\
& \left. + (1-\Phi_u) \left(\left(\frac{\frac{W_t}{\gamma_{u,l}} + \frac{R_{a,t}}{\gamma_a}}{2} \right) \right)^{1-\epsilon_u} \right]^{\frac{\beta_u}{1-\epsilon_u}} R_{k,t}^{1-\beta_u}
\end{aligned} \tag{5.35}$$

The equation 5.35 shows that the parameter γ_u has a significant impact on the slope of marginal cost function. The marginal cost decreases in parallel with the increase of output if the parameter γ_u is bigger than unity ($\gamma_u > 1$). On the other hand, the marginal cost increases in parallel with the increase of the output if the parameter γ_u is smaller than unity ($\gamma_u < 1$).

Nevertheless, if the price setting process is reconsidered based on the optimal choice of factors of production, nominal profits of the intermediate good firms is Π^n :

$$\Pi_{u,t}^n(j) = p_{u,t}(j)y_t(j) - W_t l_{j,t}(j) - V_t h_{u,t}(j) - R_{k,t} k_{u,t}(j) - \alpha R_{a,t} a_t(j) \tag{5.36}$$

$$\Pi_{u,t}^n(j) = p_{u,t}(j)y_t(j) - MC_{u,t}y_t(j) \tag{5.37}$$

Now, the intermediate goods firms need to choose their optimal price. Following Calvo (1983) and Sims (2016), in each period only a fixed proportion of the intermediate good firms ($1 - \phi_u$) can adjust their price. The remainder (ϕ_u) can partially set their price according to lagged aggregate inflation (τ_t) with the inflation indexation parameter $\zeta \in [0, 1]$. Then, the optimal price, which is chosen by the intermediate goods firms in period t , can be expressed as follow:

$$p_{u,t}(j) \begin{cases} p_{u,t}^{\#}(j) & \text{If } p_{u,t}(j) \text{ is adjusted optimally} \\ (1 + \tau_{t-1})^{\zeta} p_{u,t-1}(j) & \text{Otherwise} \end{cases} \tag{5.38}$$

If it is assumed that a firm is given an opportunity to adjust its price in period t , however, the same firm does not update its price optimally in subsequent periods. Under this setup, its price in period $t + e$ would be:

$$\begin{aligned}
p_{u,t+1}(j) &= (1 + \tau_t)^{\zeta} p_{u,t}^{\#}(j) \\
p_{u,t+2}(j) &= ((1 + \tau_{t+1})(1 + \tau_t))^{\zeta} p_{u,t}^{\#}(j) \\
&\vdots \\
p_{u,t+e}(j) &= \left(\prod_{f=0}^{e-1} (1 + \tau_{t+f}) \right)^{\zeta} p_{u,t}^{\#}(j)
\end{aligned} \tag{5.39}$$

where,

$$\prod_{f=0}^{e-1} (1 + \tau_{t+f}) = (1 + \tau_t)(1 + \tau_{t+1})(1 + \tau_{t+2}) \cdots (1 + \tau_{t+e-1}) \tag{5.40}$$

If the function in equation 5.40 is rewritten in terms of price levels:

$$\prod_{f=0}^{e-1} (1 + \tau_{t+f}) = \frac{P_t}{P_{t-1}} \frac{P_{t+1}}{P_t} \frac{P_{t+2}}{P_{t+1}} \frac{P_{t+3}}{P_{t+2}} \dots \frac{P_{t+e-1}}{P_{t+e-2}} = \frac{P_{t+e-1}}{P_{t-1}} \quad (5.41)$$

Then the non-updated price of intermediate good firms can be reformulated:

$$p_{u,t+e}(j) = \left(\frac{P_{u+e-1}}{P_{t-1}} \right)^\zeta p_{u,t}^\#(j) \quad (5.42)$$

Considering the possibility of the firm to adjust its price not only in period t , but also in period $t + e$, the profit maximization problem of the intermediate goods firm becomes dynamic because price will be chosen optimally by considering expectations of the future periods. Therefore, the intermediate goods firms will discount profits e periods into the future by $E_t \frac{\lambda_{t+e}^e}{\lambda_t} \phi_u^e$, where $E_t \frac{\lambda_{t+e}^e}{\lambda_t}$ is the nominal stochastic discount factor, λ_{t+e} is the marginal utility of wealth for the firm owners²⁷, and ϕ_z^e is the probability of a price chosen in period t is still in effect in period $t + e$. The dynamic price maximization problem, then, can be expressed in terms of profit function by plugging in the demands for intermediate goods as follows:

$$\max_{p_{u,t}^\#(j)} E_t \sum_{e=0}^{\infty} (\phi_u)^e \frac{\lambda_{t+e}^n}{\lambda_t^n} \left(p_{u,t}^\#(j) \left(\prod_{f=0}^{e-1} (1 + \tau_{t+f}) \right)^\zeta - MC_{u,t} \right) y_t(j) \quad (5.43)$$

This function can be also rewritten in terms of price level following Sims (2016):

$$\max_{p_{u,t}^\#(j)} E_t \sum_{e=0}^{\infty} (\phi_z)^e \frac{\lambda_{t+e}^n}{\lambda_t^n} \left[\left(\frac{P_{t+e-1}}{P_{t-1}} \right)^{\zeta(1-\sigma_z)} p_{u,t}^\#(j)^{1-\sigma_z} P_{u,t+e}^{\sigma_z} Y_{t+e} - MC_{u,t} \left(\frac{P_{t+e-1}}{P_{t-1}} \right)^{-\zeta\sigma_z} p_{u,t}^\#(j)^{-\sigma_z} P_{u,t+e}^{\sigma_z} Y_{t+e} \right] \quad (5.44)$$

If it is rearranged based on real marginal utility (λ_t) and real marginal cost ($mc_{u,t}$) after applying FOC, optimal price of the intermediate good firms is:

$$p_{u,t}^\#(j) = \frac{\sigma_z}{\sigma_z - 1} \frac{F_{1,u,t}}{F_{2,u,t}} \quad (5.45)$$

Here:

$$F_{1,u,t} = \lambda_t mc_{u,t} P_{u,t}^{\sigma_z} Y_t + \phi_u \left(\frac{P_t}{P_{t-1}} \right)^{-\zeta\sigma_z} E_t F_{1,u,t+1} \quad (5.46)$$

²⁷ In mainstream DSGE models and New Keynesian models, the stochastic discount factor is expressed as the marginal utility of the household. Because it is assumed that households own the firms and dividends. Here, it is imposed that the owner of the firms and profits are capital owners which will be a specific type of household.

$$F_{2,u,t} = \lambda_t P_{u,t}^{\sigma_z - 1} Y_t + \phi_u \left(\frac{P_t}{P_{t-1}} \right)^{\zeta(1-\sigma_z)} E_t F_{2,u,t+1} \quad (5.47)$$

and

$$\lambda_t = P_t \lambda_t^n, \quad mc_{u,t} = \frac{MC_{u,t}}{P_t} \quad (5.48)$$

It is worth noting that if the price setting process is flexible, which means $\phi_u = 0$, then the right-hand side of the equation 5.45 will be reduced to:

$$p_{u,t}^{\#(j)} = \frac{\sigma_u}{\sigma_u - 1} \frac{\lambda_t mc_{u,t} P_{u,t}^{\sigma_u} Y_t}{\lambda_t P_{u,t}^{\sigma_u - 1} Y_t} = \frac{\sigma_u}{\sigma_u - 1} mc_{u,t} P_{u,t} \quad (5.49)$$

$$p_{u,t}^{\#(j)} = \frac{\sigma_u}{\sigma_u - 1} MC_{u,t} \quad (5.50)$$

In other words, the optimal price for the intermediate goods firms is a fixed mark-up $\left(\frac{\sigma_u}{\sigma_u - 1} \right)$ over nominal marginal cost ($MC_{u,t}$) of the intermediate goods.

5.2.4 Wage Setting Process

In contrast to the price-stickiness, the wage-stickiness is not within the scope of this research. Following Storm & Naastepad (2012), the wage increase of low skill and high skill labour is written in parallel with NAIRU wage bargaining approach:

$$\widehat{W}_t = a_{0,l} - a_1 \mu_l + a_2 \widehat{y}_{d,l} + a_3 z_{u,l} \quad a_{0,l}, a_2, a_3 > 0 \quad (5.51)$$

and

$$\widehat{V}_t = a_{0,h} - a_1 \mu_h + a_2 \widehat{y}_{d,h} + a_3 c_{u,h} \quad a_{0,h}, a_2, a_3 > 0 \quad (5.52)$$

where a_1 represents the negative impact of unemployment μ on the rise of wages. The parameter a_2 , on the other hand, reflects the impact of productivity growth on wage bargaining power of workers. Finally, a_3 affects the wage growth positively as long as the labour union power increases.

5.2.5 Interest Rate and Rent of Capital

In the base model, the nominal interest rate is determined based on the inflation. However, more advanced monetary policies will be elaborated in chapter 7. The nominal interest rate is written as follows:

$$\ddot{i}_t = (1 - \omega_i) \dot{i}_t + \omega_i \ddot{i}_{t-1} + \theta_\tau (\tau_t - \tau) + \sigma_i \varepsilon_{i,t} \quad (5.53)$$

where \bar{i} is the steady state nominal interest rate; $\omega_d \in (-1, 1)$ is the persistence rate; and $\theta_\tau > 0$ is the elasticity of the inflation on interest rate. In the base model, the nominal interest rate is determined based on the inflation, $\sigma_{\bar{i}}$ denotes the standard deviation and $\varepsilon_{i,t}$ is an IID standard normal process.

The rent of capital, on the other hand, can be seen as a compensation for the consumption savings of capital owners. Following Acemoglu (2009), the rent of the capital is determined based on the interest rate \bar{i} and depreciation rate δ :

$$R_{k,t} = P_{d,t}(\bar{i}_t - \delta_k) \quad (5.54)$$

and

$$R_{a,t} = \varrho^{-1} P_{d,t}(\bar{i}_t - \delta_a) \quad (5.55)$$

It is assumed that only dynamic final products can be used to produce both traditional capital and automation machine. Therefore, the rental rates of the traditional capital and automation machine are written based on the price of dynamic final products. Here the parameter ϱ is an exogenous variable to analyse relative price change of automation machines over time²⁸. It is assumed that automation machine is more expensive than traditional capital in the beginning of the analysis. However, it gets cheaper along with technological progress. Thus, the parameter ϱ enables to analyse the change on the capital owner's investment choice and resource allocation between traditional capital and automation machine.

5.2.6 The Capital Stock

Following Justiniano, Primiceri, & Tambalotti (2011) and Liu, Fernald, & Basu (2012), the traditional capital and automation machine stocks evolve according to the law of motion:

$$K_{u,t} = (1 - \delta_k)K_{u,t-1} + \chi_{k,t}I_{K_{u,t-1}} \quad (5.56)$$

and

$$A_t = (1 - \delta_a)A_{t-1} + \chi_{a,t}I_{A,t-1} \quad (5.57)$$

The term χ_k and χ_a is a shock to the marginal efficiency of transforming the dynamic final products into traditional capital and automation machine which is defined as MEI (Justiniano et al., 2011). They follow the stationary stochastic process:

$$\log \chi_{u,t} = \omega_{\chi_u} \log \chi_{u,t-1} + \sigma_{\chi} \varepsilon_{\chi,t} \quad (5.58)$$

where ω_{χ_u} is the persistence shock; $\sigma_{\chi} \varepsilon_{\chi,t}$ a standard normal process with standard deviation.

²⁸ It can be thought that there is a third sector which produces only automation machine in the perfectly competitive market by using final dynamic products as production factor with ϱ technology parameter as follows:

$$Y_{a,t}(j) = \varrho D_t$$

and the profit maximization problem of automation machine producer can be written as follows :

$$\max_{D_t} P_{a,t} Y_{a,t} - P_{a,t} D_t$$

Thus, the price of the automation machine is:

$$\varrho^{-1} P_{d,t}$$

5.3 The Demand Side of the Economy

In this section, the demand side of the economy is explained based on the Neo Kaleckian models. The Neo Kaleckian models allow to study the impact of functional income distribution on the growth, demand and investment (Bhaduri & Marglin, 1990; Storm & Naastepad, 2012). A higher wage in total income might promote higher demand for consumption since workers have relatively low savings rate compared to profit earners (Storm & Naastepad, 2012). Therefore the model, which was developed by Bhaduri & Marglin (1990) and Storm & Naastepad (2012) is used to support the demand side the economy. It is assumed that the society is divided into three class economy as it is shown in Figure 5.3

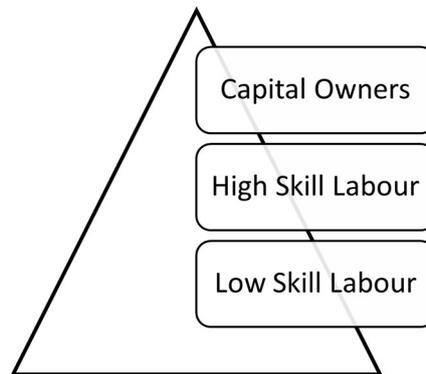


Figure 5.3 Three Class Economy

As discussed in chapters 1 and 4, automation might disturb the functional income distribution. Specifically, it is expected that robot owners and high skilled labour will take most of the benefits of the coming wave of automation. Therefore, this three-class economic structure enables to analyse the disturbing impact of automation on income distribution, economic growth, aggregate demand, and investment. The rest of this section is organized as follows: section 5.3.1 argues the income shares in the three-class economy. Section 5.3.2 elaborates on consumption preferences of income earners. Sections 5.3.3 and 5.3.4, on the other hand, is comprise of investment decisions and aggregate demand.

5.3.1 Income Shares

The starting point of modelling the demand side is the structure of income distribution. As it is shown in Figure 5.4, income is divided into two parts which are profits and wages.

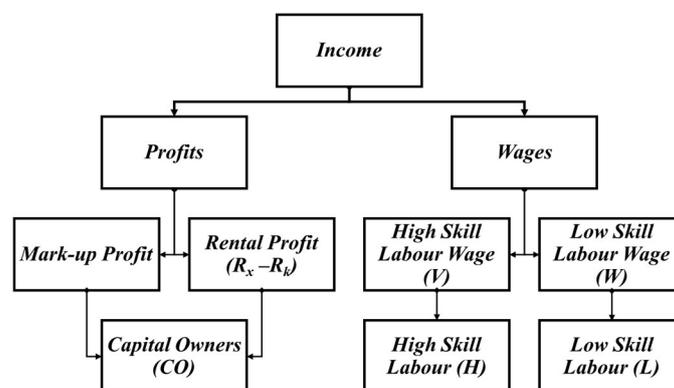


Figure 5.4 The structure of income distribution

The profit and wage shares are determined based on the theory which is explained in sections 5.2.3 and 5.2.4. There are two significant assumptions which constitute a basis for the rest of the model as well as the income shares. Firstly, capital owners, who are on the top of the list of three class economy in the Figure 5.3, do not receive any wage income. Secondly, it is assumed that low skill labour consumes all their income and do not save.

Nevertheless, capital owners take all profits which comprise mark-up profits and rental profits. The mark-up profit share is determined by a mark-up over marginal cost. On the other hand, rental profits are identified as rent for traditional capitals and automation machine. Therefore, capital owners' income share is written as follows:

$$\begin{aligned}
Income_{CO,t} = & \underbrace{\left[(P_{u,t} - \gamma_u MC_{u,t}) Y_t \right]}_{\text{Mark-Profits}} + \underbrace{\left[(1 - \beta_u) \gamma_u MC_{u,t} Y_t \right]}_{\text{Rental Profits for } R_k} \\
& + \underbrace{\left[\beta_u \gamma_u MC_{u,t} Y_t \left(\gamma_a A_t (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a \alpha A_t + \gamma_{u,l} L_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right]}_{\text{Rental Profits for } R_x}
\end{aligned} \quad (5.59)$$

Since low skill labour and high skill labour²⁹ have zero saving propensity, they do not own any traditional capital and automation machine and do not receive any profit income. Therefore, income shares of low skill labour and high skill labour are written as follows:

$$Income_{L,t} = \left[\beta_u \gamma_u MC_{u,t} Y_t \left(\gamma_{u,l} L_{u,t} (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a \alpha A_t + \gamma_{u,l} L_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right] \quad (5.60)$$

and

$$Income_{H,t} = \left[\beta_u \gamma_u MC_{u,t} Y_t \left(\gamma_{u,h} (\Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_{u,h} H_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right] \quad (5.61)$$

5.3.2 Consumption

The consumption behaviour of households will take a key role to model the demand side of the economy. It is assumed that all households, including capital owners, high skill labour, and low skill labour are identical in their preferences for the composite consumption³⁰. Following Dennis & İřcan (2007), Duarte & Restuccia (2010) and Sasaki (2012), the composite consumption problem of identical households is written as follows:

$$\max_{C_{d,t}, C_{s,t}} \bar{u} \left\{ \left(\eta^{\frac{1}{v}} C_{d,t}^{\frac{v-1}{v}} + (1 - \eta)^{\frac{1}{v}} (C_{s,t} + C_{s,min})^{\frac{v-1}{v}} \right)^{\frac{v}{v-1}} \right\} \quad (5.62)$$

²⁹ It is assumed that high skill labour have a saving propensity which is higher than zero. However, to simplify model it will be assumed that they do not use their savings to possess an ownership for firm or capital.

³⁰ In fact, consumers vary based on their consumption preferences. This variation on preferences has been one of the basis to research the structural change in mainstream economics. Kongsamut, Rebelo, & Xie (2001), for instance, developed a three sector economy (agriculture, manufacturing, and services). The non-homothetic preferences of consumers in their model led a structural change. Because the preferences of consumers shift to service from agriculture.

subject to budget constraint of respective households,

$$P_{d,t}C_{d,t} + P_{s,t}C_{s,t} \leq Income_{j,t}(1 - \psi_j) \quad (5.63)$$

where $C_{d,t}$ and $P_{d,t}$ denote the consumption of dynamic final products and the unit price of dynamic final product; $C_{s,t}$ and $P_{s,t}$ represent the consumption of stagnant final products and the unit price of stagnant final product; ν , the elasticity of substitution between two types of consumption products; $\eta \in (0, 1)$, the share of the dynamic product consumption; and $C_{s,min} \geq 0$, the subsistence consumption of the final stagnant products. $Income_{j,t}$ $j \in \{CO, L, H\}$, on the other hand, represent the earnings of the respective households. The parameter ψ_j is the saving propensity and determined exogenously. Therefore, the consumption expenses are bound by budget constraint $Income_{j,t}(1 - \psi_j)$. As it is highlighted in section 5.3.1, the saving propensity of low and high skill labour is zero $\psi_L, \psi_H = 0$, while the saving propensity of capital owners is $\psi_{CO} \in (0, 1)$.

If $\nu < 1$, the final dynamic and stagnant products complement each other for composite consumption, and otherwise they are gross substitutes. Moreover, when $C_{s,min} > 0$, the consumption preferences of the households remain relatively constant over time. As a result, the demand for the final stagnant products increases in parallel with the output increase of the final dynamic products, although the price of the final stagnant products rises relative to the price of the final dynamic products. Since the productivity and technological progress in stagnant sector is lower than the dynamic sector, more production resources start to relocate to the stagnant sector to satisfy increasing demand for stagnant sector products. Baumol (1967) assumed that the output ratio between service sector and the rest of the economy remains constant when he drew the conclusion that the employment shift occurs toward the service sector. The consumption demands for the final goods of the dynamic and the stagnant sectors can be written by solving the maximization problem in the equations 5.62 and 5.63 :

$$C_{d,t} = \left(\frac{\eta}{1-\eta}\right) \left(\frac{P_{s,t}}{P_{d,t}}\right)^\nu \left[\frac{Income_{j,t}(1 - \psi_j) - \left(\frac{\eta}{1-\eta}\right) P_{d,t} \left(\frac{P_{s,t}}{P_{d,t}}\right)^\nu C_{s,min}}{P_{s,t} + \left(\frac{\eta}{1-\eta}\right) P_{d,t} \left(\frac{P_{s,t}}{P_{d,t}}\right)^\nu} + C_{s,min} \right] \quad (5.64)$$

and

$$C_{s,t} = \frac{Income_{j,t}(1 - \psi_j) - \left(\frac{\eta}{1-\eta}\right) P_{d,t} \left(\frac{P_{s,t}}{P_{d,t}}\right)^\nu C_{s,min}}{P_{s,t} + \left(\frac{\eta}{1-\eta}\right) P_{d,t} \left(\frac{P_{s,t}}{P_{d,t}}\right)^\nu} \quad (5.65)$$

5.3.3 Investment

In section 5.3.2, it is assumed that only capital owners have saving propensity which is higher than zero. The savings of capital owners can be used to invest in traditional capital and automation machine. Therefore, capital owners make the investment decisions to increase their revenue. Following to Bhaduri & Marglin (1990), Storm & Naastepad (2012), Palley (2010, 2012, 2013, 2016), and Hartwig (2013), it is assumed that the growth rates of investment in traditional capital and automation machines $\hat{I}_{K,t}$ and \hat{I}_A depend positively on the profit share $\pi_{u,t}$, aggregate demand $X_{u,t}$, and negatively on interest rate i :

$$\hat{I}_{K,t} = \Omega_{0,K_d} \hat{A}_{K,t} + \Omega_{1,K_d} \hat{\pi}_{d,t} + \Omega_{2,K_d} \hat{X}_{d,t} - \Omega_{3,K_d} i \quad (5.66)$$

$$\hat{I}_{K_s,t} = \Omega_{0,K_s} \hat{A}_{K,t} + \Omega_{1,K_s} \hat{\pi}_{s,t} + \Omega_{2,K_s} \hat{X}_{s,t} - \Omega_{3,K_s} i \quad (5.67)$$

and

$$\hat{I}_{A,t} = \Omega_{0,A} \hat{A}_{A,t} + \Omega_{1,A} \hat{\pi}_{d,t} + \Omega_{2,A} \hat{X}_{d,t} - \Omega_{3,A} i \quad (5.68)$$

where $\hat{A}_{K,t}$ and $\hat{A}_{A,t}$ denote the other autonomous factors which Keynes (1936) identified as “animal spirits” of entrepreneurs. In particular, the parameter $\hat{A}_{A,t}$ enables to study a relatively fast pace of automation and its impact on other production factors. The coefficients Ω_{1,K_d} , Ω_{1,K_s} , and $\Omega_{1,A}$ are the elasticity of investment with respect to profit share in respective sector. Finally, the coefficients Ω_{2,K_d} , Ω_{2,K_s} , and $\Omega_{2,A}$ represent the accelerator effect due to expected demand growth. It can be thought as a signal for capital owners to invest on traditional capital and automation machine to satisfy expected increase in demand.

5.3.4 Aggregate Demand

Following Storm & Naastepad (2012) and Hartwig (2013), the aggregate demand function is written as follows:

$$X_{d,t} = C_{d,t} + I_{K_d,t} + I_{K_s,t} + I_{A,t} \quad (5.69)$$

and

$$X_{s,t} = C_{s,t} \quad (5.70)$$

where $C_{d,t}$ and $C_{s,t}$ represents the consumption demand. $I_{K_d,t}$, $I_{K_s,t}$ and $I_{A,t}$ are investment in terms of dynamic final products.

