Three Essays on Endogenous Technology and Economic Growth

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A thesis submitted for the degree of
Doctor of Philosophy in ECONOMICS

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April 2024

"...Do not pursue the past and do not lose yourself in the future.
The past is no more. The future is yet to come.
Life is here and now..."

— *Buddha*

Acknowledgements

I thank my supervisor, Dr Andreas Müller, for his invaluable guidance and support throughout my thesis. His unwavering patience and encouragement have been a constant source of encouragement, particularly when I faced challenges in comprehending certain aspects of the research. Andreas has always been available to provide me with insightful feedback and constructive criticism that have helped me refine my ideas and produce better quality work. I am grateful for his unwavering support, dedication, and guidance provided to me during my academic journey, both MRes and PhD. His contributions, including thorough interpretations and generous revisions, have allowed me to expand and deepen my research skills. I am fortunate to have had him as my supervisor for this journey, and I appreciate the invaluable time and effort he has invested in me. The skills and knowledge gained under his guidance will serve me well in future endeavours.

I also thank Dr Neslihan Sakarya for her tremendous support and guidance throughout my journey. Neslihan has been an invaluable supervisor who has provided me with invaluable insights, asked challenging and thought-provoking questions, and offered constructive feedback that has helped me evolve both personally and professionally. I am thankful for her persistent support throughout my PhD journey, which has been remarkable. Her mentorship and guidance have been essential in my academic development, and I am blessed to have had her as my co-supervisor. I am grateful for her patience, support, and mentorship.

In addition, I want to thank Professor Marcus Chambers, who also supervised me in the application of macroeconomics to real data. He was my co-supervisor only for a short period of time, but his influence on my way of thinking was immense.

Many words of thanks go to my colleagues from the Department of Economics at the University of Essex, especially Panupong Sukkerd and Ariya Phaokrueng for providing me with valuable comments and suggestions. They have been wonderful companions and we have shared numerous unforgettable experiences together. I also thank all the other attendees of the RSS seminars and my colleagues from the doctoral studies.

Special thanks go to Lorna Woollcott, the Graduate Administrator, for her invaluable support and guidance throughout my PhD studies. I cannot thank her enough for always being there to address my concerns and queries and patiently guiding me through various situations. Despite my occasional demands and requests, Lorna was always ready to assist me with a kind and cheerful demeanour, and her prompt and efficient responses were instrumental in helping me progress smoothly through my studies. Her dedication and commitment to her work are truly admirable.

I am deeply thankful for the support from the Royal Thai Government's Scholarships and the Department of Economics, Faculty of Economics at Sriracha, Kasetsart University. They have supported me since the academic year of 2019, when I started my MRes study at the University of Essex. I am deeply thankful to all the staff and my colleagues (at Kasetsart University) who have supported me since the beginning. I would also like to express my thankfulness to the Minister of Educational Affairs, the Royal Thai Embassy in London, and all the staff there who have taken good care of me, provided support and valuable information for living in the UK, and all other related matters in academic and non-academic life.

Finally, throughout my journey of pursuing a PhD, I have been fortunate enough to have infinite love, support, and encouragement from my parents, brother, supportive partner, friends, and beloved furry friends. They have stood by me through thick and thin, providing material and non-material support during the most challenging moments. Without them, I would not have been able to overcome the storms that came my way. I am hugely indebted and eternally grateful for their unconditional love and support, and for being a source of motivation for me.

Summary

This thesis contains three chapters that endeavour to provide valuable insights into the importance of endogenous technology on growth.

Chapter 1 studies a Real Business Cycle model that focuses on two regions - the technology creation and the technology adoption regions. The model examines the effect of technology creation or R&D shocks on the economic growth of different regions, and how macroeconomic variables respond to the shock. Positive technology shocks create new technologies and boost output growth. Adopting technologies from one region can benefit another region's economy. However, since the shock is temporary, variables will eventually converge to their steady states.

Chapter 2 describes a New Keynesian DSGE model that analyses the interaction between monetary policy and economic variables' volatility. The model suggests that monetary policy can impact one region and other regions through various channels, such as the technology adoption channel. The study recommends that monetary authorities in developing regions monitor this channel to support growth and stabilise economic volatility. The policy in advanced regions can also impact entrepreneurs in developing regions through the technology adoption channel, and firm owners should understand the effect of this and other transmission channels to manage their businesses smoothly in the long run.