While the consumption demand is a function of both wage and profit income as shown in section 5.3.1, the investment demand is due to savings of capital owners. In other words, if the wage share increases, the share of consumption demand on aggregate demand increases as well. This is because the saving propensity of low and high skill labour is lower than the saving propensity of capital owners.

5.3.5 Labour Market and Employment

The total mass of low skill and high skill labour that are employed by the stagnant and dynamic firms is written in the equation 5.8. It is required to identify two more equations to describe the labour market. The unemployment function can be derived as follows:

$$\mu_{l,t} = 1 - \frac{L_t}{L_t^*}, \mu_{h,t} = 1 - \frac{H_t}{H_t^*} \quad (5.71)$$

where

$$L_t^* = g_l L_0^*, H_t^* = g_h H_0^* \quad (5.72)$$

Equation 5.71 shows that the unemployment rate is a decreasing function if the growth of employment is lower than the growth of low skill and high skill labour. In a steady state condition, unemployment should be constant due to similar growth in both employment, low skill and high skill labour growth. Otherwise, there will be an excess of demand or an excess of labour supply in the labour market.

5.3.6 Growth

In the supply side of the economy, technological progress is the main factor which has an impact on the growth of output. In the demand side of the economy, on the other hand, the growth of aggregate demand might dominate output growth. Therefore, the growth of final output is written as follows:

$$g_Y = \min \left\{ \underbrace{g_{X_{u,t-1}} = \mathcal{F} \left\{ \begin{array}{l} g_{C_{u,t-1}} = \mathcal{F}((1-\pi), u) \\ g_{I,t-1} = \mathcal{F}(\pi, \dot{i}, X) \end{array} \right\}}_{\text{Aggregate Demand Gr}}, \underbrace{g_{N_{d,t-1}} = \mathcal{F}(I, \pi, \dot{i}, X)}_{\text{Technological Progress}} \right\} \quad (5.73)$$

Equation 5.73 shows that the final output growth equals to the minimum growth between technological progress and the aggregate demand growth. Technological progress³¹ is a function of investment, profit share, interest rate, and aggregate demand. The aggregate demand growth, on the other hand, is bounded by the consumption growth and investment growth. While the former one is a function of wage share and unemployment, the latter one is a function of profit share, aggregate demand and interest rate.

It is worthwhile to mention that aggregate demand is the key factor which affects both technological progress and the demand growth. Under the assumption of full capacity utilization (employment), an increase in technological progress will increase the final output and the aggregate demand which has a positive impact on technological progress. However, a change on wage share and unemployment may decrease capacity utilization. In this case investment and technological progress might slow down. In other words, actual output is determined as follows:

$$\mu_t = \frac{X_{u,t}}{Y_t^*} \quad (5.74)$$

³¹ In section III5.2.2, it is shown that technological progress is determined exogenously by a stochastic process. However, as it is elaborated by endogenizing in chapter 7, technological progress depends on investment.

where $\mu_t \in (0, 1]$ represents capacity utilization; Y_t^* represents full capacity output. If the aggregate demand growth is constrained due to decreasing wage share or unemployment, then capacity utilization μ_t takes a value less than unity ($0 < \mu_t < 1$). Besides, in the case of demand constraint via consumption channel, the final output growth equals to aggregate demand growth:

$$g_Y = g_{X_{u,t-1}} \quad (5.75)$$

5.4 Summary

In a nutshell, Chapter **Error! Reference source not found.** tries to extend the model of Hémous and Olsen (2018). For this purpose, section 5.1 discussed the main characteristics of their model. Hémous and Olsen (2018) built a rich economic model which comprises skill-biased technological change, income distribution, automation, and its impact on factor prices. They also addressed structural transformation as automated and non-automated sectors. However, their focus on income distributions was limited by high skill and low skill labour. Besides, their model is not adequate to study short-run impact of automation in the short run due to its neo-classical roots. Thus it is required to extend the model of Hémous and Olsen (2018) based on New-Keynesian and Neo-Kaleckian economic school of thoughts. While Neo-Keynesian enables to focus on the short time dynamic relationship in the economic environment, Neo-Kaleckian models enables to study the impact of income distribution on aggregate demand and investment.

Section 5.2 elaborates the supply side of the economy based on the Neo-Keynesian economic school of thoughts. Following Baumol (1967), the production function of intermediate and final good producers are defined for the stagnant and dynamic sectors. It is assumed that technological progress occurs only in the dynamic sectors. Moreover, the factor prices and their growth process are elaborated. The intermediate and final good price are derived using the sticky price model of Calvo (1983). Finally, the capital stock accumulation process is expressed.

Section 5.3, on the other hand, addresses the demand side of the economy. For this purpose, it defined the consumption preferences of household by assuming them as identical. The saving propensity of every household is defined. It is assumed that only capital owners have a saving propensity higher than zero. As a result, they are the only entity in the model who can invest capital and take profit. Furthermore, the investment decision process of capital owners are identified. Finally, the growth parameters and their relationship are elaborated.

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6

Simulation of Automation

*This chapter explores possible automation scenarios and their impacts on various macroeconomic indicators such as the productivity growth, the aggregate demand growth, the investment growth, wage and rental price change and change on utilization of production factors such as unemployment. For this purpose, the model, which is developed in chapter 5, is operationalized for a numerical analysis by using VENSIM in section 5.1. Section 5.2 addresses the data collection process and calibration. Section 5.3 discusses the short term impacts of automation on aggregate demand, productivity, wage growth, and employment. Finally, section **Error! Reference source not found.**4 discusses the results.*

6.1 Operationalizing the Model in Vensim

The model is implemented in Vensim by following the structure in chapter 5. The stagnant and dynamic sectors produce their intermediate and final products by using initial labour and capital stocks which are operationalized by a stock-flow diagram. Firms then decide their optimum price based on profit mark-up and marginal cost which is an auxiliary variable. The marginal cost is determined by the marginal cost function and production factor prices which are stock-flow variables and vary over time. This cycle is followed by the distribution of revenue between low skill, high skill labour, and capital owners as income. These agents use these incomes in order to consume the dynamic and stagnant products. Meanwhile, capital owners take investment decision to increase their production and capital stock, which is comprised of traditional capital and automation machine. They consider factors such as aggregate demand and profit share on their investment decision.

6.2 Data collection and Calibration

Before exploring the impact of automation, the model should be calibrated according to sectorial level data in the USA. For this purpose, it is essential to determine the initial value of labour and capital distributions across sectors.

6.2.1 Data Collection

Acemoglu & Guerrieri (2006) used data from the national income and product accounts (NIPA) and classified industries into two different clusters: low and high capital intensity sectors. In fact, high capital intensity sectors show similarity with the assumption of the dynamic sectors. Thus, their data are used to determine the initial distribution of production factors in this research. Besides, the following macroeconomic trends, which is shown in Table III.2, are imposed in the simulation model.

Table III.2 Macroeconomic trends between 1980-2008

<i>Trends</i>	<i>Descriptions</i>	<i>Target</i>		<i>Source</i>
		<i>1980</i>	<i>2008</i>	
ΔYp	GDP growth	2.50%	1.80%	(The World Bank, 2019a), (Acemoglu & Guerrieri, 2006)
V/W	Skill Premium	1.41	1.90	(Buera, Kaboski, & Rogerson, 2015), (D. H. Autor, Katz, & Kearney, 2005)
\ddot{i}	Real interest rate	5.73%	5.25%	(The World Bank, 2019b)
H/M	Fraction of High Skill	39%	42%	(ILO, 2019)
μ	Unemployment	-	5.78%	(The World Bank, 2019d)
I/Yp	Investment/GDP ratio	23.3%	24%	(The World Bank, 2019c), (IMF, 2019)
$1 - \pi$	Labour Income Share	62.2%	58%	(Giandrea & Sprague, 2017)

The calibration of the simulation model is based on the macroeconomic trends and data between 1980 and 2008. There are two main reason for this choice. Firstly, the income inequality started to rise after the 1980s as it is indicated in chapter 3. In addition, the data have become more available since 1980. Nevertheless, the initial values are listed in Table III.2

Table III.3 Initial values of main parameters

<i>Capital</i>		<i>Labour</i>		<i>Technology</i>		<i>Investment</i>		<i>Price</i>	
$K_{s,0}$	2500000	$L_{s,0}$	30000	$N_{s,0}$	80	$I_{K_{s,0}}$	176000	W_0	1.000
$K_{d,0}$	3000000	$H_{s,0}$	18000	$N_{d,0}$	80	$I_{K_{d,0}}$	141000	V_0	1.470
A_0	20000	$L_{d,0}$	30000			$I_{A,0}$	7000	$R_{k,0}$	0.009
		$H_{d,0}$	20000					$R_{a,0}$	0.404

Following these macroeconomic trends and initial values, the rest of the structural and shock parameters are calibrated based on studies of Hémous & Olsen (2018), Acemoglu & Guerrieri (2006), Storm & Naastepad (2012), Liu, Fernald, & Basu (2012), Galesi & Rachedi (2016), Lin & Weise (2017) and Prettner (2016), as they are shown in Table III.4

Table III.4 Calibration of structural and shock parameters

<i>Parameters</i>	<i>Descriptions</i>	<i>Values</i>	<i>Source</i>
<i>Production</i>			
σ_s	Steady-State Elas. of subs. for Stag. Sec.	9.00	(Christopoulou & Vermeulen, 2008)
σ_d	Steady-State Elas. of subs. for Dyn. Sec.	10.00	(Christopoulou & Vermeulen, 2008)
ω_{σ_s}	Persistence of Stagnant Elas. Of Subs	0.95	(Liu et al., 2012)
ω_{σ_d}	Persistence of Dynamic Elas. Of Subs	0.95	(Liu et al., 2012)
σ_{σ_s}	Stnd. deviation of Stagnant Elas. Of Subs	0.01	(Liu et al., 2012)

σ_{σ_d}	Std. deviation of Dynamic Elas. Of Subs	0.01	(Liu et al., 2012)
β_s	Output elasticity of Workforce in Stag. Sec.	0.72	(Acemoglu & Guerrieri, 2006)
β_d	Output elasticity of Workforce in Dyn. Sec.	0.52	(Acemoglu & Guerrieri, 2006)
γ_s	Return the Scale in Stag. Sec.	1.10	(Romero & McCombie, 2016)
γ_d	Return the Scale in Dyn. Sec.	0.90	(Romero & McCombie, 2016)
Φ_s	High Skill Share in Stag. Sec.	0.52	(Ko, 2015)
Φ_d	High Skill Share in Dyn. Sec.	0.64	(Lester, 2014)
Φ_{Ia}	Dyn. Product Share in Auto. Mac	0.66	(Duarte & Restuccia, 2017)
Φ_{Ikd}	Dyn. Product Share in Dyn. Capital	0.64	(Duarte & Restuccia, 2017)
Φ_{Iks}	Dyn. Product Share in Stag. Capital	0.34	(Duarte & Restuccia, 2017)
ϵ_s	Elas. of subs. of Workforce in Stag. Sec.	2.60	(Ko, 2015)
ϵ_d	Elas. of subs. of Workforce in Dyn. Sec.	2.60	(Ko, 2015)
ϵ_{Ia}	Elas. of subs. of Auto Mac.	1.14	(Duarte & Restuccia, 2017)
ϵ_{Ikd}	Elas. of subs. of Dyn Cap.	1.06	(Duarte & Restuccia, 2017)
ϵ_{Iks}	Elas. of subs. of Stag Cap.	0.67	(Duarte & Restuccia, 2017)

Technology

ω_{N_s}	Persistence of Stagnant Technology	0.95	(Liu et al., 2012)
ω_{N_d}	Persistence of Dynamic Technology	0.95	(Liu et al., 2012)
σ_{N_s}	Std. deviation of Stagnant Tech	0.01	(Liu et al., 2012)
σ_{N_d}	Std. deviation of DynamicTech	0.01	(Liu et al., 2012)
$b_{0,l}$	Productivity coeff. of Low skill	0.10	Own estimation
$b_{0,h}$	Productivity coeff. of High skill	0.20	Own estimation
$b_{0,a}$	Productivity coeff. of Automation Machine	0.10	Own estimation
$b_{1,l}$	The Kaldor-Verdoorn coeff. of Low skill	0.40	(Storm & Naastepad, 2012)
$b_{1,h}$	The Kaldor-Verdoorn coeff. of High skill	0.40	(Storm & Naastepad, 2012)
$b_{1,a}$	The Kaldor-Verdoorn coeff. of Auto. Mac.	0.40	(Storm & Naastepad, 2012)
$b_{2,l}$	The wage effect coeff. of Low skill	0.29	(Storm & Naastepad, 2012)
$b_{2,h}$	The wage effect coeff. of High skill	0.29	(Storm & Naastepad, 2012)
$b_{3,l}$	The bargaining power coeff. of Low skill	0.16	(Storm & Naastepad, 2012), (Acikgoz & Kaymak, 2011)
$b_{3,h}$	The bargaining power coeff. of High skill	0.16	(Storm & Naastepad, 2012), (Acikgoz & Kaymak, 2011)
$z_{s,l}$	The bargaining power of Low skill in Stag.	0.45	(Acikgoz & Kaymak, 2011)
$z_{d,l}$	The bargaining power of Low skill in Dyn.	0.60	(Acikgoz & Kaymak, 2011)
$z_{s,h}$	The bargaining power of High skill in Stag.	0.80	(Acikgoz & Kaymak, 2011)
$z_{d,h}$	The bargaining power of High skill in Dyn.	1.00	(Acikgoz & Kaymak, 2011)

Price

ϕ_s	The probability of sticky price in Stag. Sec.	0.78	(Galesi & Rachedi, 2016)
ϕ_d	The probability of sticky price in Dyn. Sec	0.37	(Galesi & Rachedi, 2016)

Wage

$\alpha_{0,l}$	Wage increase coeff. of Low skill.	1.000	Own estimation
$\alpha_{0,h}$	Wage increase coeff. of High skill.	1.003	Own estimation
α_1	Unemployment impact coeff for wage	0.010	Own estimation

α_2	Productivity impact coeff for wage	0.010	Own estimation
α_3	The bargaining power coeff for wage	0.010	Own estimation

Interest rate and Capital

\bar{i}	Steady-state interest rate	0.04	(Woodford, 2001)
$\omega_{\bar{i}}$	Interest rate smoothing parameter	0.95	(Lin & Weise, 2017)
$\sigma_{\bar{i}}$	Std. deviation of Interest rate	0.01	(Lin & Weise, 2017)
θ_{τ}	Monetary policy rule for inflation	2.50	(Woodford, 2001)
τ	Steady-state inflation rate	0.03	(Lin & Weise, 2017)
δ_a	Steady-state depreciation rate of Auto. Mac.	0.10	(Gomme & Lkhagvasuren, 2012), (Gomme & Rupert, 2007)
δ_k	Steady-state depreciation rate of Capital	0.03	(Gomme & Lkhagvasuren, 2012), (Gomme & Rupert, 2007)
ω_{δ_a}	Persistence of Auto. Mac. depp. Rate	0.95	(Lin & Weise, 2017)
ω_{δ_k}	Persistence of Capital depp. Rate	0.95	(Lin & Weise, 2017)
σ_{δ_a}	Std. deviation of depp. rate of Auto. Mac.	0.01	(Lin & Weise, 2017)
σ_{δ_k}	Std. deviation of depp. rate of Capital	0.01	(Lin & Weise, 2017)

The Capital Stock

χ_a	Steady-state MEI for Auto. Mac.	0.45	(Lin & Weise, 2017)
χ_k	Steady-state MEI for Capital	0.90	(Lin & Weise, 2017)
ω_{χ_a}	Persistence of Auto. Mac. MEI	0.95	(Lin & Weise, 2017)
ω_{χ_k}	Persistence of Capital MEI	0.95	(Lin & Weise, 2017)
σ_{δ_a}	Std. deviation of MEI of Auto. Mac.	0.01	(Lin & Weise, 2017)
σ_{δ_k}	Std. deviation of MEI of Capital	0.01	(Lin & Weise, 2017)

Consumption

η_C	The share of Dyn. Prod. In Consumption	0.52	Own estimation
ν_C	Elas. of subs. of Consumption	0.45	Own estimation
ψ_l	The saving propensity of Low skill	0.00	Own estimation
ψ_h	The saving propensity of High skill	0.00	Own estimation
ψ_{co}	The saving propensity of Capital Owners	0.30	Own estimation

Investment

Ω_{0,K_d}	The Animal spirit coeff. for Dyn Capital Inv	0.10	Own estimation
Ω_{0,K_s}	The Animal spirit coeff. for Stag Capital Inv	0.10	Own estimation
$\Omega_{0,A}$	The Animal spirit coeff. for Auto. Mac Inv	0.10	Own estimation
Ω_{1,K_d}	The profit share coeff. for Dyn Capital Inv	0.48	(Storm & Naastepad, 2012)
Ω_{1,K_s}	The profit share coeff. for Stag Capital Inv	0.48	(Storm & Naastepad, 2012)
$\Omega_{1,A}$	The profit share coeff. for Auto. Mac Inv	0.48	(Storm & Naastepad, 2012)
Ω_{2,K_d}	The Agg. demand coeff. for Dyn Capital Inv	0.12	(Storm & Naastepad, 2012)
Ω_{2,K_s}	The Agg demand coeff. for Stag Capital Inv	0.12	(Storm & Naastepad, 2012)
$\Omega_{2,A}$	The Agg. demand coeff. for Auto. Mac Inv	0.12	(Storm & Naastepad, 2012)
Ω_{3,K_d}	The int. rate coeff. for Dyn Capital Inv	0.30	Own estimation
Ω_{3,K_s}	The int. rate coeff. for Stag Capital Inv	0.30	Own estimation
$\Omega_{3,A}$	The int. rate coeff. for Auto. Mac Inv	0.30	Own estimation

η_I	The share of Dyn. Prod. in Investment	0.54	Own estimation
ν_I	Elas. of subs. of Investment	0.59	Own estimation

Growth

g_{χ_a}	Growth of MEI of Auto. Mac.	0.01	Own estimation
g_{χ_k}	Growth of MEI of Capital	0.01	Own estimation
g_{δ_a}	Growth of depp. rate of Auto. Mac.	0.01	Own estimation
g_{δ_k}	Growth of depp. rate of Capital	0.01	Own estimation
$g_{(L,H)}$	Growth of low and high skill labour	0.01	(Acemoglu & Guerrieri, 2006)
g_{N_s}	Growth of Stagnant Tech	0.005	(Acemoglu & Guerrieri, 2006)
g_{N_d}	Growth of Dynamic Tec	0.02	(Acemoglu & Guerrieri, 2006)

6.2.2 Calibration

Due to nature of the optimization, it is necessary to adjust some of the parameters of the VENSIM model. Overall, the majority of the calibration target is achieved. Every time step in the model equals to one business quarter. Since the model starts in 1980, it runs for 100 time steps which equals to 25 years.

6.3 The Sort Run

The short run focuses the impact of automation until 2025. Therefore, several scenarios will be analysed based on different pace of automation until 2025. These scenarios, which vary based on the change of autonomous investment decisions and the replacement of low skill labour with automation machine in the production process, are listed in Table III.5.

Table III.5 Automation Pace Scenario List

Autonomous Investment Pace	Low skill and Automation Machine Replacement Pace		
	No Replacement	Medium Replacement	High Replacement
	$\Phi_x = 0.5$	$\Phi_x = 0.75$	$\Phi_x = 1.00$
0% A_a	<i>Base Case-Scenario A1</i>	<i>Scenario A2</i>	<i>Scenario A3</i>
+5% A_a	<i>Scenario B1</i>	<i>Scenario B2</i>	<i>Scenario B3</i>
+10% A_a	<i>Scenario C1</i>	<i>Scenario C2</i>	<i>Scenario C3</i>
+25% A_a	<i>Scenario D1</i>	<i>Scenario D2</i>	<i>Scenario D3</i>

If the 100th time step of calibrated VENSIM model is taken as the starting time, the calibrated simulation model is required to run additional 80 time steps to project the impact of various automation pace scenarios.

6.3.1 Base Case

In the base case, the scenario A1, it is assumed that the low skill labour and automation machine replacement pace and autonomous investment pace for automation machine is stable. As a result, the share of automation machine Φ_x equals to 0.5, while Autonomous investment of automation machine A_a does not increase. Table III.6 shows that the growth of GDP is 3.5% in average which is calculated based on the percentage change of quarter 4 one year ago. On the other hand, when the average value of GDP is calculated based on the percentage change from the previous quarter, it is found that it equals to 0.8%. The average growth of the dynamic final products equals to 3.6%, while the average growth of the stagnant final products is 2.6%. However, it can be seen from Table III.6 that the growth of the dynamic final products are more volatile compared to the stagnant final products. It ranges between 0.8% and 8%.

In terms of unemployment, high skill labour faces 3.2% average from 2005 till 2025 while the average unemployment of low skill labour equals to 8.5%. On the one hand, majority of the employment opportunities will be created in the stagnant sector for both high skill and low skill labour. On the other hand, there will be 2.2% average decline in the growth of high skill labour employment in the dynamic sector between 2018 and 2025. The average consumption growth of the stagnant and dynamic final products equal to 2.6%. However, the growth of the stagnant final product will be more volatile.

The relative price between stagnant final product and dynamic product, on the other hand, grows when the growth of the stagnant output is less than dynamic output. It grows 1.5% in average from 2005 until 2025. Finally, the profit share equals to 43% in average. However, It starts to show an upward trend and reach 45-46% after the 2020.

Table III.6 Macroeconomic indicators in the Base Case Scenario

Year	GDP_t^*	S_t^*	D_t^*	$L_{S,t}^*$	$L_{D,t}^*$	$H_{S,t}^*$	$H_{D,t}^*$	$U_{L,t}$	$U_{H,t}$	$C_{S,t}^*$	$C_{D,t}^*$	$I_{S,t}^*$	$I_{D,t}^*$	$P_{R,t}^*$	$\frac{V}{W}$	π
2006	3.2	2.4	1.2	0.6	-0.7	3.2	1.5	12.0	4.3	7.5	2.9	1.3	-2.4	-5.7	2.20	0.40
2007	4.1	0.1	5.5	0.5	0.9	1.2	2.6	12.5	4.1	-4.6	2.4	5.3	12.8	14.1	2.24	0.43
2008	2.2	2.8	1.9	4.1	-0.7	1.4	1.7	11.0	4.0	4.5	2.4	0.5	-0.9	-2.3	2.27	0.42
2009	6.1	1.4	3.9	1.0	-0.9	0.4	1.4	11.5	4.8	1.8	3.9	5.2	7.8	5.7	2.31	0.44
2010	-0.1	2.9	1.3	-2.8	-1.0	3.0	2.5	14.7	3.4	4.0	0.5	1.0	-2.5	-5.5	2.35	0.42
2011	0.6	3.1	2.4	1.4	0.0	2.1	1.7	14.8	2.9	1.6	1.0	6.2	4.9	-0.6	2.39	0.41
2012	5.3	2.5	2.9	4.0	-0.3	1.5	2.0	13.2	2.7	3.9	3.6	0.7	1.3	1.3	2.43	0.42
2013	0.9	1.0	2.1	2.4	-0.9	1.5	1.1	12.8	2.7	2.0	0.9	4.5	2.9	-1.5	2.57	0.41
2014	3.8	2.4	3.8	2.1	-2.0	1.4	1.0	12.7	2.8	-0.6	2.1	-3.3	0.5	5.9	2.51	0.43
2015	5.3	2.8	2.4	4.9	-1.1	1.7	0.6	10.5	2.8	4.7	4.9	12.7	12.5	2.5	2.55	0.44
2016	5.6	2.7	5.9	3.6	-1.0	1.6	0.6	9.1	2.9	1.1	3.7	3.4	6.8	6.4	2.58	0.45
2017	3.4	3.6	6.3	5.0	0.3	1.7	1.1	6.5	2.7	6.7	4.3	4.5	2.6	-2.1	2.62	0.41
2018	1.9	2.7	0.8	4.4	-2.8	1.4	-1.4	4.7	3.4	1.2	0.8	-0.8	-0.9	-0.4	2.65	0.43
2019	3.8	2.9	5.3	4.2	-2.9	3.0	-1.0	2.9	2.9	4.1	2.9	11.2	9.2	-0.9	2.68	0.41
2020	1.1	3.4	2.7	2.3	-4.8	2.7	-2.8	2.9	2.9	1.7	0.9	-3.1	-3.4	-1.1	2.70	0.42
2021	7.1	1.5	5.3	1.0	2.2	1.9	-1.0	2.9	3.0	0.5	3.6	9.5	13.0	7.2	2.73	0.45
2022	3.9	2.4	5.1	-1.9	4.9	2.6	-3.2	5.0	3.1	4.8	3.4	3.7	2.7	-1.0	2.75	0.42
2023	1.5	4.8	3.2	4.1	-1.2	2.4	-1.5	3.0	2.9	-0.2	1.3	0.0	1.9	3.2	2.78	0.45
2024	0.6	3.4	1.2	2.2	-4.1	2.4	-2.6	3.0	3.0	7.3	1.8	8.6	2.2	-8.5	2.81	0.41
2025	10.7	2.4	8.0	-1.3	8.1	2.4	-2.3	4.1	3.0	-0.3	5.8	4.9	12.8	14.1	2.83	0.46

* indicates percentage change from Quarter one year ago. Therefore it shows percentage change in from Quarter 4 in 2005 till quarter 4 in 2025.

Other variables represent quarter 4 value of respective year.

6.3.2 Economic Growth

It is argued by many researchers that automation and digitalization will have a positive impact on economic growth and productivity. The findings of this study verify these arguments. As shown in Figure 6.1, Automation and digitalization with high replacement rate may provide an additional 8% GDP growth compared to the base case scenario. It is also illustrated that the scenarios with high replacement rate demonstrate higher growth compared scenarios with no replacement. It shows that average growth for high replacement is 3%, which is higher than trend growth (2%), while no replacement scenarios are less than 2% growth in average. One possible explanation is that the replacement of low-skill labour with highly productive automation machine enables to produce more dynamic products in dynamic sector, while idle low skill labour starts to shift stagnant sectors.

This explanation can be verified by the growth in the dynamic products which is shown in Figure 6.2. On the one hand, the high replacement of low skill labour in the dynamic sector boosts the productivity and enables to produce 25% more dynamic products compared to the base case scenario.

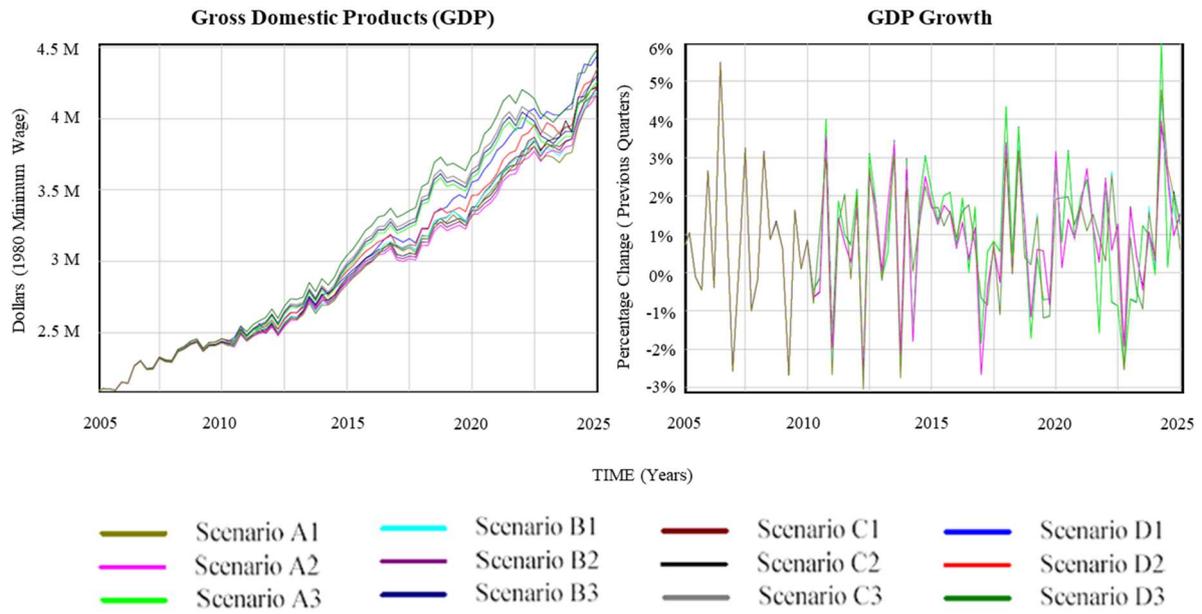


Figure 6.1 GDP Growth

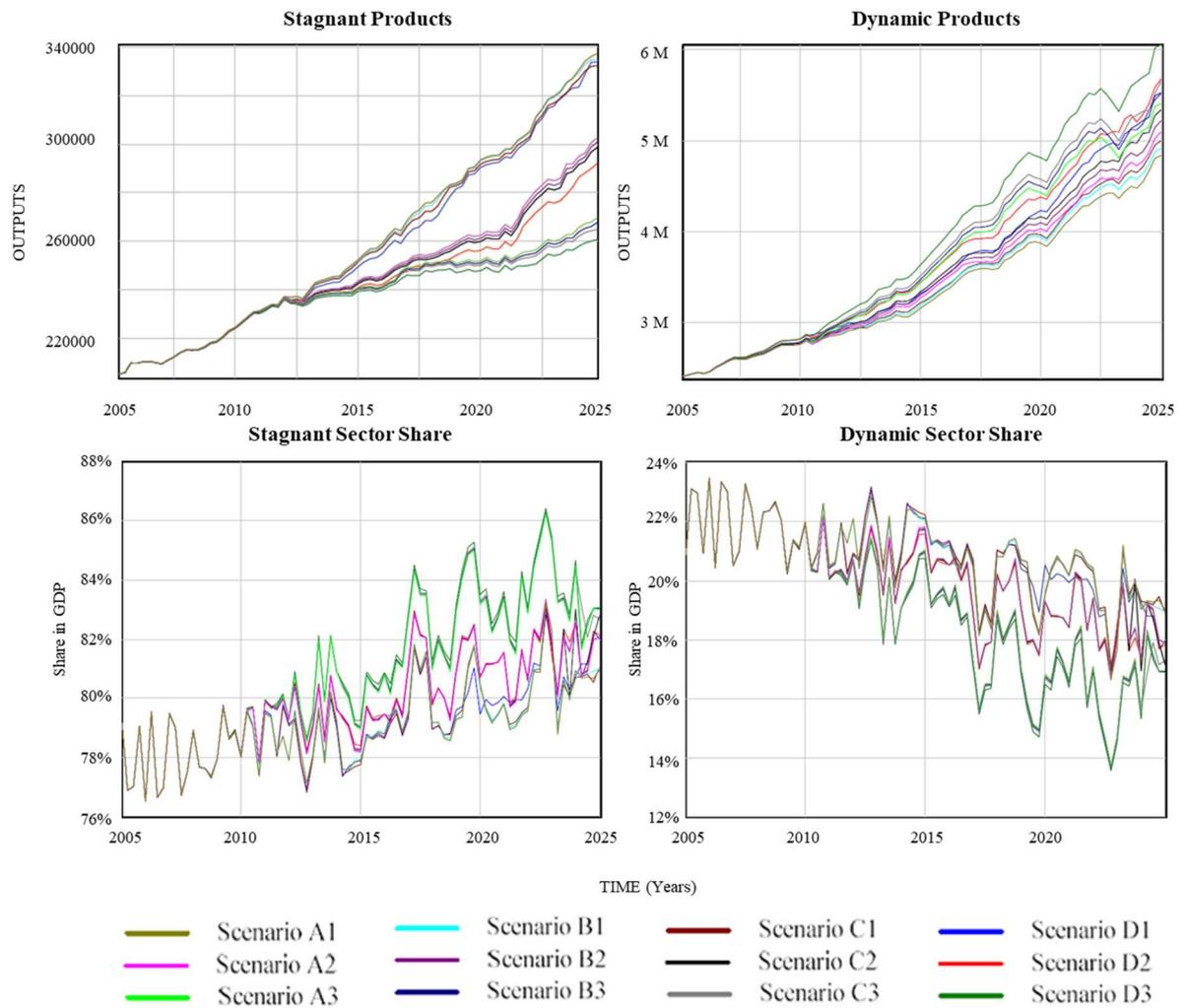


Figure 6.2 Dynamic and Stagnant Sector

On the other hand, this growth in the dynamic sector comes at a price. The final outputs of the stagnant sectors decrease 22% compared to the base case scenario. This result reflects the importance of the demand growth in production. As it is elaborated in section 6.3.3 and 6.3.5, the decline in employment and labour share due to high replacement of low-skill and automation machine results in demand constraint not only for the stagnant products, but also dynamic products.

This argument can be also verified by the share of stagnant and dynamic sector under various low-skill labour and automation machine replacement scenarios. While production quantities in the dynamic sector increases up to 25% compared to the base case, its share declines to 14% of total GDP while it is around 20% for the base case scenario.

In a nutshell, automation and digitalization can increase production by replacing relatively low productive labour with highly productive robots and machines in dynamic sector. However, its productivity is constrained by declining demand in overall.

6.3.3 Employment

The debate on disruptive impact of automation and digitalization has focused on the change on employment. While it is claimed that automation at a high pace will result in a rise in unemployment, it is also argued that productivity growth will boost economic activity and create new job opportunities, especially for high skill labour. However, it is believed that the job creation part will be skill-biased and uneven. In other words, while demand for high skill labour will increase, it is expected that the demand for low skill labour will decline.

The simulation results demonstrate that the pace of the automation will be a major factor to determine the demand for both high skill and low skill labour. Figure 6.3 shows that the demand for high skill labour in the dynamic sector increases up to 42% with high replacement rate compared to the base case scenario. This dramatic change is not only due to automation and digitalization, but also the fact that labour has a greater tendency to shift from the dynamic sector to the stagnant sector due to uneven technological change between dynamic and stagnant sectors.

The demand for high skill labour in stagnant sector, on the other hand, decreases with the increasing pace of replacement between low skill labour and automation machine. The main reason for this trend is that the demand for stagnant products decreases due to declining employment in the dynamic sector. The decline in demand of high skill labour in stagnant sector is around 16% compared to base case scenario.

The demand for low skill workers in the dynamic sector declined in general. However, its magnitude depends on the pace of automation. A high replacement rate of low skill labour with automation machine can accelerate the shift from the dynamic sector to the stagnant sector. The demand for low skill labour in the stagnant sector has similarities with the demand for the high skill labour in the stagnant sector. It can be seen in Figure 6.3 that the magnitude of decline in the demand of low skill labour in stagnant sector increases in parallel with the replacement rate.

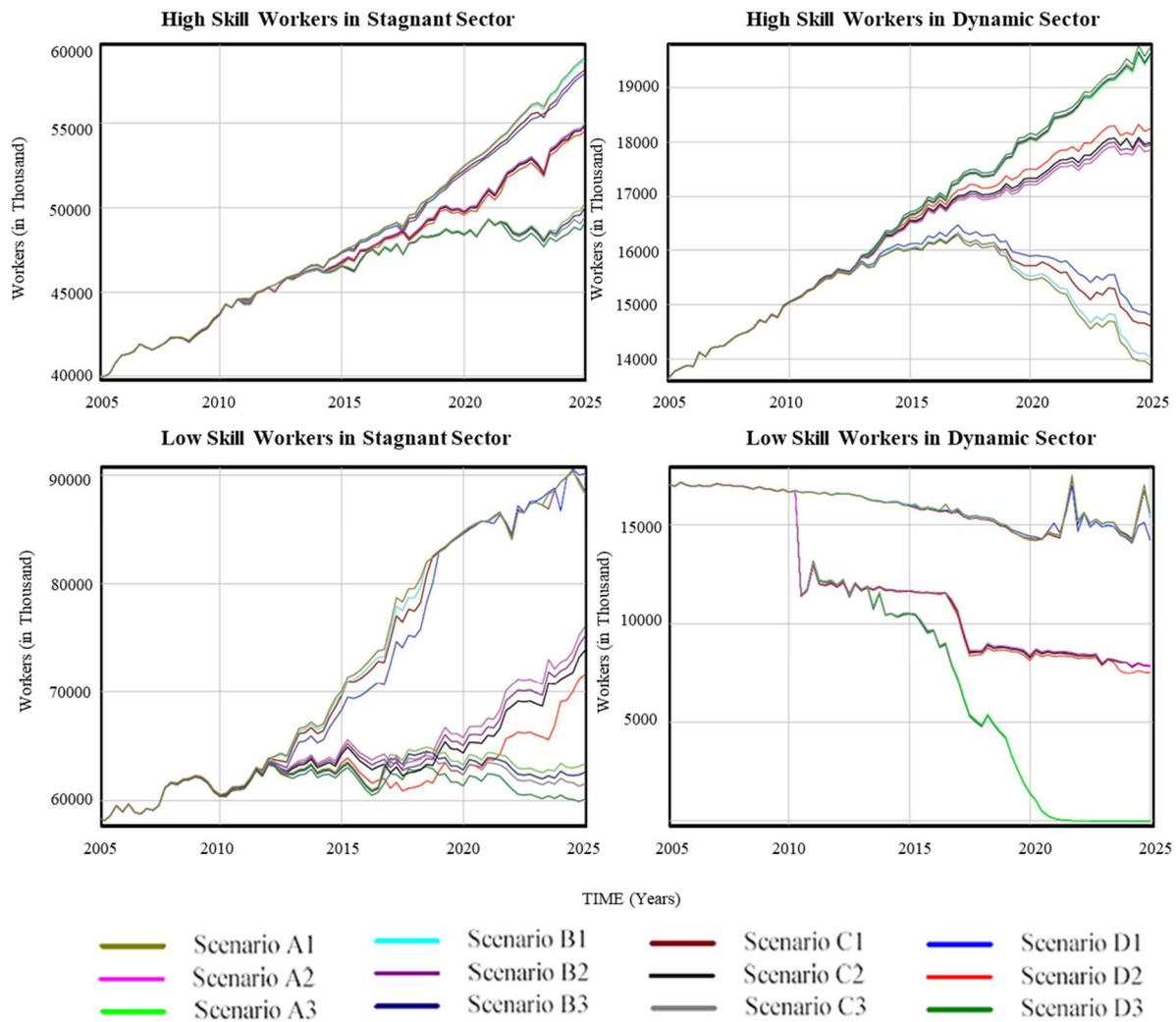


Figure 6.3 Employment in The Dynamic and The Stagnant Sector

As a result, the unemployment rate of the low skill labour increases in parallel with the pace of automation. Figure 6.4 shows that the unemployment rate might rise to more than 40% until 2025 in the case of high replacement rate. The medium replacement rate might result in around 25%. The high skill unemployment rate, on the other hand, remain around 3% for the no replacement and medium replacement scenarios. However, it may reach around 8% in the case of high replacement between low skill and automaton machine in the dynamic sector.

In conclusion, the simulations results confirm the claims that automation and digitalization will cause a rise in unemployment. Although it brings various job opportunities for high skill workers, it will disrupt the available jobs for low skill workers. The general unemployment rate can reach around 30% in the case of high replacement rate.

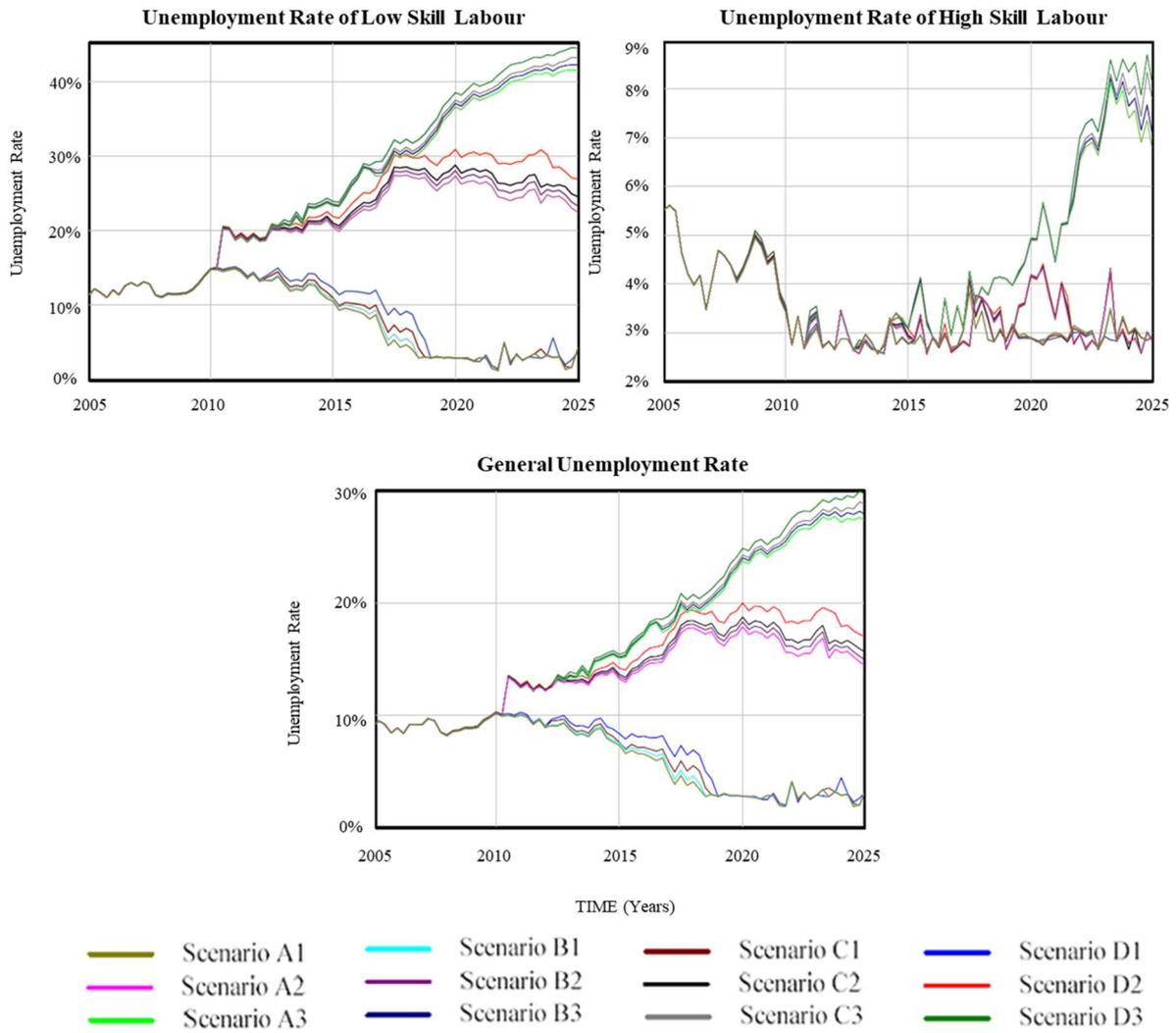


Figure 6.4 Sectoral and General Unemployment Rate

6.3.4 Income Share

It is debated that income inequality will rise in parallel with automation. As it is discussed in Chapter 3, income inequality has worsened since the 1980's. Figure 6.5 illustrates that income share of profit earners will rise from 42% to 46%, while labour share of income will decrease from 58% to 54%.

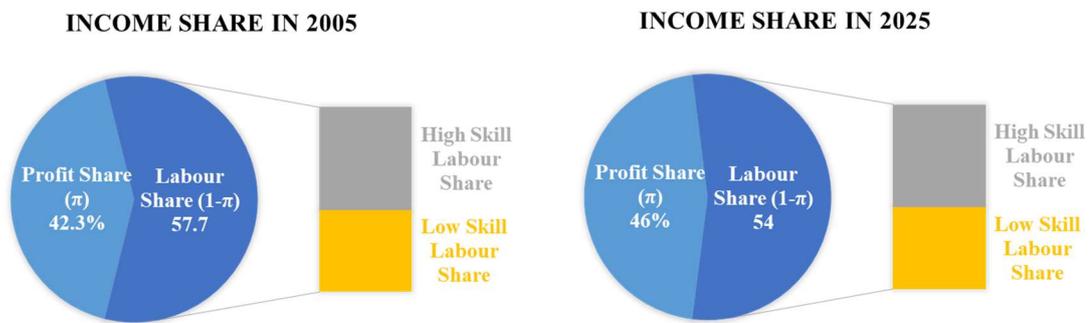


Figure 6.5 Income Share

In the sectorial level, the profit share in dynamic sector increases in parallel with automation and capital deepening. As a result of unbalanced growth in technology and capital deepening in the dynamic sector, labour force starts to shift to stagnant sector. This mechanism leads to a rise in profit share in the dynamic sector. The profit share in the dynamic sector can reach 55% in the case of high replacement rate. Low skill income share in dynamic sector has been declined based on the magnitude of replacement rate between low skill labour and automation machine. It might result in 0% in the case of high replacement rate.

The profit share in the stagnant sector, on the other hand, might increase and reach around 44%. The income share of low skill labour can be around 27% while the income share of high skill labour might be around 29% in stagnant sector.

In sum, the labour share declines. This trend might be worsened by the pace of automation and digitalization process.

6.3.5 Aggregate Demand

Automation and digitalization are expected to boost the economic growth. However, it is argued that the lack of aggregate demand growth will be one of the major constraints on sustaining this growth. In this chapter, the growth of the aggregate demand is analysed under two sub-sections as it is addressed in section 5.3.6. These sections are the consumption growth and investment growth.

6.3.5.1 Consumption Growth

The consumption growth is a function of labour share of income and unemployment. While it increases in parallel with rise of labour share of income, the unemployment rate has negative impact on it. As a result it has declined to 3% on average since the 1980's (U.S. Bureau of Economic Analysis, 2018b). Based on the results of section 6.3.4, one can assume that the consumption growth will continue to decline. The magnitude of the decline might be larger than expected based on the rise of the unemployment rate.

The simulation results demonstrate that automation and digitalization, regardless the pace of replacement between low skill labour and automation machine, will affect the consumption growth negatively as shown in Figure 6.6. The results of the simulation generally match with the data between 2010-2018 (U.S. Bureau of Economic Analysis, 2018b) for the scenarios with no-replacement rate. However, it can be seen that the consumption growth will be negative in the case of medium pace and high pace of replacement. In other words, households will start to consume less.

In conclusion, households will start to consume less in parallel with increasing pace of automation. As a result, the aggregate demand growth might start to decline.