Chapter 3 highlights the empirical importance of R&D and technology transfer in driving economic growth and boosting productivity. The study demonstrates that R&D is essential for productivity growth as it promotes innovation and facilitates technology transfer, especially in developing countries that need to catch up on technological advancements. Productivity can also increase through international trade and human capital. International trade can bring new markets, technologies, and resources, while human capital is essential for a country's growth and development. These findings emphasise the need to invest in technology transfer and innovation to boost economic growth.

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Chapter 1

The Role of R&D as the Driving Force of Economic Growth

Within the first chapter of this study, a Real Business Cycle (RBC) model is introduced, which presents two distinct regions - one centred around technology creation and the other on technology adoption. The model takes into account households with both skilled and unskilled labour and includes an endogenous technology mechanism as a means of capturing economic growth within these regions. The study's main finding indicates that the region that depended on R&D experienced a more significant economic growth rate than the adoption-focused region in response to positive technology R&D shock. The study, therefore, suggests that authorities should increase funding for skilled labour and R&D in both regions. Furthermore, the region with the technology adoption section should aim to improve its R&D capacity in order to keep pace with the rapid economic growth experienced by its technology-creating counterpart.

1.1 Introduction

One of the most important mechanisms of market competition is technological creation which produces differentiated commodities with the highest productivity efficiency of firms. If the force for technology creation has raised the competition across firms, regions, and countries, its net effect is significantly agreed as a determination of productivity. The aggregate impact of technological creation could be observed in an economy's gross domestic product (GDP) in terms of its total annual outputs. For example, the GDP per capita for the world, developed countries, and developing countries from 1999 to 2019 in U.S. dollars have steadily increased. Developed countries have a much higher level of GDP per capita when compared to the GDP per capita of developing countries and the overall world GDP. This indicates a significant disparity in economic prosperity between developed and developing nations (USDA Economic Research Service, 2021). However, the different levels of economic growth could not be accounted for only by the GDP, labour, and capital stocks.

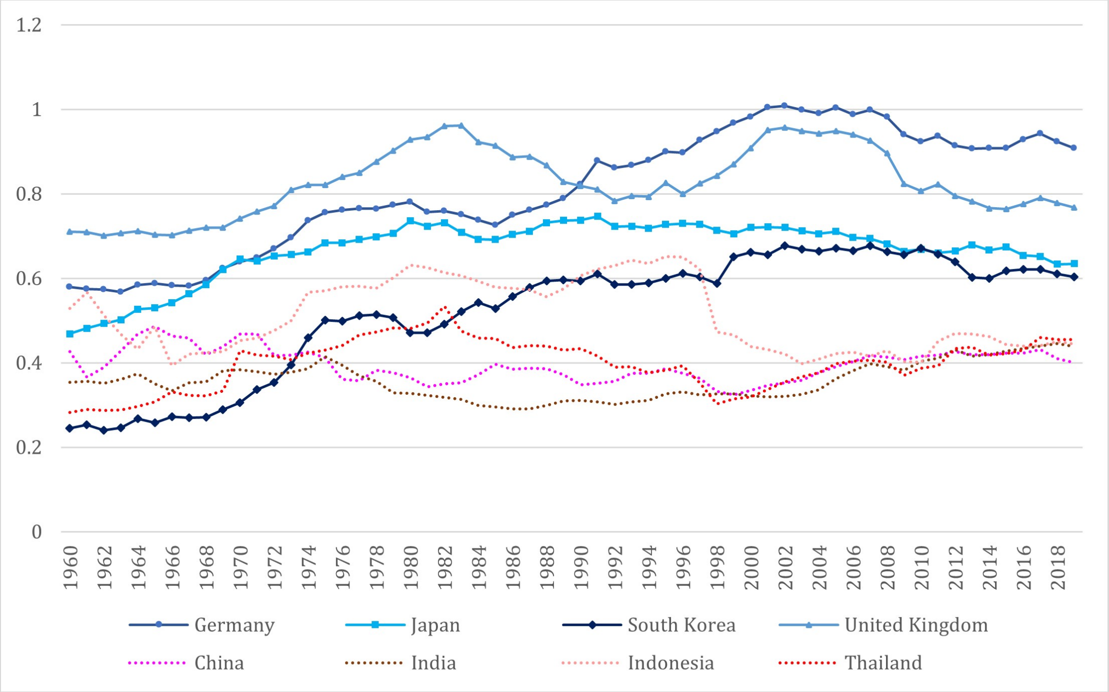
Several studies conducted by the National Bureau of Economic Research, like the ones by Alston and Pardey (2020) and Klenow and Li (2021), have shown that technological innovation is a critical factor in the growth of outputs, even with a given quantity of labour and capital stocks. Figure 1.1 illustrates the total factor productivity (TFP) levels of selected developed and developing countries from 1960 to 2018 at a constant purchasing power parity (PPP) rate. The chart indicates significant improvements in TFP levels over time for developed countries such as Germany, Japan, the Republic of Korea or South Korea, and the United Kingdom. In contrast, developing countries like the People's Republic of China, India, Indonesia, and Thailand have seen only a slight improvement in their TFP levels. This disparity in TFP levels is closely tied to economic growth, national income, and people's welfare.