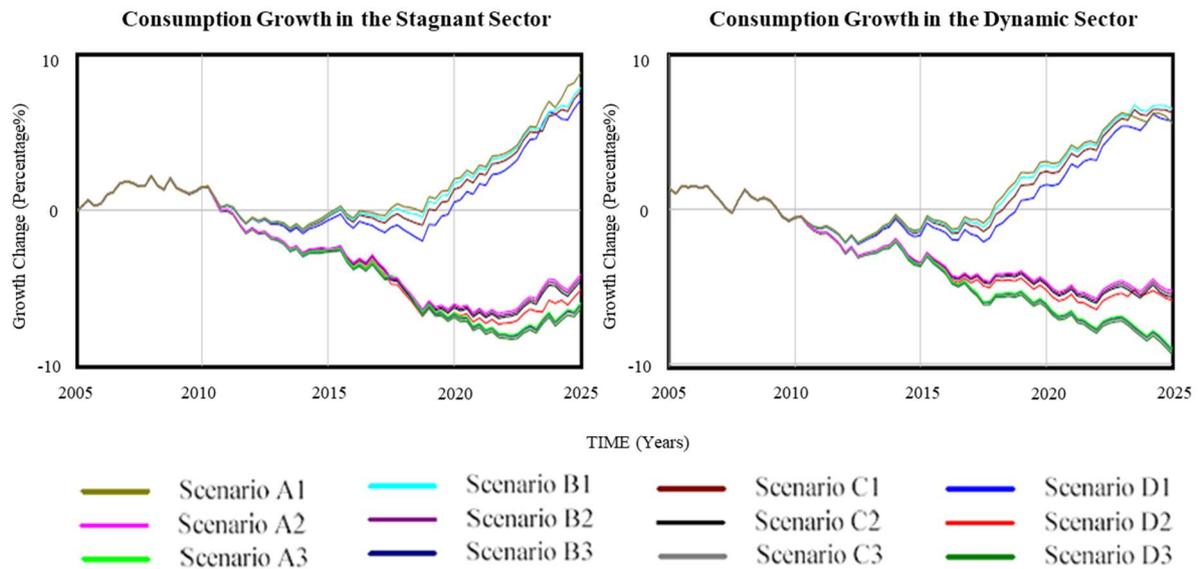


Figure 6.6 Consumption Growth

6.3.5.2 Investment Growth

The investment growth, unlike the consumption growth, is a function of profit share of income interest rate and aggregate demand. While it increases in parallel with the rise of profit share of income, the interest rate has a negative impact on it. The investment growth has been around 10% and comprised around 20% of the GDP since the 1980's. Based on the results of section 6.3.4, one can assume that the investment growth is expected to grow due to the increase of the profit share of income. However, the aggregate demand might play a vital role to determine the investment growth at a later stage.

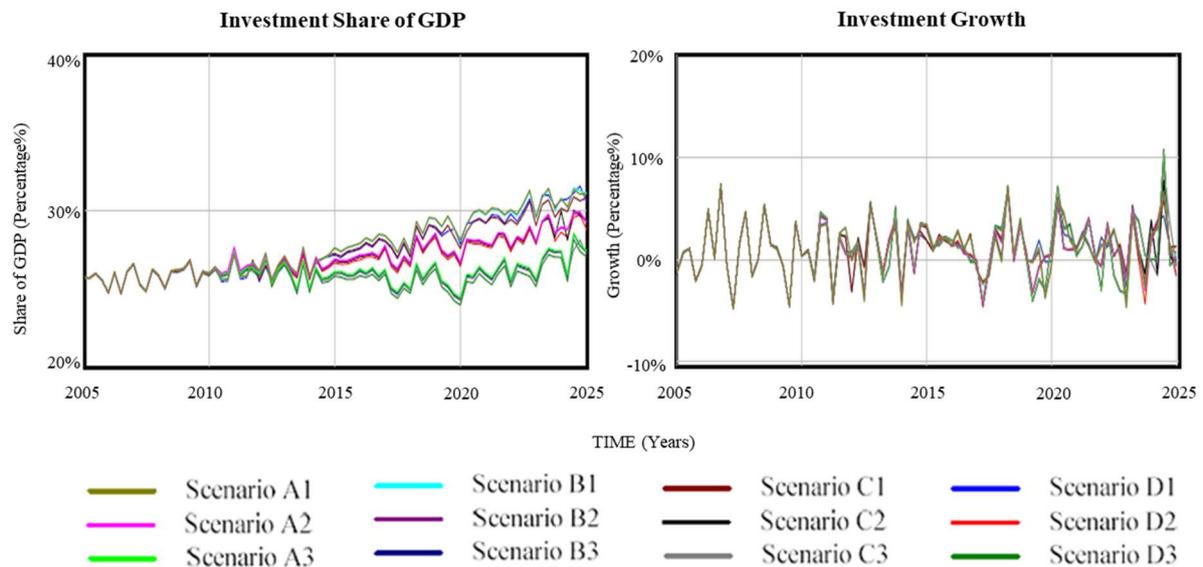


Figure 6.7 Investment Growth

The Figure 6.7 illustrates that the investment share of GDP decreases in parallel with the rise in the replacement of low skill labour with automation machine. While it is more than 30% when there is no

replacement, it declines to 25% in the case of high replacement rate. Nevertheless, the growth rate of the investment is more volatile in the case of high replacement which indicates the role of declining aggregate demand.

Although the trend of both the investment share of GDP and the growth rate of investment is similar to real data in the USA (U.S. Bureau of Economic Analysis, 2018a, 2018c), the share of the investment of GDP has recorded lower than 20% between 2010 and 2018. It implies that in reality, the decline on the aggregate demand had more impact compared to the model. Based on this conclusion, one can argue that the economic growth, which is addressed in the section 6.3.2, could be lower than what the simulation results projected.

In a nutshell, automation and digitalization will affect negatively the growth of aggregate demand. While the decline on consumption growth might be compensated by growth in investment growth, the aggregate demand will eventually decline in the later stage of automation and digitalization.

6.3.6 Capacity Utilization

Capacity utilization is used to measure how much of the full capacity of the production is used. Here, full capacity means using all possible production resources. It can be measured by the ratio of demand and full capacity production. The data shows that the capacity utilization in the USA has been 75% since 2005 (Board of Governors of the Federal Reserve System (US), 2018). As shown in Figure 6.8, the utilization of production capacity decreases in parallel with the rise of replacement rate. In particular, the decline in dynamic sector indicates the fact that the relative growth of output compared to the aggregate demand will be higher in the case of high pace of replacement. While capital owners might ignore this fact in the short term, they can increase their capacity utilization in the long term.

It implies that capital owners or firms will reallocate their production resources in order to increase their profitability and optimize their resource consumption. That might worsen the employment rate both in dynamic and stagnant sectors. Because as owners of capital, they might prefer to minimize their labour force usage while maximizing their capital usage. However, while maximising their profit, capital owners will also consider the price of producing resources. If wages are lower than the rent of the capital, labour force might be chosen as a primary production resource. In the case of low wage, on the other hand, the aggregate demand might decline. Needless to say, both cases will slow down the production and economic growth.

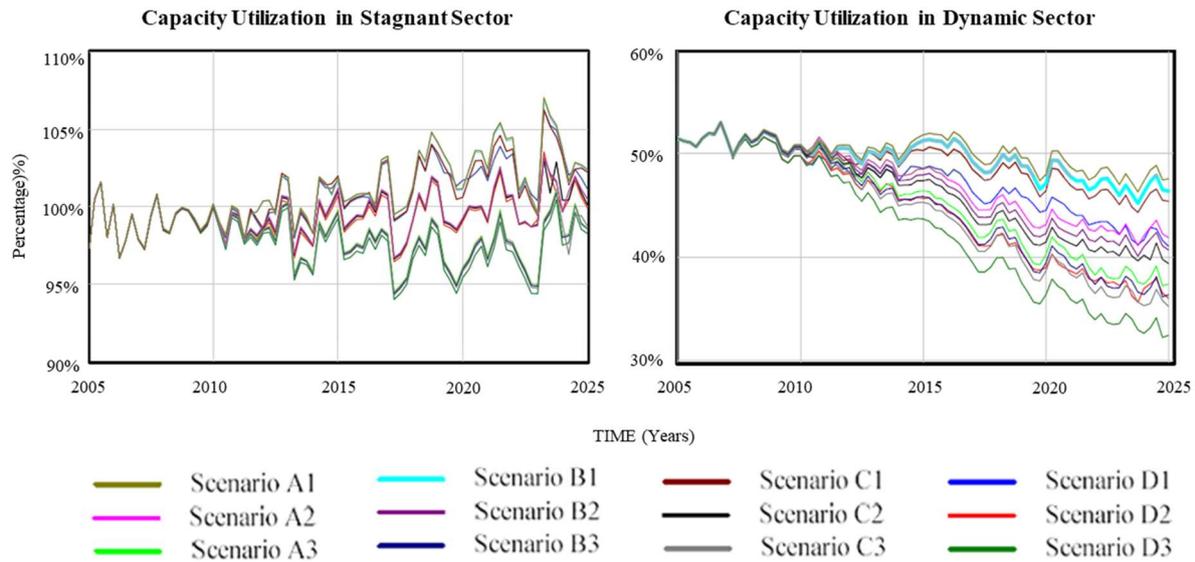


Figure 6.8 Capacity Utilization

6.3.7 Price, Wages and Rent

It is expected that automation and digitalization will decrease the price of the products, while it increases the wages. On the other hand, one can assume that the unemployment rate will be a vital factor on the final level of the wages. Based on the results of the section 6.3.3, it can be argued that the impact of the unemployment on low skill wage will manifest itself compared to high skill wage.

6.3.7.1 Price of Final Products

The argument regarding the price of final products is that it will decrease over time due thanks to decreasing marginal cost and increasing economic of scale. Figure 6.9 demonstrate that both the price of dynamic and stagnant products will decrease in parallel with the rise in the pace of replacement rate. In particular, the decrease on price is more visible on dynamic sector products.

As discussed in section 6.3.2, the scale of production and productivity increase more in dynamic sector than the stagnant sector. This excess in production enables firm owners to produce same product with less resources. As a result, the price of the dynamic products can decrease up to 30%. The decline on the price can be also seen on the aggregate price level in the Figure 6.10. The relative price, on the other hand, might rise around 50% in the case of high pace replacement of robots with low skill labour.

In conclusion, automation and digitalization will lead a fall on the price thanks to increasing productivity and decreasing marginal cost. This fall will be more distinctive in the dynamic sector where automation and technological progress happening. As a result, relative price between the stagnant final products and the final dynamic final product will rise.

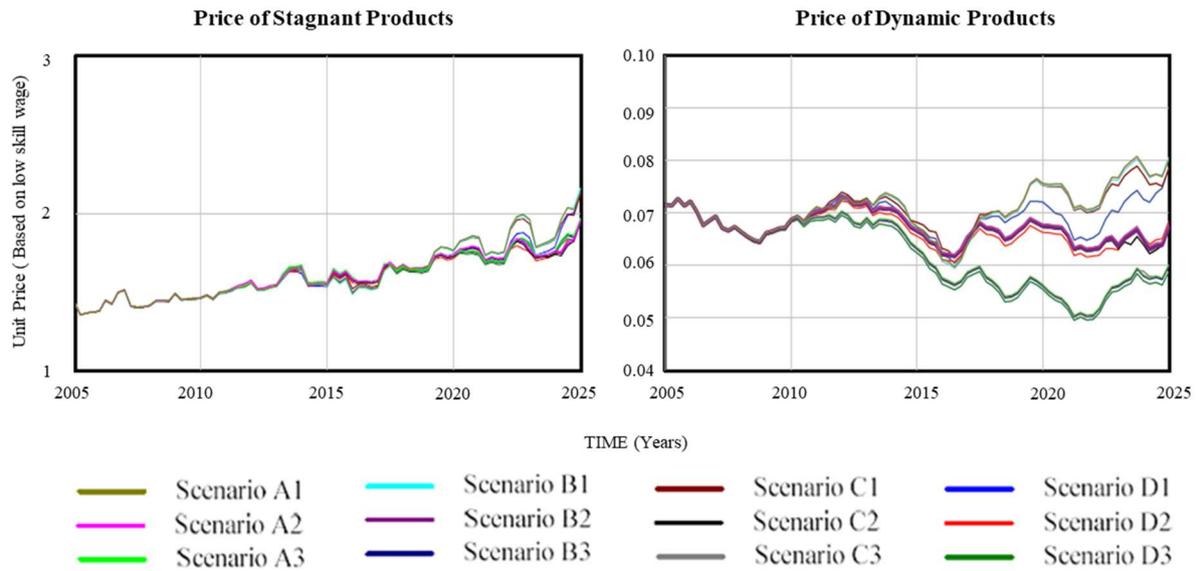


Figure 6.9 Price of Products

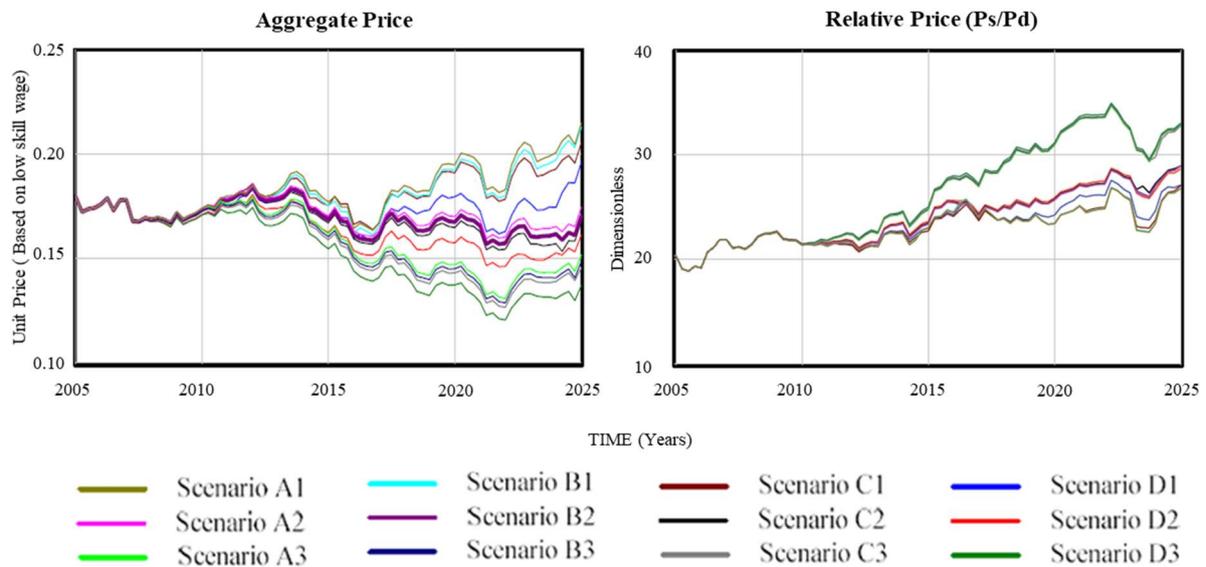
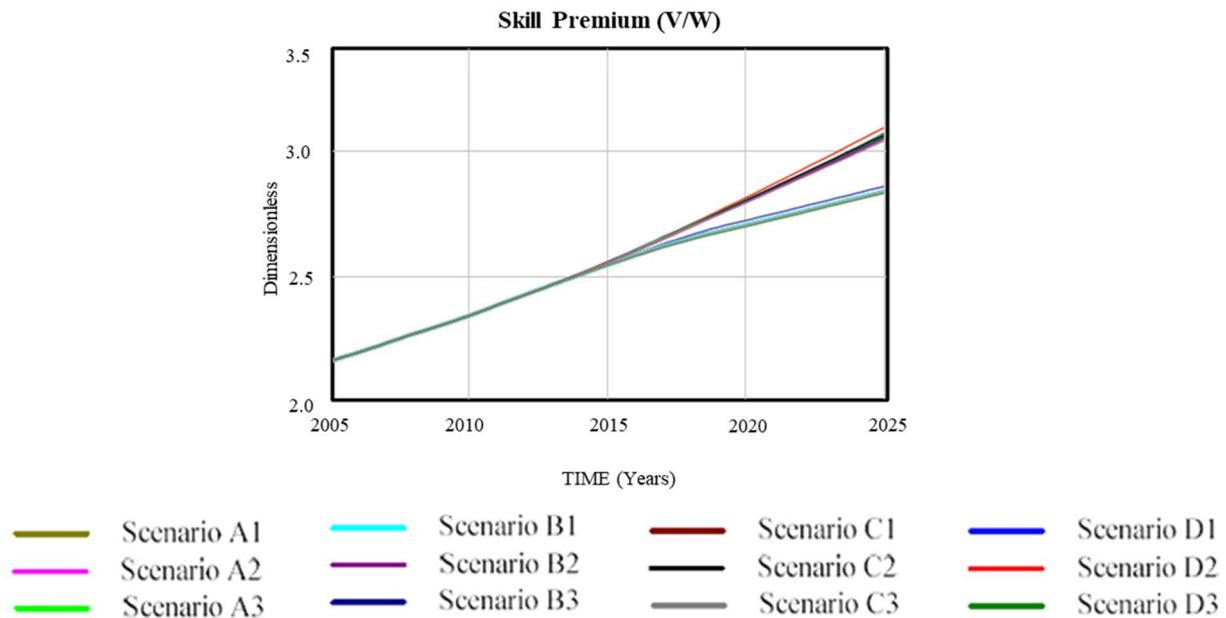


Figure 6.10 Aggregate Price and Relative Price

6.3.7.2 Wage

The impact of automation and digitalization on price of production factors has two major impacts. Firstly, it will determine the level of utilization for every production factor in the long term. Secondly, it will impact income inequality. On the one hand, it is argued that the increasing productivity will push the wage of high skill labour. On the other hand, the rising unemployment will have a negative impact on wage, in particularly wage of low skill labour.

Regardless of the pace of automation, the skill premium increases over time. However, its acceleration rate increases with high pace of replacement rate. It also shows that automation increases the income inequality due to its impact on the skill premium.



Although there is a rise on the skill premium, it is not possible to decompose the main drivers behind of this change based on the results of the simulation. In fact, the simulation model is incapable to capture and the assess the impact of unemployment, productivity and labour unions. However, it is sufficient to show that income inequality will be affected negatively due to automation and digitalization.

6.4 Discussion of Results

This section discusses the preference of initial allocation of production factors, sensitivity of the parameters, and the results of the simulation in section 6.3. It also compares the results with the rest of the literature. For this purpose, section 6.4.1 addresses the structural change and workforce transition along with automation based on the simulation results. Section 6.4.2 discusses the impact of automation on income inequality and growth. Section **Error! Reference source not found.**, on the other hand, evaluates the possible barriers for automation and technological progress. Finally, section 0 focuses the comparison between the result of our simulation and results of other studies, while section 0 explains the sensitivity of initial production factor allocation and parameters.

6.4.1 Automation and Workforce Transition

As it is suggested, automation and digitalization will lead a workforce transition between the dynamic and the stagnant sectors. In fact, the workforce transition takes place even without automation in line with technological advancement of the dynamic sectors compared the stagnant sector. Figure 6.11 illustrates that productivity growth is 3 times higher in the dynamic sector compared to stagnant sector in the base case scenario. Therefore, it is possible to produce final dynamic products with more efficiency. Automation and digitalization, on the other hand, will determine the degree of workforce transition and structural transformation.

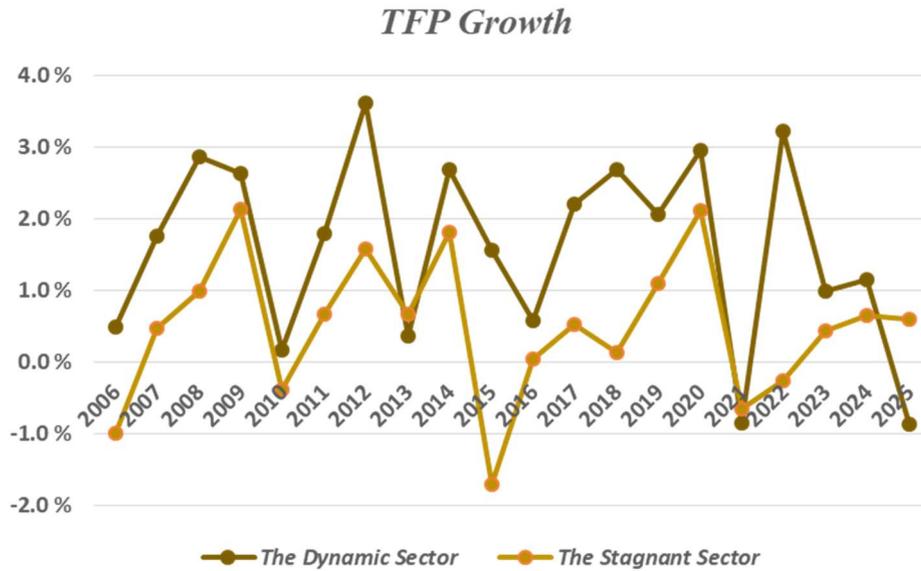


Figure 6.11 TFP Growth

As it is shown in Table III.6 Macroeconomic indicators in the Base Case Scenario both the high skill and low skill employment in the stagnant sector grow around 2% on average annually, while the high skill and low skill employment growths in the dynamic sector equal to 0.1% and -0.4% on average in the base case scenario. On the other hand, when there is a high pace of replacement between automation machine and low skill labour, the growth employment of low skill labour in the dynamic sector decreases sharply (-33% in average), while the employment growth of low skill labour increases around 1% in the dynamic sector. As a result, it can be concluded that automation will aggravate the structural transformation and the workforce transition from the dynamic sector to the stagnant sector.

There is another implication due to the workforce transition and structural change. The simulation result shows that the relative price increases 1.5% on average annually in the base case scenario, while its growth increases in parallel with the pace of automation. In the extreme case (Scenario D3) the growth of the relative price equals to 2.6% on average annually. That implies that the relative cost of stagnant final product consumption increases over time. One explanation of this consequence is that increasing wage in the dynamic sector results in the rise of the production cost of the stagnant sector. Therefore, the simulations result conforms with the “Cost Disease” (Baumol, 1967).

6.4.2 Automation, Income Inequality and Growth

Automation and digitalization will boost the productivity and economic growth. Section 6.3.2 is discussed that there might be additional 8% GDP growth compared to base case scenario if there is a high pace of replacement between automation machine and low skill labour. In fact, the dynamic sector can become 25% more productive in parallel with automation. Automation and digitalization , on the other hand, affects the income inequality negatively. Especially in extreme case (Scenario D3), there is a sharp decline for the employment in the dynamic sector. As a consequence, the profit share in the dynamic sector increases to 55%. On average, the labour share will decline from 60% to 55% if there will be high pace of replacement between automation machine and low skill labour. This result means that income inequality will continue to increase.

In terms of economic growth, such a rise in the profit share will give encourage investment both for automation and traditional capital in the earlier stage of automation and digitalization.. Therefore, one can argue that this additional investment will boost the economic growth. However, the rising income inequality will discourage people to consume. In particular, low skill labour, who has low saving propensity, will be affected by the rising income inequality. As a result, the economic growth might be depressed due to declining consumption growth and demand constraints. The simulation results showed that the consumption growth might decline 10% in the extreme case.

In a nutshell, automation and digitalization will increase productivity and the economic growth. However, it will affect income inequality negatively. Therefore, one can conclude that there will be growth in the short run thanks to automation and digitalization. However, this economic growth will be constrained by the lack of demand and declining consumption growth. In other words, the economic growth might be decline due to increasing income inequality in the long run

6.4.3 Comparison with Other Studies

This section will compare the result of this simulation with the rest of the literature. In general the simulation results echo the findings of other studies such as Acemoglu & Restrepo (2016, 2017b), Hémous and Olsen (2018), Lin & Weise (2017), and Pretner (2016) in terms of the economic growth and the productivity gains. In addition, income inequality increases in the studies of Acemoglu & Restrepo (2016, 2017b), Hémous and Olsen (2018) as it does in this research

However, the result of this study show differences in terms of structural change. This study found that, there will be a shift from dynamic sector to stagnant sector due to technological change and automation. Acemoglu & Restrepo (2016, 2017b), on the other hand argued that the economic growth will follow a balanced path. Their argument is that there is a balancing power which mitigate the structural change and unbalanced growth. They stated that the creating of new job and task will be labour biased. In other words, new tasks or routines cannot be executed by automation machine. As a result, there won't be a drastic change and workforce transition from dynamic sector to stagnant sector. Hémous and Olsen (2018), on the other hand, found a similar outcome to ours. They stated that the economic growth will be unbalanced due to the rising skill premium and the declining labour share.

6.4.4 Discussion of Initial Preferences and Sensitivity of Parameters

As it is addressed in the section 6.2, the parameters and initial values are adjusted to match historical macroeconomic trend with the result of our simulation between 1980 and 2005. It is also required to conduct a sensitivity analysis to understand how much the result will change if the underlying assumption of in section 6.2. To identify the parameters which are sensitive to change, the assumptions, which are made for optimization parameters and initial production factor allocation, are analysed. The main reason for this approach is that, such a small change in the optimization parameters can lead a volatility for the main macroeconomic trends.

During the calibration process, it is found that there two main channels which lead volatility and crush for simulation. The first channel is the allocation of production factors at the beginning of the simulation. The allocation of resources and price is used to determine the final products and income distribution. If the parameters of production function are not adjusted, it causes a significant change between the initial

value of production resource allocation and the allocation on the second time step. This volatility may end up a model crash if the initial values are not big enough. The second channel is related the optimization functions parameters. In particular, the productivity and wage functions affect the optimization process significantly. In a setting in which production factors are volatile, optimized variables will follow similar patterns in the following time steps. As a result, a systematic failure and simulation crash may occur. For instance, if the change on the unemployment is radical, the wage and productivity might be influenced significantly. To fix this problem, several variables are imposed a static behaviour by changing the optimization problem.

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Endogenous Technological Change and Macroeconomic Policies

This section aims to extend the dynamic model which is introduced in chapter 5. For this purpose, section 5.1 expands the model by endogenizing technological change. Section 5.2 identifies Fiscal policies, while section 5.3 focuses on Monetary Policies. Finally, section 7.4 summarizes the chapter.

7.1 Endogenized Technological Change

Endogenized Technological Change is a relatively a new development in the field of economics. Contrary to neoclassical growth model of Solow, it can explain the factors that influence long-term economic growth (Gancia & Zilibotti, 2005). Romer (1990) developed a new model for growth and technological change by taking the monopolistic competition framework of Dixit and Stiglitz (1977). There are mainly two approaches in terms of innovation. While vertical innovation replaces the vintage product with a new one and increases productivity, Romer's model increases the variety of the product which can be considered as horizontal innovation. The distinctive characteristic of this type of innovation it does not replace old existing methods.

Romer (1990) also introduced an R&D sector which produces technology and blueprints for new inputs and product variety. He assumed that production of variety or input is risky and a costly process. Every new type of product has a possibility of failing and incurring sunk costs. Here the sunk cost can be thought of as a research expense. It occurs only once while the new type of products is introduced. As a result, the product markets, where the product variety increases, become monopolistic rather than competitive. Each firm that developed a new type of product in the production line is granted with the perpetual right to produce and make profit. Technological change takes place when the new type of products and blueprints accumulates in this scope. In the rest of this section, technological change is decomposed as horizontal innovation and the automation of tasks. While horizontal innovation increases the product variety, automation of tasks studies the process of automation.

7.1.1 Horizontal Innovation

Following Jones (1995; 2013), new intermediate inputs and blueprints are developed by high skill labour which utilizes previous stock of blueprints or intermediate inputs. It is assumed that the rate which high skill labour invent a blueprint is a function of blueprints in the economy. However, it might be also possible that the most obvious blueprints have been invented. Therefore the possibility to find a new blueprint decreases in parallel with the stock level of accumulated blueprints. Besides, there is also a possibility of duplication and overlap between new blueprints. That mechanism impacts the accumulation process of blueprints negatively. Therefore, the stock of the intermediate inputs accumulate according to:

$$\widehat{N}_u = g_{n,u} N_u^{\mu_{1,u}} h_{N_u}^{\mu_{2,u}} \quad (7.76)$$

In the equation 7.76, $\mu_1 < 0$ correspond the case which Jones (1995) refers as “*fishing out*”. In other words, the rate of horizontal innovation decreases as a result of the rise in the level of knowledge. $\mu_1 = 0$ indicates that the innovation process is not related with previous innovations. Finally, $\mu_1 = 1$ refers the case which there is an increasing returns to scale with previous innovations. In his study, Romer (1990) assumed that $\mu_1 = 1$. In this research, it is taken as follows:

$$\mu_1 < 1 \quad (7.77)$$

The parameter μ_2 , on the other hand, symbolizes the duplication and overlap of research activities which are conducted by high skill labour. Therefore, it is assumed that:

$$0 < \mu_2 \leq 1 \quad (7.78)$$

7.1.2 Automation of Tasks

Following Hémous and Olsen (2018), it is assumed that intermediate firms, which operate in dynamic sectors, can hire high skill labour to invent methods for automation of tasks. As a result, automation of a specific task evolves with a poisson process according to:

$$\Phi_{A,t} = g_A \Phi_{A,t-1}^{\mu_A} (N_{d,t} h_A(i))^{\mu_A} \quad (7.79)$$

$g_A > 0$ refers to productivity of automation technology, while $\Phi_{A,t-1}^{\mu_A}$ represent the knowledge spillovers of automated technology. Finally, $N_{d,t}$ represents the knowledge spillovers of the increasing variety of intermediate products in dynamic sector. It is worth to note that the horizontal innovation can compensate the reduction in the production factors utilization as long as $\Phi_{A,t}$ is stable. That is possible if and only if the new intermediate inputs are born as low skill labour biased.

As a result, horizontal innovation and the pace of automation depends on the allocation of high skill labour between sectors, innovation and automation technology. If equation 5.8 is rewritten again:

$$H = H_s + H_D + H_{N_s} + H_{N_D} + H_A \quad (7.80)$$

7.1.3 Innovation Allocation

Naqvi & Stockhammer (2018) suggested that the firm’s R&D efforts depends on firm’s profitability and economic growth. Therefore, it is assumed that a fraction of intermediate firms’ profits are invested in horizontal innovation and automation research:

$$R\&D_u = \tau_u \prod_{u,t}^n(j) \quad (7.81)$$

Based on the empirica data (OECD, 2019), it is assumed that the fraction in the dynamic sector is higher than the stagnant sectors.

$$1 > \tau_D > \tau_s \geq 0 \quad (7.82)$$

This assumption can be verified by long term the value maximization of firms investment decisions in equilibrium. Let's assume that an intermediate firm wants to maximize its value. Therefore, it needs to make a decision to invest to research activities and have a perpetual right to a new type of intermediate product. It can also invest in bonds which give a return based on the interest rate. The present value of this firm can be written as:

$$V_{N_u,t} = \prod_{u,t}^n(j) + q(i)V_{\hat{N}}\hat{N} - h_{N_u}v + \frac{V_{N_u,t+1}}{1+i_{t+1}} \quad (7.83)$$

This equation indicates that the present value of an intermediate firm equals to the sum of present profits and appreciation in the value of the firm which is calculated by discounted present value. Because it is assumed in chapter 5 that all intermediate firms are identical, their profits are stationary and identical for all intermediate firms. The profits of the intermediate firms, on the other hand, depends on expected gain from horizontal innovation and sunk cost. It is assumed that the possibility in which a research will be successful is $q(i) \in [0, 1]$. Free entry in the intermediate sector for horizontal innovation imposes that profits which are generated by blueprints cannot be more than the sunk cost. The intermediate firms maximize:

$$q(i)V_{\hat{N}}\hat{N} - h_{N_u}v \leq 0 \quad (7.84)$$

The equation 7.84 implies that the sunk cost of developing a new intermediate product increases due to possibility of fail compared to its success as an asset. In other word, sectors which have a high possibility of failure face much higher sunk costs. As a result, these sectors will be less willing to invest in R&D. Stagnant sectors such as healthcare have faced a relatively high sunk cost and less productivity gain in the USA (David, Tramontin, & Zemmell, 2010).

7.2 Fiscal Policies

Fiscal policies are policy instruments of government to control and manipulate the national economy. According to Keynes (1936), a change in the fiscal spending can affect the level of aggregate demand and overall economic activity. Especially, taxes on high income groups and taxes on capital and rent gains may impact aggregate demand positively. Therefore, fiscal policies can be used to stabilize the economy, increase the income distribution and increase aggregate demand. There are three distinctive stances for the government fiscal policies based on the public consumption and taxes (Giannoulakis, 2017). These stances are listed as follows:

- **Neutral fiscal policy** is the fiscal policy stance when the economy does not face any recession or boom (Giannoulakis, 2017). The spending of the government is balanced by tax revenue. Besides, the outcome of this kind of stance does not have any impact on overall economic activity.
- **Expansionary fiscal policy** is generally undertaken when there is a recession in the economy (Giannoulakis, 2017). The government spending exceeds the tax revenue in order to boost the economic activity. As a result, they are also called as reflationary fiscal policy.
- **Contractionary fiscal policy** is generally undertaken to pay back government debts (Giannoulakis, 2017). The government spending is lower than tax revenue.

There are several ways to fund government spending such as taxation and issuing Government bonds. To keep the analysis simple, this study focuses only on taxation. Direct and indirect taxes are two main taxation methods. The burden of indirect taxes is generally passed on to consumers. However, taxes on income and capital gains can impact income distribution positively. Therefore, this study focuses on direct taxes.

7.2.1 Government revenues

In the scope of this study, government revenues come from income tax and robots. The income tax is part of the direct taxes. It applies to all low skill household, high skill household and capital owners. A fraction of their income is taken by government to fund the government spending. The robot tax, on the other hand, is the part of the debate for how the government takes precaution in order to manage the automation age (Guerreiro et al., 2017). Therefore, the total revenue of the government can be written as follows:

$$G_{Revenue} = t_{CO}[Income_{CO,t} - R_{AA}] + t_L Income_{L,t} + t_H Income_{H,t} + t_A R_{AA} \quad (7.85)$$

In this equation, the parameters t_{CO} , t_L and t_H reflects the respective income tax share. The last part of the equation denotes the tax on the rental income of automation.

7.2.2 Government Spending

The government spending includes a wide range of activities such as education, healthcare, infrastructure, military and research purpose. The government might provide transfers to low income group in order to minimize inequality. Therefore, the total spending of the government can be written as follows:

$$G_{spendings} = C_G + Income_T \quad (7.86)$$

In this equation, $Income_T$ reflects the income transfer to low income groups which include Low skill household and high skill household. Because it is assumed that all households are identical in terms of their consumption preferences, it does not matter how income transfer allocated among those two skill groups in terms of its impact on aggregate demand. The government consumption, on the other hand, follows similar structure with consumption of household. However, the consumption elasticity and the share of dynamic final goods differs.

Under this configuration, the equations 5.59, 5.60, 5.61 and 5.63 can be written as follows:

$$Net\ Income_{CO,t} = \left[\underbrace{\frac{[(P_{u,t} - Y_u MC_{u,t})Y_t]}{Mark-up\ Profits}}_{Mark-up\ Profits} + \underbrace{\frac{[(1 - \beta_u)Y_u MC_{u,t}Y_t]}{Rental\ Profits\ for\ R_k}}_{Rental\ Profits\ for\ R_k} \right] (1 - t_{CO}) + \underbrace{\left[\beta_u Y_u MC_{u,t} Y_t \left(\gamma_a A_t (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a \alpha A_t + \gamma_{u,l} L_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right]}_{Rental\ Profits\ for\ R_x} (1 - t_A) \quad (7.87)$$

$$Net\ Income_{L,t} = \left[\beta_u Y_u M C_{u,t} Y_t \left(\gamma_{u,l} L_{u,t} (1 - \Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_a \alpha A_t + \gamma_{u,l} L_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right] (1 - t_L) + \Phi_L Income_T \quad (7.88)$$

$$Net\ Income_{H,t} = \left[\beta_u Y_u M C_{u,t} Y_t \left(\gamma_{u,h} (\Phi_u)^{\frac{1}{\epsilon_u}} (\gamma_{u,h} H_{u,t})^{\frac{-1}{\epsilon_u}} M_{u,t}^{\frac{1-\epsilon_u}{\epsilon_u}} \right) \right] * (1 - t_H) + (1 - \Phi_L) Income_T \quad (7.89)$$

and

$$P_{d,t} C_{d,t} + P_{s,t} C_{s,t} \leq Net\ Income_{j,t} (1 - \psi_j) \quad (7.90)$$

7.3 Monetary Policies

Monetary Policies are policy instruments of central banks to control a wide variety of macroeconomic indicators such as price level and stability, inflation and currency unemployment rate and growth as discussed chapter 3.

Money supply and interest rate are two main policy instruments which enable central banks to achieve their target in terms of price level, inflation and unemployment. Money supply is a process which enables central banks to manipulate the quantity of the money which circulates in the economy (Mishkin, 2000). Central banks can manage money supply by selling and buying financial instruments such as government bonds and foreign currencies. The interest rate policy instrument, on the other hand, is a tool to manage the rate of interest in order to manipulate the cost of borrowing and lending in the economy (Mishkin, 2000). To keep the analysis simple, this study only focuses on interest rate manipulation. Besides, it is not effective to add money supply without a mechanism which introduces government bonds. A simple interest rate rule is introduced in chapter 5. This section will extend it by following Taylor rule (Woodford, 2001).

In the base model, the nominal interest rate is determined based on the inflation. However, it is not adequate to address manipulate GDP growth and capacity utilization. The capacity utilization is important in terms of manipulating the unemployment rate. The interest rule can be rewritten as follows:

$$\ddot{i}_t = (1 - \omega_i) \ddot{i} + \omega_i \ddot{i}_{t-1} + \theta_\tau (\tau_t - \tau) + \theta_Y (X_t - Y_t) + \sigma_i \varepsilon_{i,t} \quad (7.91)$$

This rule causes a countercyclical monetary policy. When the real inflation rate is more than its target value, central bank increases the interest rate in order to cool down the economic growth and reduce the inflation rate to its target value. When the unemployment rate is high, i.e. when the capacity utilization lower than full employment of production factors, central bank reduces the interest rate in order to boost economic activity.

7.4 Summary

In brief, this chapter extends the basic economic model by introducing endogenized technological change and the macroeconomic policies. Endogenized technological change is modelled in two dimensions in section 7.1. These dimensions are listed as horizontal innovation and automation of tasks. While horizontal innovation increases variety of intermediate inputs to increase scale of final production, automation of task leads replacement of low skill labour with automation machines.

Section 7.2 addresses fiscal policies which are controlled and monitored by government in order to manage economic growth, aggregate demand and income distribution. There are several ways to fund the government spending such as borrowing (government bonds) and taxation. To keep the model simple, only direct tax and robot tax are studied.

Finally, section 7.3 improves the monetary policy which is introduced in chapter 5. To ensure that monetary policy can control inflation rate, price level and unemployment rate, a policy variable, which enables to manipulate capacity utilization, is introduced.

IV

Synthesis: Conclusion and Recommendation

Conclusion and Recommendation

This section synthesises overall findings of research question which is framed in chapter 1 with the methodology which is presented in chapter 2. Chapter 3 and Chapter 4 provides a basis and framework for developing a dynamic economic model to simulate various scenarios to answer the main research question. Chapter 5 develops a dynamic economic model under the assumption of two different schools of economic thoughts. Section 6, on the other hand, explores different scenarios which are based on the various pace of automation. Chapter 7 extends the basic model with endogenous technological change and macroeconomic policy implications. In order to conclude the overall research, section 8.1 answers research questions based on the results from chapter 3 to chapter 7. Section 8.2 provides recommendations based on the conclusion in section 8.1. Section 8.3 presents the limitations of this research and model which has been developed in part III. Finally, section 8.4 focuses reflection about the overall research project.

8.1 Revisiting The Research Question

The debate of the disruptive impact of digitalization has taken the attention of various researchers, policymakers, and society in general. On the one hand, automation and artificial intelligence are expected to be in the centre of future economic growth which has been slowing down since the 2000s. On the other hand, it is expected to cause a rise in income inequality which has been one of the societal challenges, which resulted in disruption of the economy since the 1970s. This research, therefore, has started with an aim to shed light on these disruptive impacts of digitalization and automation on income inequality and macroeconomic indicators. It is feared that the collision of disruptive impacts of digitalization and income inequality may result in an economic recession and stagnation of productivity. In the context of the disruptive impact of automation, several studies focused on the development of economic models to explore various scenarios in the long run. However, these studies generally limited in their scope on productivity gains and advantages of digitalization in the long run. Thus, the main research question is framed as follows:

How can Automation in the short run be framed to explore its impact on income inequality and macroeconomic variables in the multi-actor arena ?

The main research question is broken into seven sub research question. Therefore answering these sub question can lead this study to reach its aim.

What is the impact of deepened income inequality on macroeconomic variables and technological progress?

The first step of this research focuses on the disruptive impact of income inequality on macroeconomic variables to understand the possible collision between automation and income inequality. Therefore, a literature review has been conducted to analyse the impact of income inequality since the 18th century. It can be seen that income inequality has impacted aggregate demand negatively due to increasing rent and price on stagnant products. Due to budget constraints, the demand for the goods of more productive sectors has diminished. As a result, economic growth has stagnated due to demand constraints. To

analyse the main drivers of recent income inequality, a multi-actor scan and policy analysis has been executed. It can be seen that there have been five major actors who influenced the macroeconomic policies and income inequality since the 1970s. These actors listed as Federal Government, Federal Reserve Bank (Central Bank), Labour unions, Firms and Workers for USA. Due to a paradigm shift in macroeconomic policies after 1980s income distribution has been disrupted. Even though the productivity has increased in the 1990s the overall growth has been stagnant since then.

How can technological progress be conceptualised?

After analysing the factor which caused income inequality and its impact on macroeconomic variables, it is required to understand the main dynamic of digitalization and automation. A context study has been conducted to decompose the main elements of technological progress. It is understood that the digitalization and automation share similarities with the previous wave of technological progress. However, there is the difference regarding the pace of transition. Therefore, a framework developed based on the findings of context study. This framework has four dimensions which are shared by all waves of technological progress. These dimensions are listed as follows:

- ***The growth of Productivity*** indicates the growth in production due to a new idea and task creation, labour augmentation, capital augmentation, and capital accumulation.
- ***Structural Transformation*** refers to the shift in the main activity of the economy. There are two different structural transformations which were discussed. Balanced growth presents the growth of production factors based on the Kaldor's fact in a balanced way. The unbalanced growth path refers to the uneven growth of production factors across sectors due to uneven technological change in sectors.
- ***Factor Bias*** indicates the direction which technological progress follow. In other words, technological progress is generally in favour of a specific production factor. These factor biases are as follows:
 - ***Capital Biased***
 - ***Skill-Biased***
 - ***Unskilled-Biased***
- ***Income Inequality*** is the final dimension of this framework. Income inequality occurs due to the reallocation of production factors, structural transformation, and creative destruction.

The findings of the first research subquestion and the framework, which is developed as a part of the second research subquestion, are used to study the impact of automation on macroeconomic indicators in the short run.

How can automation of jobs be framed?

To answer this question, a literature review on the New Keynesian economic models and Neo-Kaleckian economic model have been conducted. The New Keynesian economic models are used to study fiscal policies, monetary policies, and the business cycle. They are effective for the supply side of the economy and optimization in the short run. On the other hand, Neo-Kaleckian economic models are effective to study income distribution, the impact of income inequality on macroeconomic indicators and the demand side of the economy. A two-sector economic model with final and intermediate goods producing firm is introduced. As production factors, low skill labour, high skill labour, traditional capital, and automation machine are used. It is assumed that automation realizes only in the dynamic sector which is progressive in terms of productivity growth. Technological progress along with the price and wage mechanism is introduced in the supply side of the economy. To understand the price mechanism, it is assumed that prices are sticky. In the demand side of the economy, income distribution structure, consumption preferences, investment structure, and growth dynamics are introduced.

What is the impact of automation on income inequality?

As it is suggested by Hémous & Olsen (2018) and Acemoglu & Restrepo (2016), automation and digitalization disrupt income distribution and raise income inequality. There are two channels by which income distribution has affected. The first channel resulted from increasing skill premium. The skill premium increased over time due to an increasing demand for high skill labour, deunitization in stagnant sectors and replacement of low skill labour from highly productive sectors. As a result, the income share is worsened especially for the low skill labour group. The second channel is caused by capital accumulation and automation. Automation and capital accumulation resulted in a rise in profit share in the overall economy. Based on the results, the profit share may reach 58% in 2025 from 54% in 2005. Nevertheless, while automation replaces the low skill labour from the dynamic sector and causes a shift to stagnant sectors, technological progress leads an overall decrease in human capital in the dynamic sector. As a result of unbalanced growth, more production factors have been deployed in the stagnant sectors.

What is the impact of automation and income inequality on aggregate demand and investment?

As it is indicated before in the answer of the previous research question, automation and digitalization worsen income distribution. Their aggregated impact, therefore, results in a decline of consumption growth. The magnitude of this impact might be bigger with a sudden change in the employment level. It is shown that the consumption growth fell to 3% from 5-6% since last ten years. The growth on the investment level, on the other hand, is not sufficient in the later stage of automation and digitalization. It is shown in chapter 6 that the investment growth and share of investment decline faster with the increasing pace of automation. The results of the simulation show that the investment share of GDP might decline to 20% from 30% in the base case scenario. Even though these results do not match with empirical data perfectly, they indicate that investment might decline much faster than it is expected due to the decline in aggregate demand.

How can the innovation and technological change be endogenised?

This research question aims to study the impact of automation and income inequality on technological change if it is assumed that technological change depends on research and development decisions of the intermediate product firms. Based on the model extension in chapter 7, it is shown that R&D spending is a fraction of the intermediate product firms' profit. In the short run, the pace of horizontal innovation and automation of tasks depends on allocation of R&D spending between these two research activities. If more resources and spending are allocated for the purpose of automation of existing tasks, the pace of automation increases. In the long run, on the other hand, it is assumed that the creation of a new tasks, which is labour biased, will lead a balanced growth as Acemoglu & Restrepo (2016, 2018a; 2018).

What is the impact of fiscal and monetary policies?

While fiscal policies minimize the negative impact of automation on income distribution and aggregate demand, it is not entirely effective to offset the disruptive impacts of income inequality and digitalization. It is seen that fiscal policies do not stimulate a jump in the consumption of dynamic products due to consumption preferences of the low-income household for the stagnant products. Due to its high price and a budget deficit of low-income household, the growth of the consumption growth remained limited. The high-interest rate, on the other hand, reduces investment and slows down economic growth. Even though it increases the capital and automation machine factor price in the long run, a high-interest rate is disruptive in the short run.