The aggregate impact of technological creation on productivity can be seen in an economy's GDP. The GDP is a critical indicator of a country's economic growth, national income, and the standard of living of its citizens. The increase in GDP per capita worldwide reflects the positive impact of technological innovation on people's welfare. The levels of economic growth, national income, and people's welfare vary significantly between developed and developing countries. Various factors influence the economic growth levels of different countries. Among these factors, institutional quality, human capital, and investment in research and development (R&D) are particularly significant. The presence of robust institutions that support economic activity, a well-educated and skilled workforce, and a culture of innovation, are all crucial elements that contribute to economic growth. These factors are especially important in developing countries, where they can stimulate rapid economic development.

Hence, technological innovation is a crucial factor that drives competition in the market and boosts productivity levels. It has contributed significantly to the growth of an economy's GDP, which has led to an increase in people's living standards worldwide. The impact of technological innovation on economic development, national income, and people's welfare varies significantly between developed and developing countries.

The UNESCO Institute for Statistics (UIS) is accountable for collecting detailed information on the spending patterns of every country's research and development (R&D). In general, developed countries tend to invest considerably more in R&D activities than their developing counterparts. This is due to various factors, including access to funding, government support, and the availability of highly skilled researchers. The UIS data shows that this divide between developed and developing countries continues to widen,

Figure 1.1: TFP Level at Current PPPs - tracks Total Factor Productivity (TFP) levels at constant Purchasing Power Parity (PPP) rates for one country relative to the US in terms of the prices.



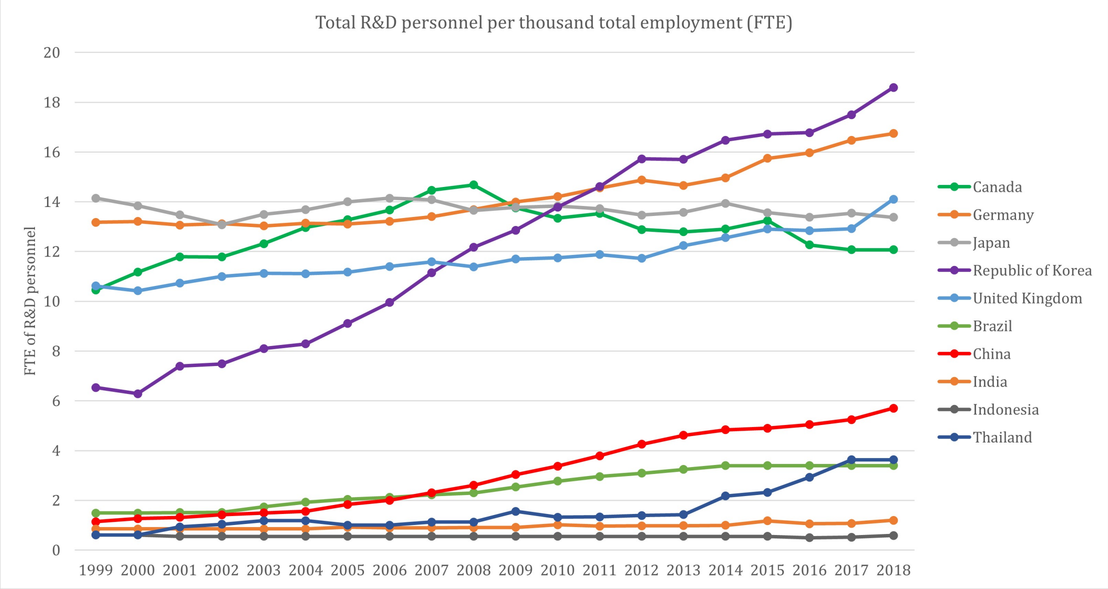
Source: Penn World Table, University of Groningen (https://febpwt.webhosting.rug.nl, accessed March 31,2022)