8.2 Recommendations for the Societal Challenge

The recommendations here are addressed to policy-makers, especially government agencies. It can be seen from in section 8.1 that fiscal policies are not adequate to manage the disruptive impact of the automation in the short run. In the long run, on the other hand, more drastic measures should be taken in order to have an increasing economic growth.

1. It can be seen that the consumption preferences of households lead to an unbalanced growth and structural change in the economy. Due to high prices in the stagnant sector and budget constraints of low income groups, the consumption of dynamic products remained limited. The lack of demand and profits discourage entrepreneurs and intermediate products firms to invest in R&D activities as it happened in Britain in 18th century due to the corn law. It is essential to promote consumption of dynamic products and take measures to reduce the price of the products of stagnant sectors.
2. The growth in productivity of the stagnant sector has been declining due to low investment in R&D activities. In chapter 7, it is argued that the possibility of failure in research activities of the stagnant sector discourage the intermediate sector producers to invest in R&D activities. The federal government may take a role as key entrepreneur in this field and invest in risky research areas to promote technological progress in the stagnant sectors as Mazzucato (2015) suggested for green technological progress.

3. The federal government can collaborate with central bank to promote full employment in national level. In fact, the focus should be employment in the dynamic sector where the most of the productivity gains will occur thanks to automation and digitalization.
4. The federal government should take initiatives to ensure that labour has sufficient competencies before they are discharged. That can be done by promoting job training course. The government should also consider to improve financial aid for laid-off workers. As it can be seen from simulation, the unemployment is one of the significant reason for the declining consumption growth. Supporting laid-off workers may minimize the negative impact of unemployment on the consumption growth.
5. The federal government should take action to reform education system to address the market need in terms of skills for the automation and digitalization. The government should provide incentives to technical college, in particular the one related to digitalization, automation and computer science.
6. The government should provide incentives such as tax reduction or interest free credits for risky R&D activities. They should characterize in which sector public or private R&D investment will be more efficient.

8.3 Limitations and Future Research

This section addresses limitations of this research and future research which can be complementary for this study.

8.3.1 Limitations

Due to time limit and complexity of the model and data availability, there are several assumption and reduction on complexity of the model which might limit the scope of the research. These limitations are listed as follows :

- **Data availability:** This study assumes a sharp distinction in terms of labour (high skill and low skill labour) and sector (the dynamic and the stagnant sectors). However, there is not a such a sharp distinction in real life. For instance, data is available for some skill groups since 1990s in the USA. Besides these skill groups classified as low, medium and high skill groups. It is not easy to make a distinction for medium skill workers. Another data related problem is regarding sectors. For instance, it is assumed that stagnant sectors reflects the service sector in general. However, there are service industries, which focus on data and automation. Therefore, the data which are used in the simulation may not reflect the reality.
- **Model Structure:** The assumption while building the dynamic model put some constraints in order to gain a deep understanding of automation. The first constrained due to simplification of automation of tasks and replacement. It is assumed a share of the jobs will be executed by robots. However, that prevents this study to explore the direction of new task. In other words, a new

role might be labour or automation biased. Acemoglu & Restrepo (2016, 2018a; 2018) solved this problem by introducing a indexation system to identify each role separately. Therefore, in their model the pace of automation and technological progress are independent from each other. The second problem results from the assumption regarding consumption preferences of the households. It is assumed that household are identical in terms of their consumption basket preferences. However, the consumption patterns of high income groups may vary in time. Therefore, this assumption prevent this study to make a deep analysis in terms of the real structural transformation due to consumption preferences. Finally, the assumption regarding household income and saving propensity make a sharp distinction. However, it is not possible to separate the ownership of the firms and income channels among household in reality.

- **Optimization and Sensitivity:** As it is indicated in section 6.4.4, it was required to impose a stable trend for wage growth and productivity to minimize volatility in optimization and model failure. This assumption caused over simplification productivity and wage structure. As a result, the productivity and skill premium have a linear trend which might not be occurred. Even though it does not create a significant problem in terms of macroeconomic trends, it prevents to gain a deep insight the impact of automation o production factor price and efficiency of labour. T

8.3.2 Future Research

Based on the chapter 5, 6, 7 and section 8.2 and section 8.3.1, some future research space are determined. These future research can be listed as follows:

1. It is required to make more detailed classification in terms of automation machine. The automation machine in this study represents artificial intelligence, machine learning algorithms. However, their degree of complementarity vary based on the skill groups. An advanced AI can even replace a high skill labour. Therefore an empirical study is required to analyse these impacts.
2. As indicated in section 8.3.1, the current structure of the model does not enable to study different pace of automation and technological change. A system, which based on the indexation of task and routines, might solve this problem. However, it will make more complex this study. Therefore , a follow-up study might be a better option.
3. This study missing overlapping generation models. Overlapping generation models are used to study allocation of resources among different generations. When the aging problem of the western world considered, automation might have different consequences in the long run.
4. This study focused on United states due to availability of the data. The same model might give different results when it is applied to different countries. Therefore it might be used as a basis to build a general model which can be used to analyse every countries.
5. An empirical study which focuses on industries and their need for automation machine, labour and technological development level might be complementary for this study. It can also be used to verify the result of this study.

8.4 Reflection

This section reflects the motivations for model assumptions and discusses what can be done better when author take a step back. Due to author interest and own ambitions, a dynamic economic model developed to conduct this project. The author wanted to enhance his knowledge in the area economic modelling and quantitative research. However, the research project exceed its complexity limit and the core aim. In fact, the economic model have become over complex which is not necessary in the scope of this research. Besides, the author misunderstanding of economic school of thoughts caused a time delay for the project. For instance, Author had difficulties to impose to changing profit share into Neoclassical and New Keynesian models. Neo classical and New Keynesian models work based on the assumption that there is a full employment and profit share is zero in the long run. Nevertheless, the main lesson which is learned from this research project can be listed as follows:

1. In terms of modelling, it should start as simple as possible. In the core of model, it is required to focus what you want to achieve with this research. In fact, that might be the toughest task in whole project. It is generally much easier to make models more complex
2. Along with dynamic model, an agent based model could be interesting to work with in order to make a distinction for investment choice and consumption choice etc.
3. It is not easy to find the data which matches with your interest. Therefore, before implying an assumptions it is better to check data availability in terms of simulation.
4. Vensim is very resource platform for visualization, but it has limitations. It might be better to use a python script to make a numerical analysis.

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V

Appendices

A.

Vensim Implementation

```
a0l= Constant ( User Defined parameter)

a1= Constant ( User Defined parameter)

a2= Constant ( User Defined parameter)

a3= Constant ( User Defined parameter)

aoh= Constant ( User Defined parameter)

AR=
    YpsilonNd*Betad*MCdT*phix*GammaaNd*At*((1-
phid)^(1/epsilonNd))*((1-phix)*GammaaNd
*Ldt+phix*GammaaNd*At)^(-1/epsilonNd)*(1/(Mdt^((epsilonNd-1
)/epsilonNd)))*Dt*UA/2
Units: price

At= INTEG (
    "At(+)"-"At(-)",
    "At(ss)")
Units: Capital

"At(+)"=
    (((phiIa)^(1/epsilonIa))*((Idt*(Iat/Total
Investment))^(epsilonIa-1)/epsilonIa
))+((1-phiIa)^(1/epsilonIa))*((Ist*(Iat/Total
Investment))^(epsilonIa-1)/epsilonIa
)))^(epsilonIa/(epsilonIa-1))*chia
Units: Capital/Year

"At(-)"=
    At*deltaa
Units: **undefined**

"At(ss)"= Constant ( User Defined parameter)

Automation pace= Constant ( User Defined parameter)

Äa=
    0.2+Investment Pace*PULSE(101, 80 )
Units: **undefined**

Äkd= Constant ( User Defined parameter)

Äks= Constant ( User Defined parameter)

b0a= Constant ( User Defined parameter)

b0h= Constant ( User Defined parameter)
```

```

b0l= Constant ( User Defined parameter)

b1a= Constant ( User Defined parameter)

b1h= Constant ( User Defined parameter)

b1l= Constant ( User Defined parameter)

b2h= Constant ( User Defined parameter)

b2l= Constant ( User Defined parameter)

b3h= Constant ( User Defined parameter)

b3l= Constant ( User Defined parameter)

Betad= Constant ( User Defined parameter)

betas= Constant ( User Defined parameter)

"C/GDP"=
    Total Consexp/GDP
Units: **undefined**

Capital Owners Household= INTEG (
    Income COt-ConsexpCo-Invest,
    0)
Units: price

Cdt=
    (etaC/(1-etaC))*Prupsilon*(((Total Consexp-(etaC/(1-
etaC)))*(Pdt/Pt)*Prupsilon
*Csmn)/((Pst/Pt)+(etaC/(1-etaC))*(Pdt/Pt)*Prupsilon))
    +Csmn)
Units: **undefined**

chia=
    EXP(1)^( (1-omegachia)*LOG("Chia(ss)", EXP(1)
)+ (omegachia)*LOG("chia(-1)",
    EXP(1) )+sigmaepsilonchia)
Units: Outputs/workers

"chia(-1)"=
    DELAY1I(chia, 1 , "Chia(ss)" )
Units: **undefined**

"chia(^)"=
    LOG( chia/"chia(-1)" , EXP(1) )
Units: **undefined**

"Chia(ss)"= INTEG (
    "chia(ss) (+)",
    0.45)
Units: **undefined**

"chia(ss) (+)"=
    "g(chia)"*"Chia(ss)"
Units: **undefined**

```

```

chik=
    EXP(1)^( (1-omegachik)*LOG("chik(ss)", EXP(1)
)+ (omegachik)*LOG("chik(-1)",
    EXP(1) )+sigmaepsilonchik)
Units: Outputs/workers

"chik(-1)"=
    DELAY1I(chik, 1 , "chik(ss)" )
Units: **undefined**

"chik(^)"=
    LOG( chik/"chik(-1)" , EXP(1) )
Units: **undefined**

"chik(ss)"= INTEG (
    "chik(ss) (+)",
    0.9)
Units: **undefined**

"chik(ss) (+)"=
    "g(chik)"*"chik(ss)"
Units: **undefined**

ConsexpCo=
    Income COt*(1-psico)
Units: price/Year

ConsexpH=
    Income Ht*(1-psih)
Units: price/Year

ConsexpL=
    Income Lt*(1-psil)
Units: price/Year

Csmin= Constant ( User Defined parameter)

Cst=
    (Total Consexp-(etaC/(1-
etaC))* (Pdt/Pt)*Prupsilon*Csmin)/ ((Pst/Pt)+(etaC/(
1-etaC))* (Pdt/Pt)*Prupsilon)
Units: **undefined**

deltaa=
    MIN(EXP(1)^( (1-omegadeltaa)*LOG("deltaa(ss)", EXP(1)
)+ (omegadeltaa)*LOG("deltaa(-1)"
, EXP(1) )+sigmaepsilondeltaa), 1 )
Units: **undefined**
EXP(1)^( (1-omegadeltaa)*LOG("deltaa(ss)", EXP(1)
)+ (omegadeltaa)*LOG("deltaa(-1)", EXP(1)
)+sigmaepsilondeltaa)

"deltaa(-1)"=
    DELAY1I(deltaa, 1 , "deltaa(ss)" )
Units: **undefined**

"deltaa(ss)"= INTEG (

```

```

    "deltaa(ss) (+)",
        0.1)
Units: **undefined**

"deltaa(ss) (+)"=
    "g(deltaa)"*"deltaa(ss)"
Units: **undefined**

deltak=
    EXP(1)^( (1-omegadeltak)*LOG("deltak(ss)", EXP(1)
)+ (omegadeltak)*LOG("deltak(-1)"
, EXP(1) )+sigmaepsilondeltak)
Units: **undefined**

"deltak(-1)"=
    DELAY1I(deltak, 1 , "deltak(ss)" )
Units: **undefined**

"deltak(ss)"= INTEG (
    "deltak(ss) (+)",
    0.033)
Units: **undefined**

"deltak(ss) (+)"=
    "g(deltak)"*"deltak(ss)"
Units: **undefined**

Deltalambdahd=
    (lambdahd/"lambdahd(-1)")-1
Units: **undefined**

Deltalambdahs=
    (lambdahs/"lambdahs(-1)")-1
Units: **undefined**

Deltalambdakd=
    (lambdakd/"lambdakd(-1)")-1
Units: **undefined**

Deltalambdald=
    (lambdald/"lambdald(-1)")-1
Units: **undefined**

Deltalambdals=
    (lambdals/"lambdals(-1)")-1
Units: **undefined**

Deltalambdaxd=
    (lambdaxd/"lambdaxd(-1)")-1
Units: **undefined**

DGDP=
    KdR+Profitd+VHd+WLd+AR
Units: **undefined**

"DGDP(-1)"=
    DELAY1I(DGDP, 1 , DGDP )
Units: **undefined**

```

```

"DGDP (^)"=
    LN(DGDP/"DGDP(-1)")
Units: **undefined**

"DGDP/GDP"=
    (DGDP/Pt)/GDP
Units: **undefined**

dnh= Constant ( User Defined parameter)

dnl= Constant ( User Defined parameter)

Dt=
    (Ndt^((sigmad/(sigmad-1))-
(1+Betad)*Ypsilond)) * ((Mdt^Betad) * (Kdt^(1-Betad)
))^Ypsilond
Units: Outputs

"Dt(-1)"=
    DELAY1I(Dt, 1, Dt)
Units: **undefined**

"Dt (^)"=
    LN(Dt/"Dt(-1)")
Units: **undefined**
Dt-"Dt(-1)"

"dt(j)"=
    ((( "mdt(j) " ) ^Betad) * ((Kdt/Ndt)^(1-Betad))) ^Ypsilond
Units: **undefined**

"Dt(ss)"= INITIAL(
    Dt)
Units: **undefined**

DtPdt=
    Dt*Pdt
Units: **undefined**

epsilonIa= Constant ( User Defined parameter)

epsilonIkd= Constant ( User Defined parameter)

epsilonIks= Constant ( User Defined parameter)

epsilonI= Constant ( User Defined parameter)

etaC= Constant ( User Defined parameter)
consumption share of dynamic

etaG= Constant ( User Defined parameter)
consumption share of dynamic

etaI= Constant ( User Defined parameter)
consumption share of dynamic

```

```

EXdt=
    Cdt*(1+"g(Cd)")+Idt
Units: **undefined**

EXst=
    Cst*(1+"g(Cs)")+Ist
Units: **undefined**

"g(Cd)"=
    (EXP(1)^(omegagCd*LOG(1+"g(Cd) (-1)", EXP(1) )+(1-
    omeagagCd)*(LOG((1+"g(ss)"
    ), EXP(1) )+thetapi*LOG( ((1-pi)/(1-"pi(sslh)")) , EXP(1) )-
    ThetaU*LOG( (Um
    /"U(ss)" , EXP(1))) +sigmaepsilongCd))-1
Units: **undefined**

"g(Cd) (-1)"=
    DELAY1I( "g(Cd)" , 1 , "g(ss)" )
Units: **undefined**

"g(chia)"= Constant ( User Defined parameter)

"g(chik)"= Constant ( User Defined parameter)

"g(Cs)"=
    (EXP(1)^(omegagCs*LOG(1+"g(Cs) (-1)", EXP(1) )+(1-
    omeagagCs)*(LOG((1+"g(ss)"
    ), EXP(1) )+thetapi*LOG( ((1-pi)/(1-"pi(sslh)")) , EXP(1) )-
    ThetaU*LOG( (Um
    /"U(ss)" , EXP(1))) +sigmaepsilongCs))-1
Units: **undefined**

"g(Cs) (-1)"=
    DELAY1I( "g(Cs)" , 1 , "g(ss)" )
Units: **undefined**

"g(deltaa)"= Constant ( User Defined parameter)

"g(deltak)"= Constant ( User Defined parameter)

"g(Nd)"= Constant ( User Defined parameter)

"g(Ns)"= Constant ( User Defined parameter)

"g(ss)"= Constant ( User Defined parameter)

"G/GDP"= Constant ( User Defined parameter)

gammaa= INTEG (
    "gammaa (+)"-"gammaa (-)",
    gammaaass)
Units: **undefined**

"gammaa (+)"=
    MIN( (EXP(1)^(b0a+b1a*LN(Dt/"Dt(ss)")))*gammaaass ,
    gammaa*(1+RANDOM NORMAL
    ( -0.005 , 0.015 , 0 , 0.006 , 100 ) ) )

```

```

Units: **undefined**
(EXP(1)^(b0a+b1a*LN(Dt/"Dt(ss)")))*gammaass

"gammaa(-)"=
    gammaa
Units: **undefined**

GammaaNd=
    gammaa*Ndt
Units: **undefined**

"GammaaNd(^)"=
    LN(GammahNd/DELAY1I(GammahNd, 1 , GammahNd ))
Units: **undefined**

gammaass=
    2
Units: **undefined**

gammahd= INTEG (
    "gammahd(+)"-"gammahd(-)",
    gammahdss)
Units: **undefined**

"gammahd(+)"=
    MIN(
    (EXP(1)^(b0h+b1h*LN(Dt/"Dt(ss)")+b2h*LN("Vh(+)"/"Vhs(ss)")+b3h*Zdh))*
    gammahdss , gammahd*(1+RANDOM NORMAL( -0.003 , 0.025 , 0.0005 , 0.006
    , 10
    )))
Units: **undefined**
(EXP(1)^(b0h+b1h*LN(Dt/"Dt(ss)")+b2h*LN("Vh(+)"/"Vhs(ss)")+b3h*Zd
h))*gammahdss

"gammahd(-)"=
    gammahd
Units: **undefined**

gammahdss= Constant ( User Defined parameter)

GammahNd=
    gammahd*Ndt
Units: **undefined**

"GammahNd(^)"=
    LN(GammahNd/DELAY1I(GammahNd, 1 , GammahNd ))
Units: **undefined**

GammahNs=
    gammahs*Nst
Units: **undefined**

"GammahNs(^)"=
    LN(GammahNs/DELAY1I(GammahNs, 1 , GammahNs ))
Units: **undefined**

gammahs= INTEG (
    MAX(0, "gammahs(+)" )-"gammahs(-)",

```

```

        gammahsss)
Units: **undefined**

"gammahs (+) "=
    MIN( (EXP(1) ^ (b0h+b1h*LN(St/"St(ss)"+b2h*LN("Vh(+)" / "Vhs(ss)"+b
3h*Zsh)))*gammahsss
, gammahs*(1+RANDOM NORMAL( -0.003 , 0.02 , 0 , 0.005 , 10 )) )
Units: **undefined**
(EXP(1) ^ (b0h+b1h*LN(St/"St(ss)"+b2h*LN("Vh(+)" / "Vhs(ss)"+b3h*Zs
h)))*gammahsss

"gammahs (-) "=
    gammahs
Units: **undefined**

gammahsss= Constant ( User Defined parameter)

gammald= INTEG (
    "gammald(+)"-"gammald(-)",
    gammaldss)
Units: **undefined**

"gammald(+)"=
    MIN(
    (EXP(1) ^ (b0l+b1l*LN(Dt/"Dt(ss)"+b2l*LN("Wl(+)" / "Wl(ss)"+b3l*Zdl)))*ga
mmaldss
, gammald*(1+RANDOM NORMAL( -0.003 , 0.015 , 0 , 0.005 , 100 )) )
Units: **undefined**
(EXP(1) ^ (b0l+b1l*LN(Dt/"Dt(ss)"+b2l*LN("Wl(+)" / "Wl(ss)"+b3l*Zdl
)))*gammaldss

"gammald(-)"=
    gammald
Units: **undefined**

gammaldss= Constant ( User Defined parameter)

GammalNd=
    gammald*Ndt
Units: **undefined**

"GammalNd(^)"=
    LN(GammalNd/DELAY1I(GammalNd, 1 , GammalNd ))
Units: **undefined**

GammalNs=
    gammals*Nst
Units: **undefined**

"GammalNs(^)"=
    LN(GammalNs/DELAY1I(GammalNs, 1 , GammalNs ))
Units: **undefined**

gammals= INTEG (
    "gammals(+)"-"gammals(-)",
    gammalsss)
Units: **undefined**

```

```

"gamma(+)"=
    MIN( (EXP(1)^(b01+b11*LN(St/"St(ss)"+b21*LN("Wl(+)"/"Wl(ss)"+b3
1*Zs1)))*gamma(ss
, gamma*(1+RANDOM NORMAL( -0.004 , 0.015 , 0 , 0.005 , 100 )) )
Units: **undefined**
(EXP(1)^(b01+b11*LN(St/"St(ss)"+b21*LN("Wl(+)"/"Wl(ss)"+b31*Zs1
    ))*gamma(ss

"gamma(-)"=
    gamma
Units: **undefined**

gamma(ss= Constant ( User Defined parameter)

GDP=
    (DGDP+SGDP)/Pt
Units: **undefined**

"GDP(-1)"=
    DELAY1I(GDP, 1 , GDP )
Units: **undefined**

"GDP(^)"=
    LN(GDP/"GDP(-1)")
Units: **undefined**
(GDP/"GDP(-1)")-1

Gdt=
    (etaG/(1-etaG))*PrupsilonG*((Government Consumption-(etaG/(1-
etaG))*Pdt/
Pt)*PrupsilonG*Gsmn)/((Pst/Pt)+(etaG/(1-etaG
    ))*(Pdt/Pt)*PrupsilonG)
    +Gsmn)
Units: **undefined**

gnh= Constant ( User Defined parameter)

gnl= Constant ( User Defined parameter)

Government Consumption=
    Government Spendings*(1-Share of Transfer)
Units: **undefined**

Government Spendings=
    Income Tax Revenue+Robot Tax Revenue
Units: **undefined**

"GS(^)"=
    (Government Consumption/DELAY1I(Government Consumption, 1 ,
Government Consumption
    ))-1
Units: **undefined**
LOG( Total Investment/DELAY1I(Total Investment, 1 , Total
    Investment ) , 10 )

Gsmn= Constant ( User Defined parameter)

Gst=

```

```

(Government Consumption-(etaG/(1-
etaG))* (Pdt/Pt)*PrupsilonG*Gsmn)/((Pst/Pt
)+(etaG/(1-etaG))* (Pdt/Pt)*PrupsilonG)
Units: **undefined**

H=
Hdt+Hst
Units: **undefined**

"H/HL"=
H/(H+L)
Units: **undefined**

hd demand=
(1/(((("dt(j)")^(1-
Ypsilond)/Ypsilond))* (1/Ypsilond)))*Betad*(1/gammahd)* (
phid*( (Vh/gammahd)^(-epsilond)))* (1/(phid*( (Vh
/gammahd)^(1-epsilond))+ (1-phid)* (((1-
phix)*(Wl/gammaald))+ (phix*(Ra/gammaa
)))^(1-epsilond))))*MCd*( (pdi/Pdt)^(-sigmad))* (Ndt^(sigmad/
(sigmad-1)))* (EXdt/(Ndt^(sigmad/(sigmad-1))))^(1/Ypsilond))
Units: workers
(Ypsilond/(((Xdt/(Ndt^((1+Ypsilond*(sigmad-1))/(sigmad-1))))^(1-
Ypsilond)/Ypsilond))))*Betad*( (phid)*( (Vh)^(-epsilond)
))* (1/(phid*(Vh^(1-
epsilond))+ (1-phid)* (Wl+Ra)^(1-epsilond))))* (pdi*(sigmad-
1)/sigm
ad)*
((pdi/Pdt)^(-sigmad))* (Ndt^(1/(sigmad-
1)))* ((Xdt/(Ndt^(1/(sigmad-
1))))^(1/Ypsilond))

"Hd(+)"=
IF THEN ELSE("Ud(%)>0.8, MAX(SMOOTH((hd demand*Ndt)*1.016, 2 ),
SMOOTH((Hdt
/MAX("Us(%)", RANDOM NORMAL(0.96, 1.04 , 1 , 0.01 , 100 ) ))*1.016, 2
) ) ,
SMOOTH(Hdt*RANDOM NORMAL(0.97, 0.99 , 0.985 , 0.01 , 100 ), 2 ) )
Units: workers/Year
Ndt*hd demand SMOOTH N(Ndt*hd demand*1.2, 2 , Hdt , 0.5 )

"Hd(-)"=
Hdt
Units: **undefined**

Hdt= INTEG (
"Hd(+)"-"Hd(-)",
20000)
Units: workers

"High-skill Household"= INTEG (
Income Ht-ConsexpH,
0)
Units: price

HNd=
RDd/Vh
Units: **undefined**

```

```

HNs=
    RDs/Vh
Units: **undefined**

hs demand=
    (1/(((("st(i)")^(1-
Ypsilons)/Ypsilons))*betas*(1/gammahs)*(
phis*((Vh/gammahs)^(-epsilons))*1/(phis*((Vh/gammahs)^(1-
epsilons))+1-phis
))*((Wl/gammahs)^(1-epsilons))))*MCs*((psi/Pst)^(-
sigmas))*(Nst^(sigmas/(sigmas
-1)))*(EXst/(Nst^(sigmas/(sigmas-1))))^(1/Ypsilons))
Units: workers
(Ypsilons/(((Xst/(Ns^((1+Ypsilons*(sigmas-1))/(sigmas-1))))^(1-Y
psilons)/Ypsilons))))*betas*((phis)*(Vh^(-epsilons)))*
(1/(phis*(Vh^(1-
epsilons))+1-phis)*(Wl^(1-epsilons))))*(psi*(sigmas-
1)/sigmas)*(
    (psi
    /Pst)^(-sigmas))*(Ns^(1/(sigmas-1)))*(Xst/(Ns^(1/(sigmas-
1))))^(
    1/Ypsilons))

"Hs(+)"=
    MIN(IF THEN ELSE((ABS(SMOOTH3( hs demand*Nst*"Us(%)" , 4 )-
Hst)/Hst)<=0.025
, SMOOTH3( hs demand*Nst*MAX( RANDOM NORMAL(0.985, 1.018 , 1 ,0.01 ,
10 ) ,
"Us(%)" ) , 4 ) , Hst*MAX( RANDOM NORMAL(0.985, 1.018 , 1 ,0.01 , 10 )
, "Us(%)"
)
) , 0.975*NH-Hdt )
Units: workers/Year
hs demand*Nst SMOOTH N(hs demand*Nst*1.2, 4 , Hst , 0.5 )

"Hs(-)"=
    Hst
Units: workers/Year

Hst= INTEG (
    "Hs(+)"-"Hs(-)",
    18000)
Units: workers

"i(-1)"=
    DELAY1I( it , 1 , "i(ss)" )
Units: **undefined**

"i(ss)"= Constant ( User Defined parameter)

"I/GDP"=
    (Total Investment+RDd+RDs)/GDP
Units: **undefined**

"Ia(ss)"= INITIAL(
    GDP*0.005)
Units: **undefined**

```

```

Iat= INTEG (
    MAX( 0, "Iat(+)" )-"Iat(-)",
    "Ia(ss)")
Units: **undefined**

"Iat(+)"=
    (EXP(1)^(omega0a*Äa+omega1a*LN(pid/"pid(ssco)")+omega2a*"Xdt(^)"
-omega3a*
it))*Iat
Units: **undefined**
(omega0a*Äa+omega1a*"pid(^)" +omega2a*"Xdt(^)"-omega3a*it)*Iat
    (10^(omega0a*Äa+omega1a*LOG( (pid/"pi(ss)" ) , 10
    )+omega2a*"Xdt(^)"-omega3a*it))*"Ia(ss)"

"Iat(-)"=
    Iat
Units: **undefined**

Idt=
    (etaI/(1-etaI))*PrupsilonI*((Total Investment-(etaI/(1-
etaI))*(Pdt/Pt)*PrupsilonI
*IsmIn)/((Pst/Pt)+(etaI/(1-etaI))*(Pdt/Pt)*PrupsilonI))
    +Ismin)
Units: **undefined**

"Ikd(ss)"= INITIAL(
    GDP*0.125)
Units: **undefined**
"Kd(ss)"*Capital

Ikdt= INTEG (
    MAX( 0, "Ikdt(+)" )-"Ikdt(-)",
    "Ikd(ss)")
Units: **undefined**

"Ikdt(+)"=
    (EXP(1)^(omega0kd*Äkd+omega1kd*LN(pid/"pid(ssco)")+omega2kd*"Xdt
(^)"-omega3kd
*it))*Ikdt
Units: **undefined**
(omega0kd*Äkd+omega1kd*"pid(^)" +omega2kd*"Xdt(^)"-omega3kd*it)*I
    kdt (10^(omega0kd*Äkd+omega1kd*LOG( (pid/"pi(ss)" ) , 10
    )+omega2kd*"Xdt(^)"-omega3kd*it))*"Ikd(ss)"

"Ikdt(-)"=
    Ikdt
Units: **undefined**

"Iks(ss)"= INITIAL(
    GDP*0.1)
Units: **undefined**
"Ks(ss)"*Capital

Ikst= INTEG (
    MAX( 0, "Ikst(+)" )-"Ikst(-)",
    "Iks(ss)")
Units: **undefined**

```

```

"Ikst(+)"=
    (EXP(1)^(omega0ks*Äks+omegalks*LN(pis/"pis(ssco)")+omega2ks*"Xst
(^)"-omega3ks
*it))*Ikst
Units: **undefined**
(omega0ks*Äks+omegalks*"pis(^)" +omega2ks*"Xst(^)"-omega3ks*it)*I
kst (10^(omega0ks*Äks+omegalks*LOG( (pis/"pis(ss)" ) , 10
)+omega2ks*"Xst(^)"-omega3ks*it))*"Iks(ss)"

"Ikst(-)"=
    Ikst
Units: **undefined**

Income COt=
    ((KdR+KsR+Profitd+Profits)*(1-tco)+AR*(1-ta))/Pt
Units: price/Year

Income Ht=
    ((VHd+VHs)*(1-th)/Pt)+RDd+RDs
Units: price/Year

Income Lt=
    ((Wld+WLs)*(1-tl)/Pt)+Income T
Units: price/Year

Income T=
    Government Spendings*Share of Transfer
Units: **undefined**

Income Tax Revenue=
    ((Wld+WLs)*tl+(VHd+VHs)*th+(KdR+KsR+Profitd+Profits)*tco)/Pt
Units: **undefined**

Invest=
    Total Investment+RDd+RDs
Units: **undefined**

Investment Pace= Constant ( User Defined parameter)

Ismin= Constant ( User Defined parameter)

Ist=
    (Total Investment-(etaI/(1-
etaI))*(Pdt/Pt)*PrupsilonI*Ismin)/((Pst/Pt)+(etaI
/(1-etaI))*(Pdt/Pt)*PrupsilonI)
Units: **undefined**

it=
    (EXP(1)^(omegai*LOG(1+"i(-1)", EXP(1) )+(1-
omegai)*(LOG((1+"i(ss)" )*(1+tau
), EXP(1) )+thetatau*LOG( ((1+tau)/(1+"tau(ss)" ) , EXP(1)
))+sigmaepsiloni
))-1
Units: **undefined**

"it(^)"=
    LN(it/"i(-1)")

```

```

Units: **undefined**

kd demando=
    (1/(((("dt(j)")^((1-Ypsilond)/Ypsilond))* (1/Ypsilond)))*(1-
Betad)*(1/Rk)*MCd
*((pdi/Pdt)^(-sigmad))* (Ndt^(sigmad/(sigmad-
1)))* ((EXdt/(Ndt^(sigmad/(sigmad
-1))))^(1/Ypsilond))
Units: Capital
(1-Betad)*(1/Rk)*(pdi*(Sigmad-1)/Sigmad)* ((pdi/Pdt)^(-Sigmad))*De
mandD

"Kd(ss)"= Constant ( User Defined parameter)

KdR=
    Ypsilond*(1-Betad)*MCdT*Dt*UKd
Units: price

Kdt= INTEG (
    "Kdt(+)"-"Kdt(-)",
    "Kd(ss)")
Units: Capital

"Kdt(+)"=
    (((phiIkd)^(1/epsilonIkd))* (Idt*(Ikdt/Total
Investment))^(epsilonIkd-1)
/epsilonIkd)+((1-phiIkd)^(1/epsilonIkd))* ((Ist*(Ikdt/Total
Investment))^(epsilonIkd-1)/epsilonIkd))^(epsilonIkd/(epsilonIkd-1))*chik
Units: Capital/Year

"Kdt(-)"=
    Kdt*deltak
Units: **undefined**

ks demando=
    (1/(((("st(i)")^((1-Ypsilons)/Ypsilons))* (1/Ypsilons)))*(1-
betas)*(1/Rk)*MCs
*((psi/Pst)^(-sigmas))* (Nst^(sigmas/(sigmas-
1)))* ((EXst/(Nst^(sigmas/(sigmas
-1))))^(1/Ypsilons))
Units: Capital
(1-Betas)*(1/Rk)*(psi*(Sigmas-1)/Sigmas)* ((psi/Pst)^(-Sigmas))*De
mandS

"Ks(ss)"= Constant ( User Defined parameter)

KsR=
    Ypsilons*(1-betas)*MCsT*St
Units: price

Kst= INTEG (
    "Kst(+)"-"Kst(-)",
    "Ks(ss)")
Units: Capital

"Kst(+)"=

```

```

      (((phiIks)^(1/epsilonIks))*((Idt*(Ikst/Total
Investment))^(epsilonIks-1)
/epsilonIks))+((1-phiIks)^(1/epsilonIks))*((Ist*(Ikst/Total
Investment))^(epsilonIks-1/epsilonIks)))^(epsilonIks/(epsilonIks-1))*chik
Units: Capital/Year

```

```

"Kst(-)"=
      Kst*deltak
Units: Capital/Year

```

```

L=
      Ldt+Lst
Units: **undefined**

```

```

lambdahd=
      Dt/Hdt
Units: **undefined**

```

```

"lambdahd(-1)"= ACTIVE INITIAL (
      DELAY1(lambdahd, 1 ),
      lambdahd)
Units: **undefined**

```

```

lambdahs=
      St/Hst
Units: **undefined**

```

```

"lambdahs(-1)"= ACTIVE INITIAL (
      DELAY1(lambdahs, 1 ),
      lambdahs)
Units: **undefined**

```

```

lambdakd=
      Dt/Kdt
Units: **undefined**

```

```

"lambdakd(-1)"= ACTIVE INITIAL (
      DELAY1(lambdakd, 1 ),
      lambdakd)
Units: **undefined**

```

```

lambdaKs=
      St/Kst
Units: **undefined**

```

```

lambdald=
      Dt/Ldt
Units: **undefined**

```

```

"lambdald(-1)"= ACTIVE INITIAL (
      DELAY1(lambdald, 1 ),
      lambdald)
Units: **undefined**

```

```

lambdals=
      St/Lst
Units: **undefined**

```

```

"lambdals(-1)"= ACTIVE INITIAL (
    DELAY1(lambdals, 1 ),
    lambdals)
Units: **undefined**

lambdaxd=
    Dt/At
Units: **undefined**

"lambdaxd(-1)"= ACTIVE INITIAL (
    DELAY1(lambdaxd, 1 ),
    lambdaxd)
Units: **undefined**

ld demand=
    (1/(((("dt(j)")^(1-
Ypsilond)/Ypsilond))*(1/Ypsilond)))*Betad*(1/gammald)*(
1-phix)*((1-phid)*(((1-phix)*(Wl/gammald))+(phix*(Ra/gammaa))
)^(-epsilond)))*(1/(phid*((Vh/gammahd)^(1-epsilond))+(1-
phid)*(((1-phix)*(
(Wl/gammald))+(phix*(Ra/gammaa))^(1-epsilond)))))*MCd*((pdi/
Pdt)^(-sigmad))*(Ndt^(sigmad/(sigmad-
1)))*((EXdt/(Ndt^(sigmad/(sigmad-1)))
)^((1/Ypsilond))
Units: workers
(Ypsilond/(((Xdt/(Ndt^((1+Ypsilond*(sigmad-1))/(sigmad-1))))^(1-
Ypsilond)/Ypsilond))))*Betad*((1-phid)*((Wl+Ra)^(-epsilond
)))*1/(phid*(Vh
^(1-epsilond))+1-phid)*((Wl+Ra)^(1-
epsilond))))*(pdi*(sigmad-1)/
sigmad
)*((pdi/Pdt)^(-sigmad))*(Ndt^(1/(sigmad-
1)))*((Xdt/(Ndt^(1/(sigma
d-1))))^(1/Ypsilond))

"Ld(+)"=
    IF THEN ELSE("Ud(%)">0.8, IF THEN ELSE(phix<=0.5, MAX(SMOOTH(ld
demand*Ndt
, 2 ), SMOOTH(Ldt/MAX("Us(%)", RANDOM NORMAL(0.98, 1.02 , 1 , 0.01 ,
100 )
), 2 ) ) , MIN(SMOOTH(ld demand*Ndt, 2 ), SMOOTH(Ldt/MAX("Us(%)",
RANDOM NORMAL
(0.98, 1.02 , 1 , 0.01 , 100 ) ), 2 ) ) ) , SMOOTH(Ldt*RANDOM
NORMAL(0.95,
0.99 , 1 , 0.97 , 100 ), 2 ) )
Units: workers/Year
Ndt*ld demand SMOOTH N(Ndt*ld demand*1.2, 2 , Ldt , 0.5 )

"Ld(-)"=
    Ldt
Units: **undefined**

Ldt= INTEG (
    "Ld(+)"-"Ld(-)",
    30000)
Units: workers

```

```

"Low-skill Household"= INTEG (
    Income Lt-ConseXP,
    0)
Units: price

ls demand=
    (1/(((("st(i)")^(1-
Ypsilons)/Ypsilons))* (1/Ypsilons))) *betas*(1/gammals)* (
(1-phis)* ((Wl/gammals)^(-epsilons)))* (1/((phis*(Vh/gammahd)^ (1-
epsilons)))
+((1-phis)* ((Wl/gammals)^(1-epsilons)))) *MCs*((psi/Pst)^(-
sigmas))* (Nst^(sigmas
/(sigmas-1)))* ((EXst/(Nst^(sigmas/(sigmas-1))))^(1/Ypsilons))
Units: workers
(Ypsilons/(((Xst/(Ns^((1+Ypsilons*(sigmas-1))/(sigmas-1))))^( (1-Y
psilons)/Ypsilons)))) *betas*((1-phis)* (Wl^(-epsilons)
)* (1/(phis*(Vh^( 1-
epsilons))+ (1-phis)* (Wl^(1-epsilons)))) * (psi*(sigmas-
1)/sigmas)* (
    (psi
    /Pst)^(-sigmas))* (Ns^(1/(sigmas-1)))* ((Xst/(Ns^(1/(sigmas-
1))))^(
    1/Ypsilons))

"Ls(+)"=
    MIN(IF THEN ELSE((ABS(SMOOTH3( ls demand*Nst*"Us(%)" , 4 )-
Lst)/Lst)<=0.025
, SMOOTH3( ls demand*Nst*MAX( RANDOM NORMAL(0.985, 1.018 , 1 ,0.01 ,
10 ) ,
"Us(%)" ) , 4 ) , Lst*
    MAX( RANDOM NORMAL(0.985, 1.018 , 1 ,0.01 , 10 ) , "Us(%)" )
    ) , 0.975*NL-Ldt )
Units: workers/Year
ls demand*Nst SMOOTH N(ls demand*Nst*1.2*"Us(%)" , 4 , Lst , 0.5 )

"Ls(-)"=
    Lst
Units: **undefined**

Lst= INTEG (
    "Ls(+)"-"Ls(-)",
    30000)
Units: workers

MCd=
    (("dt(j)")^(1-
Ypsilond)/Ypsilond))* (1/Ypsilond)* (1/(Betad^Betad))* (1/((1-
Betad)^(1-Betad)))* (Rk^(1-Betad
    )) * ((phid*(Vh/gammahd)^(1-epsilond))+ (1-phid)* (((1-
phix)* (Wl/gammahd))+ (
phix*(Ra/gammaa))^(1-epsilond)))^(Betad/(1-epsilond))
Units: price/Outputs
((Dt/(Nd^((1+RSd*(Sigmad-1))/(Sigmad-1))))^( (1-RSd)/RSd))* (1/RSd)
    * (1/(Betad^Betad))* (1/((1-Betad)^(1-Betad)))* (Rk^(1-
Betad))* ((Phi
    d*(Wh^(1-Epsilond))+ (1-Phid)* ((Wl+Rx)^(1-
Epsilond)))^(Betad/(1-Ep
    silond)))

```

```

      ((Phid*(Wh^(1-Epsilon)))+(1-Phid)*((Phix*(Wl^(1-
Epsilon)))+(1-Phi
      d)*(Rx^(1-Epsilon)))^(1-Epsilon)/(1-
Epsilon)))^(Betad/(1-Eps
      ilond))

"mcd(real)"=
      Mcd/Pt
Units: **undefined**

"MCd(ss)1"= INITIAL(
      "Wl(ss)/(Ypsilon*Betad*GammalNd*(1-phix)*((1-
phid)^(1/epsilon))*((1-phix
      )*GammalNd*Ldt+phix*GammaaNd*At)^(-1/epsilon))*1/(Mdt^((epsilon
      -
      1)/epsilon))*Dt))
Units: price
Ypsilon*Betad*MCdT*GammalNd*Ldt*((1-phid)^(1/epsilon))*((Gammal
      Nd*Ldt+GammaaNd*At)^(-1/epsilon))*1/(Mdt^((epsilon-
      1)/epsilon))*Dt

MCdT=
      Mcd*(Ndt^(1/(1-sigmad)))
Units: **undefined**

MCs=
      (("st(i)")^(1-
Ypsilon)/Ypsilon))*1/Ypsilon*1/(betas^betas)*1/((1-
betas)^(1-betas))*Rk^(1-betas
      )*((phis*((Vh/gammahs)^(1-epsilon))+1-phis)*(Wl/gammals)^(1-
epsilon))
      )^(betas/(1-epsilon))
Units: price/Outputs
((St/(Ns^((1+RSs*(Sigmas-1))/(Sigmas-1))))^((1-RSs)/RSs))*1/RSs
      *1/(Betas^Betas)*1/((1-Betas)^(1-Betas))*Rk^(1-
Betas))*((Phi
      s*(Wh^(1-Epsilon))+1-Phis)*(Wl^(1-Epsilon)))^(Betas/(1-
Epsilon
      s)))

"mcs(real)"=
      MCs/Pt
Units: **undefined**

"MCs(ss)1"= INITIAL(
      "Wl(ss)/(Ypsilon*betas*GammalNs*((1-
phis)^(1/epsilon))*((GammalNs*Lst)^
      (-1/epsilon))*1/(Mst^((epsilon-1)/epsilon))*
      St))
Units: price
Ypsilon*betas*MCsT*((1-phis)^(1/epsilon))*((GammalNs*Lst)^((eps
      ilons-1)/epsilon))*1/(Mst^((epsilon-1)/epsilon))* St

MCsT=
      MCs*(Nst^(1/(1-sigmas)))
Units: **undefined**

Mdt=

```

```

      ((phid)^(1/epsilond))*((GammahNd*Hdt)^(epsilond-
1)/epsilond))+((1-phid)^(
1/epsilond))*(((1-phix)*GammalNd*Ldt+phix*GammaaNu*At)^(epsilond
-1)/epsilond))^(epsilond
/(epsilond-1))
Units: **undefined**
      ((Phix)^(1/EpsilonX))*((Ld)^(EpsilonX-1)/EpsilonX))+((1-Phix)^(
1/EpsilonX))*((X)^(EpsilonX-
1)/EpsilonX))^(EpsilonX*(Epsilond-
1))/((EpsilonX-1)*Epsilond))

"mdt(j)"=
      ((phid)^(1/epsilond))*((gammahd*(Hdt/Ndt)^(epsilond-
1)/epsilond))+((1-phid
)^(1/epsilond))*(((1-
phix)*gammald*Ldt+phix*gammaa*At)/Ndt)^(epsilond-1)/
epsilond))^(epsilond/(epsilond-1))
Units: **undefined**

Mst=
      ((phis)^(1/epsilons))*((GammahNs*Hst)^(epsilons-
1)/epsilons))+((1-phis)^(
1/epsilons))*((GammalNs*Lst)^(epsilons-1)/epsilons))^(epsilons
)/(epsilons-1))
Units: **undefined**

"mst(i)"=
      ((phis)^(1/epsilons))*((gammahs*(Hst/Nst)^(epsilons-
1)/epsilons))+((1-phis
)^(1/epsilons))*((gammals*(Lst/Nst)^(epsilons-1)/epsilons))^(
epsilons
)/(epsilons-1))
Units: **undefined**

Muh=
      1-((Hdt+Hst)/NH)
Units: **undefined**

Mul=
      1-((Ldt+Lst)/NL)
Units: **undefined**

Nd ≡ INTEG (
      "Nd ~+",
      80)
Units: **undefined**

"Nd ~+"=
      "g(Nd)"*(Nd ~sanNd)*(HNd^sanHNd)
Units: **undefined**

Ndt=
      EXP( 1 )^((1-omegaNd)*LOG(Nd ~, EXP( 1 ) ))+(omegaNd)*LOG("Ndt (-
1)", EXP(
1 ) )+sigmaepsilonNd)
Units: Outputs/workers

"Ndt(-1)"=

```

```

    DELAY1I(Ndt, 1, Ndt)
Units: **undefined**

New firmd=
    Ndt-"Ndt(-1)"
Units: **undefined**

New firms=
    Nst-"Nst(-1)"
Units: **undefined**

NH= INTEG (
    "NH(+)"-"NH(-)",
    (Hdt+Hst)/(1-"U(ss)"))
Units: **undefined**

"NH(+)"=
    gnh*NH
Units: **undefined**

"NH(-)"=
    dnh*NH
Units: **undefined**

NL= INTEG (
    "NL(+)"-"NL(-)",
    (Ldt+Lst)/(1-"U(ss)"))
Units: **undefined**

"NL(+)"=
    NL*gnl
Units: **undefined**

"NL(-)"=
    NL*dnl
Units: **undefined**

NLH=
    NH+NL
Units: **undefined**

Ns ≡ INTEG (
    "Ns~(+)",
    80)
Units: **undefined**

"Ns~(+)"=
    "g(Ns)"*(Ns~sanNs)*(HNs^sanHNs)
Units: **undefined**

Nst=
    EXP( 1 )^((1-omegaNs)*LOG(Ns~, EXP( 1 ) )+(omegaNs)*LOG("Nst(-1)", EXP( 1 ) )+sigmaepsilonNs)
Units: Dmnl

"Nst(-1)"=
    DELAY1I(Nst, 1, Ns~)

```

```

Units: **undefined**

O1D=
    (Quarter1D)*StickyD ratio*Pulsed
Units: **undefined**

O1S=
    (Quarter1S)*StickyS ratio*Pulses
Units: **undefined**

O2D=
    (Quarter2D)*StickyD ratio*Pulsed
Units: **undefined**

O2S=
    (Quarter2S)*StickyS ratio*Pulses
Units: **undefined**

O3D=
    (Quarter3D)*StickyD ratio*Pulsed
Units: **undefined**

O3S=
    (Quarter3S)*StickyS ratio*Pulses
Units: **undefined**

O4D=
    Quarter4D*Pulsed
Units: **undefined**

O4S=
    Quarter4S*Pulses
Units: **undefined**

omega0a= Constant ( User Defined parameter)
omega0kd= Constant ( User Defined parameter)
omega0ks= Constant ( User Defined parameter)
omega1a= Constant ( User Defined parameter)
omega1kd= Constant ( User Defined parameter)
omega1ks= Constant ( User Defined parameter)
omega2a= Constant ( User Defined parameter)
omega2kd= Constant ( User Defined parameter)
omega2ks= Constant ( User Defined parameter)
omega3a= Constant ( User Defined parameter)
omega3kd= Constant ( User Defined parameter)
omega3ks= Constant ( User Defined parameter)

```

```

omegachia= Constant ( User Defined parameter)

omegachik= Constant ( User Defined parameter)

omegadeltaa= Constant ( User Defined parameter)

omegadeltak= Constant ( User Defined parameter)

omegagCd= Constant ( User Defined parameter)

omegagCs= Constant ( User Defined parameter)

omegai= Constant ( User Defined parameter)

omegaNd= Constant ( User Defined parameter)

omegaNs= Constant ( User Defined parameter)

omegasigmad= Constant ( User Defined parameter)

omegasigmas= Constant ( User Defined parameter)

OptimalAt=
    Ndt*x demando
Units: **undefined**

OptimalKdt=
    kd demando*Ndt
Units: **undefined**

OptimalKst=
    ks demando*Nst
Units: **undefined**

OptimumD= INTEG (
    New firmd+O1D+O2D+O3D+O4D-Q1D,
    Ndt)
Units: **undefined**

OptimumS= INTEG (
    New firms+O1S+O2S+O3S+O4S-Q1S,
    Nst)
Units: **undefined**

"Pa (^)"=
    LOG(((phiIa*(Pdt^(1-epsilonIa))+(1-phiIa)*(Pst^(1-
epsilonIa)))^(1/(1-epsilonIa
))) * chia) / ("chia(-1)"*DELAY1I(((phiIa*(Pdt^(1-epsilonIa))+(1-
phiIa)*(Pst^(1
-epsilonIa)))^(1/(1-epsilonIa))), 1 , ((phiIa*(Pdt^(1-epsilonIa))+(1-
phiIa)
*(Pst^(1-epsilonIa)))^(1/(1-epsilonIa))) ), 10 )
Units: **undefined**
((phiIa*(Pdt^(1-epsilonIa))+(1-phiIa)*(Pst^(1-epsilonIa)))^(1/(1-
epsilonIa)))

Pd1=
    DELAY1I(Pdot, Timed , Pdot )

```

```

Units: **undefined**

Pd2=
    DELAY1I(Pd1, Timed , Pd1)
Units: **undefined**

Pd3=
    DELAY1I(Pd2, Timed , Pd2 )
Units: **undefined**

Pd4=
    DELAY1I(Pd3, Timed , Pd3 )
Units: **undefined**

pdi=
    MCd*"Profitmark-upd"
Units: **undefined**
MCd*"Profitmark-upd"

Pdot=
    pdi*(Ndt^(1/(1-sigmad)))
Units: price/Outputs
Pdt*(Nd^(1/(1-Sigmad)))

Pdt=
    (Pdot*OptimumD+Pd1*Quarter1D+Pd2*Quarter2D+Pd3*Quarter3D+Pd4*Quarter4D)/(OptimumD+Quarter1D+Quarter2D+Quarter3D+Quarter4D)
Units: **undefined**

phid= Constant ( User Defined parameter)

phiIa= Constant ( User Defined parameter)

phiIkd= Constant ( User Defined parameter)

phiIks= Constant ( User Defined parameter)

phis= Constant ( User Defined parameter)

phix=
    0.1+RAMP(0.005,20,40)+RAMP(0.015,40,60)+RAMP(Automation pace,120,160)
Units: **undefined**

pi=
    (KdR+KsR+Profitd+Profits+AR)/(DGDP+SGDP)
Units: **undefined**

"pi(sslh)"= Constant ( User Defined parameter)

pid=
    (KdR+Profitd+AR)/DGDP
Units: **undefined**

"pid(ssco)"=
    DELAY1I(pid, 1 , 0.5 )

```

```

Units: **undefined**

pis=
    (Profits+KsR)/SGDP
Units: **undefined**

"pis(ssco)"=
    DELAY1I(pis, 1 , 0.4 )
Units: **undefined**

"Pk(^)"=
    LOG( ((phiIkd*(Pdt^(1-epsilonIkd))+(1-phiIkd)*(Pst^(1-
epsilonIkd)))^(1/(1
-epsilonIkd)))*chik)/("chik(-1)"*DELAY1I( ((phiIkd*(Pdt^(1-
epsilonIkd))+(1-
phiIkd)*(Pst^(1-epsilonIkd)))^(1/(1-epsilonIkd))) , 1 ,
((phiIkd*(Pdt^(1-epsilonIkd
))+1-phiIkd)*(Pst^(1-epsilonIkd)))^(1/(1-epsilonIkd))) ) ) , 10 )
Units: **undefined**
    ((phiIkd*(Pdt^(1-epsilonIkd))+1-phiIkd)*(Pst^(1-epsilonIkd)))^(1
/(1-epsilonIkd))

Pr=
    Pst/Pdt
Units: Dmnl
Relative Price

Profitd=
    (Pdt-MCdT*Ypsilond)*Dt*MIN(DELAY1I( "Ud(%)" , 1 , 0.6 ) , 1 )
Units: price
    DELAY1I( "Ud(%)" , 1 , 0.6 )

"Profitmark-upd"=
    sigmad/(sigmad-1)
Units: Dmnl

"Profitmark-ups"=
    sigmas/(sigmas-1)
Units: Dmnl

Profits=
    (Pst-MCsT*Ypsilons)*St
Units: price

Prupsilon=
    Pr^upsilon
Units: **undefined**

PrupsilonG=
    Pr^upsilonG
Units: **undefined**

PrupsilonI=
    Pr^upsilonI
Units: **undefined**

Ps1=
    DELAY1I(Psot, Times , Psot )

```

```

Units: **undefined**

Ps2=
    DELAY1I(Ps1, Times , Ps1 )
Units: **undefined**

Ps3=
    DELAY1I(Ps2, Times , Ps2 )
Units: **undefined**

Ps4=
    DELAY1I(Ps3, Times , Ps3 )
Units: **undefined**

psi=
    "Profitmark-ups"*MCs
Units: **undefined**

psico= Constant ( User Defined parameter)

psih= Constant ( User Defined parameter)

psil= Constant ( User Defined parameter)

Psot=
    psi*(Nst^(1/(1-sigmas)))
Units: price/Outputs

Pst=
    (Psot*OptimumS+Ps1*Quarter1S+Ps2*Quarter2S+Ps3*Quarter3S+Ps4*Quarter4S)/(OptimumS
+Quarter1S+Quarter2S+Quarter3S+Quarter4S
    )
Units: **undefined**

Pt=
    (Dt*Pdt+St*Pst)/(Dt+St)
Units: price/Outputs
General Price

"Pt(-1)"= ACTIVE INITIAL (
    DELAY1(Pt, 1 ),
    Pt)
Units: **undefined**

Pulsed=
    PULSE TRAIN(0, 1 , Timed , FINAL TIME )
Units: **undefined**

Pulses=
    PULSE TRAIN(0, 1 , Times , FINAL TIME )
Units: **undefined**

Q1D=
    OptimumD*StickyD ratio*Pulsed
Units: **undefined**

Q1S=

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    OptimumS*StickyS ratio*Pulses
Units: **undefined**

Q2D=
    Quarter1D*StickyD ratio*Pulsed
Units: **undefined**

Q2S=
    Quarter1S*StickyS ratio*Pulses
Units: **undefined**

Q3D=
    Quarter2D*StickyD ratio*Pulsed
Units: **undefined**

Q3S=
    Quarter2S*StickyS ratio*Pulses
Units: **undefined**

Q4D=
    Quarter3D*StickyD ratio*Pulsed
Units: **undefined**

Q4S=
    Quarter3S*StickyS ratio*Pulses
Units: **undefined**

Quarter1D= INTEG (
    Q1D-O1D-Q2D,
    0)
Units: **undefined**

Quarter1S= INTEG (
    Q1S-O1S-Q2S,
    0)
Units: **undefined**

Quarter2D= INTEG (
    Q2D-O2D-Q3D,
    0)
Units: **undefined**

Quarter2S= INTEG (
    Q2S-O2S-Q3S,
    0)
Units: **undefined**

Quarter3D= INTEG (
    Q3D-O3D-Q4D,
    0)
Units: **undefined**

Quarter3S= INTEG (
    Q3S-O3S-Q4S,
    0)
Units: **undefined**

Quarter4D= INTEG (

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    Q4D-O4D,
    0)
Units: **undefined**

Quarter4S= INTEG (
    Q4S-O4S,
    0)
Units: **undefined**

Ra= INTEG (
    "Ra(+)"-"Ra(-)",
    "Rad(ss)"*2)
Units: price

"Ra(+)"=
    (EXP(1)^(LOG( (it+deltaa)/("i(-1)"+"deltaa(-1)"), EXP(1) ))) *Ra
Units: **undefined**

"Ra(-)"=
    Ra
Units: **undefined**

"Rad(ss)"= INITIAL(
    Ypsilond*Betad*"MCd(ss)1"*GammaaNd*phix*( (1-
    phid)^(1/epsilond))*((1-phix)
    *GammalNd*Ldt+phix*GammaaNd*At)^(-1/epsilond))* (1/(Mdt^((epsilond
    -1
    )/epsilond)))*Dt)
Units: price

RDd=
    (((KdR+Profitd)*(1-tco)+AR*(1-ta))/Pt)*RDdshare)
Units: **undefined**

RDdshare= Constant ( User Defined parameter)

RDs=
    ((KsR+Profits)*(1-tco)/Pt)*Rdsshare)
Units: **undefined**

Rdsshare= Constant ( User Defined parameter)

Rk= INTEG (
    "Rk(+)"-"Rk(-)",
    "Rks(ss)")
Units: price

"Rk(+)"=
    (EXP(1)^(LOG( (it+deltak)/("i(-1)"+"deltak(-1)"), EXP(1) ))) *Rk
Units: **undefined**
Pt*(it+1+deltak)

"Rk(-)"=
    Rk
Units: **undefined**

"Rkd(ss)"= INITIAL(
    Ypsilond*(1-Betad)*"MCd(ss)1"*Dt*(1/Kst))

```

```

Units: price

"Rks(ss)"= INITIAL(
    Ypsilons*(1-betas)*"MCs(ss)1"*St*(1/Kst)
Units: price

Robot Tax Revenue=
    AR*ta/Pt
Units: **undefined**

sanHNd= Constant ( User Defined parameter)

sanHNs= Constant ( User Defined parameter)

sanNd= Constant ( User Defined parameter)

sanNs= Constant ( User Defined parameter)

SGDP=
    KsR+Profits+VHs+WLs
Units: **undefined**

"SGDP(-1)"=
    DELAY1I(SGDP, 1 , SGDP )
Units: **undefined**

"SGDP(^)"=
    LN(SGDP/"SGDP(-1)")
Units: **undefined**

"SGDP/GDP"=
    (SGDP/Pt)/GDP
Units: **undefined**

Share of Transfer= Constant ( User Defined parameter)

sigmad=
    EXP(1)^(omegasigmad*LOG( "sigmad(-1)" , EXP(1) )+(1-
omegasigmad)*LOG( "sigmad(ss)"
    , EXP(1) )+sigmaepsilonpd)
Units: Dmnl

"sigmad(-1)"=
    DELAY1I(sigmad, 1 , "sigmad(ss)" )
Units: **undefined**

"sigmad(ss)"= Constant ( User Defined parameter)

sigmaepsilonchia=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 100)
Units: **undefined**

sigmaepsilonchik=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 100)
Units: **undefined**

sigmaepsilondeltaa=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 100)

```

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Units: **undefined**

sigmaepsilondeltak=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 100)
Units: **undefined**

sigmaepsilongCd=
    RANDOM NORMAL( -0.005 , 0.01 , 0 , 0.005 , 10)
Units: **undefined**
RANDOM NORMAL(0.001, 0.003 , 0.0015 , 0.0005 , 0.002 )

sigmaepsilongCs=
    RANDOM NORMAL( -0.005 , 0.01 , 0 , 0.005 , 10)
Units: **undefined**
RANDOM NORMAL(0.001, 0.003 , 0.0015 , 0.0005 , 0.002 )

sigmaepsiloni=
    RANDOM NORMAL( -0.01 , 0.01 , 0.0005 , 0.005 , 100)
Units: **undefined**

sigmaepsilonNd=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 1 )
Units: **undefined**

sigmaepsilonNs=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 1 )
Units: **undefined**

sigmaepsilonpd=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 10)
Units: **undefined**

sigmaepsilonps=
    RANDOM NORMAL( -0.01 , 0.01 , 0 , 0.01 , 10)
Units: **undefined**

sigmas=
    EXP(1)^(omegasigmas*LOG( "sigmas(-1)" , EXP(1) )+(1-
omegasigmas)*LOG( "sigmas(ss)"
, EXP(1) )+sigmaepsilonps)
Units: Dmnl

"sigmas(-1)"=
    DELAY1I(sigmas, 1 , "sigmas(ss)" )
Units: **undefined**

"sigmas(ss)"= Constant ( User Defined parameter)

St=
    (Nst^((sigmas/(sigmas-1))-
(1+betas)*Ypsilons))*((Mst^betas)*(Kst^(1-betas)
))^Ypsilons
Units: Outputs

"St(-1)"=
    DELAY1I(St, 1 , St )
Units: **undefined**

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"St(^)"=
    LN(St/"St(-1)")
Units: **undefined**
St-"St(-1)"

"st(i)"=
    (("mst(i)"^betas)*((Kst/Nst)^(1-betas)))^Ypsilons
Units: **undefined**

"St(ss)"= INITIAL(
    St)
Units: **undefined**

StickyD ratio= Constant ( User Defined parameter)

StickyS ratio= Constant ( User Defined parameter)

StPst=
    Pst*St
Units: **undefined**

ta= Constant ( User Defined parameter)

tau=
    IF THEN ELSE( (Pt/"Pt(-1)")-1<=0 , "tau(ss)" , (Pt/"Pt(-1)")-1 )
Units: **undefined**
(Pt/"Pt(-1)")-1

"tau(ss)"= Constant ( User Defined parameter)

TCd=
    Ldt*Wl+Hdt*Vh+Kdt*Rk+At*Ra
Units: **undefined**

tco= Constant ( User Defined parameter)

TCs=
    Lst*Wl+Hst*Vh+Kst*Rk
Units: **undefined**

th= Constant ( User Defined parameter)

thetapi= Constant ( User Defined parameter)

thetatau= Constant ( User Defined parameter)

ThetaU= Constant ( User Defined parameter)

"TI(^)"=
    ((Total Investment+RDd+RDs)/DELAY1I((Total Investment+RDd+RDs),
1 , (Total Investment
+RDd+RDs) ))-1
Units: **undefined**
LOG( Total Investment/DELAY1I(Total Investment, 1 , Total
Investment ) , 10 )

Timed= Constant ( User Defined parameter)

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```

Times= Constant ( User Defined parameter)

t1= Constant ( User Defined parameter)

Total Consexp=
    ConsexpCo+ConsexpH+ConsexpL
Units: **undefined**

Total Investment=
    Ikdt+Ikst+Iat
Units: **undefined**

"U(ss)"= Constant ( User Defined parameter)

UA=
    DELAY1I(MIN(OptimalAt/At, 1 )*MAX("Ud(%)", 0.8 ), 1 , 0.2 )
Units: **undefined**
MIN(DELAY1I(OptimalAt/At, 1 , 0.2 ), 1 )*RANDOM NORMAL( 0.7 ,
    0.85 , 0.75 , 0.03 , 10 )

UCd=
    TCd/Dt
Units: **undefined**

UCs=
    TCs/St
Units: **undefined**

"Ud(%) "=
    Xdt/Dt
Units: **undefined**

"Ud(^) "=
    LN(Xdt/Dt)
Units: **undefined**

UKd=
    DELAY1I(MIN(OptimalKdt/Kdt, 1 )*MAX("Ud(%)", 0.8 ), 1 , 0.75 )
Units: **undefined**
MIN(DELAY1I(OptimalKdt/Kdt, 1 , 0.6 ), 0.8 )*RANDOM NORMAL( 0.7
    , 0.85 , 0.75 , 0.03 , 10 )

UKs=
    DELAY1I(OptimalKst/Kst, 1 , 1 )
Units: **undefined**

Um=
    IF THEN ELSE( (1-(Hdt+Hst+Ldt+Lst)/(NH+NL))<=0 , "U(ss)" , 1-
    (Hdt+Hst+Ldt+
    Lst)/(NH+NL) )
Units: **undefined**
1-(Hdt+Hst+Ldt+Lst)/(NH+NL)

epsilon= Constant ( User Defined parameter)

epsilonG= Constant ( User Defined parameter)

epsilonI= Constant ( User Defined parameter)

```

```

"Us (%)" =
    Xst/St
Units: **undefined**

"Us (^)" =
    LN(Xst/St)
Units: **undefined**

Vh= INTEG (
    "Vh(+)"-"Vh(-)",
    "Vhs(ss)")
Units: price

"Vh(+)" =
    (aoh-
a1*Muh+a2*((Hst/(Hdt+Hst))*"GammahNs(^)" + (Hdt/(Hdt+Hst))*"GammahNd(^)"
)+a3*((Hst/(Hdt+Hst))*Zsh+(Hdt/(Hdt+Hst))*Zdh))*Vh
Units: **undefined**
(aoh-a1*Muh+a2*((Hst/(Hdt+Hst))*"GammahNs(^)" + (Hdt/(Hdt+Hst))*"Ga
mmahNd(^)" +a3*((Hst/(Hdt+Hst))*Zsh+(Hdt/(Hdt+Hst))*Zdh))*Vh

"Vh(-)" =
    Vh
Units: **undefined**

VHd=
    Betad*Ypsilond*MCdT*(phid^(1/epsilond))*((GammahNd*Hdt)^( (epsilo
nd-1)/epsilond
))* (1/(Mdt^((epsilond-1)/epsilond)))*Dt
Units: price

"Vhd(ss)" = INITIAL(
    Betad*Ypsilond*"MCd(ss)1"*GammahNd*(phid^(1/epsilond))*((GammahN
d*Hdt)^(-1
/epsilond))* (1/(Mdt^((epsilond-1)/epsilond)))*Dt)
Units: price

VHs=
    betas*Ypsilons*MCsT*(phis^(1/epsilons))*((GammahNs*Hst)^( (epsilo
ns-1)/epsilons
))* (1/(Mst^((epsilons-1)/epsilons)))*St
Units: price

"Vhs(ss)" = INITIAL(
    betas*Ypsilons*"MCs(ss)1"*GammahNs*(phis^(1/epsilons))*((GammahN
s*Hst)^(-1
/epsilons))* (1/(Mst^((epsilons-1)/epsilons)))*St)
Units: price

Wl= INTEG (
    "Wl(+)"-"Wl(-)",
    "Wl(ss)")
Units: price

"Wl(+)" =

```

```

(a01-
a1*Mul+a2*((Lst/(Ldt+Lst))*"GammalNs(^)"+(Lst/(Ldt+Lst))*"GammalNd(^)"
)+a3*((Lst/(Ldt+Lst))*Zsl+(Lst/(Ldt+Lst))*Zdl))*Wl
Units: **undefined**
(a01-a1*Mul+a2*((Lst/(Ldt+Lst))*"GammalNs(^)"+(Lst/(Ldt+Lst))*"Ga
mmalNd(^)" )+a3*((Lst/(Ldt+Lst))*Zsl+(Lst/(Ldt+Lst))*Zdl))*Wl
"Wl(-)"=
Wl
Units: **undefined**
"Wl(ss)"= Constant ( User Defined parameter)
Wld=
Ypsilond*Betad*MCdT*(1-phix)*GammalNd*Ldt*((1-
phid)^(1/epsilond))*((1-phix
)*GammalNd*Ldt+phix*GammaaNd*At)^(-1/epsilond))*(1/(Mdt^((epsilond-
1)/epsilond)))*Dt
Units: price
Wls=
Ypsilons*betas*MCsT*((1-
phis)^(1/epsilons))*((GammalNs*Lst)^((epsilons-1)/
epsilons))*1/(Mst^((epsilons-1)/epsilons))*
St
Units: price
x demando=
(1/(((("dt(j)")^(1-
Ypsilond)/Ypsilond))*(1/Ypsilond)))*Betad*(1/gammaa)*(phix
))*((1-phid)*(((1-phix)*(Wl/gammald))+(phix*(Ra/gammaa)))
^(-epsilond))*1/(phid*((Vh/gammahd)^(1-epsilond))+(1-
phid)*(((1-phix)*(
Wl/gammald))+(phix*(Ra/gammaa)))^(1-epsilond)))*MCd*((pdi/Pdt
)^(-sigmad))*Ndt^(sigmad/(sigmad-
1))*((EXdt/(Ndt^(sigmad/(sigmad-1))))^(
1/Ypsilond))
Units: Capital
Betad*((1-Phid)*((Wl+Rx)^(-Epsilon)))*1/(Phid*(Wh^(1-Epsilon))
+(1-Phid)*((Wl+Rx)^(1-Epsilon)))*pdi*(Sigma-
1)/Sigma)*((pdi/
Pdt)^(-Sigma))*DemandD
Xdt=
Cdt+Idt+Gdt
Units: **undefined**
"Xdt(-1)"=
DELAY1I(Xdt, 1 , Xdt )
Units: **undefined**
"Xdt(^)"=
LN(Xdt/"Xdt(-1)")
Units: **undefined**
Xst=
Cst+Ist+Gst

```

Units: **undefined**

"Xst(-1)"=
DELAY1I(Xst, 1 , Xst)

Units: **undefined**

"Xst(^)"=
LN(Xst/"Xst(-1)")

Units: **undefined**

Xt=
(Xdt*Pdt+Xst*Pst)/Pt

Units: **undefined**

Ypsilond= Constant (User Defined parameter)

Ypsilons= Constant (User Defined parameter)

Zdh= Constant (User Defined parameter)

Zdl= Constant (User Defined parameter)

Zsh= Constant (User Defined parameter)

Zsl= Constant (User Defined parameter)