which could have long-term implications for global innovation and scientific progress. This investment in R&D enhances the capacity and contributes to the economic growth of developed countries, as they benefit from the gains as a part of their national income and welfare. Developed countries are often at the forefront of innovation while developing countries adopt new technologies at a rapid pace. The investment in R&D should be directly proportional to the number of skilled workers, which often highlights the gap between developed and developing countries.

Figure 1.2 presents a comprehensive analysis of the total R&D personnel per thousand total employment (FTE) in five developed countries, namely Japan, Germany, the United Kingdom, Canada, and the Republic of Korea, and five developing countries, including Brazil, the People's Republic of China, India, Indonesia, and Thailand. The data reveals that developed countries have a significantly higher number of R&D personnel compared to developing countries. For instance, Canada ranks first among countries with the highest number of R&D personnel per thousand total employment at 18.59. Germany comes in second place with 16.74, followed by Japan at 14.68, and the United Kingdom at 14.15. In contrast, developing countries have significantly lower numbers of R&D personnel, except for the Republic of Korea, which has a high performance in developing. The People's Republic of China has the highest number of R&D personnel among developing countries at 5.70, followed by Thailand at 3.63, Brazil at 3.39, India at 1.20, and Indonesia at 0.61.

The data shows that the gap in R&D personnel between developed and developing countries is a significant cause of the knowledge gap between the two. The need for R&D personnel in developing countries significantly affects innovation and productivity, which ultimately impacts economic growth. It is crucial for developing countries to allocate resources towards R&D personnel in order to narrow the gap between themselves and the advanced economies and to stimulate innovation. Failing to do so would mean risking a fall behind and losing the potential for sustained growth and prosperity.

Figure 1.2: Total R&D personnel per thousand total employment (FTE).



Source: the UNESCO Institute for Statistics (UIS) (http://data.uis.unesco.org, accessed March 06,2022)

This study aims to explore the impact of technology on productivity and economic growth, drawing on the works of Krugman (1991) and Acemoğlu (2007). Both authors have discussed the role of technology in the production process and its impact on endogenous productivity. While other recent literature suggests that technology should be considered as an external factor, recent innovations, such as machines used in the agricultural and manufacturing sectors, have become complementary to these processes, making technological creation and innovation essential for economic growth and productivity.

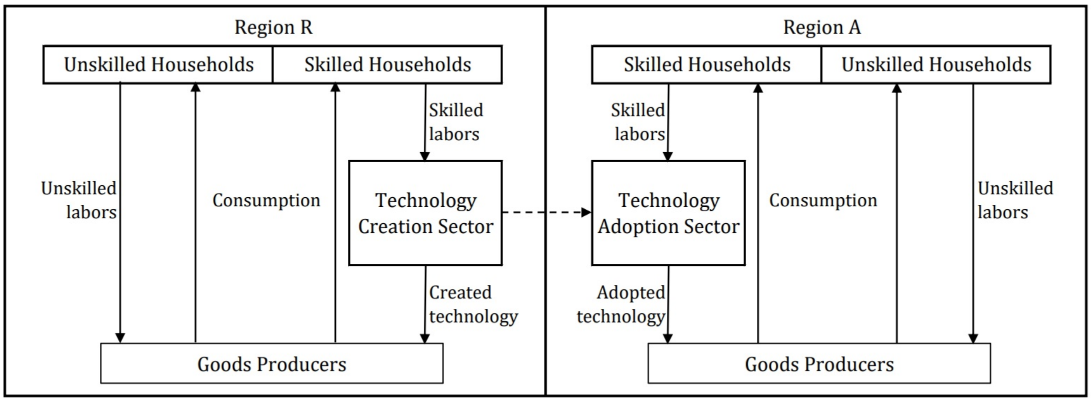
To achieve this goal, this study will draw on the theoretical framework of Anzoategui et al. (2019), which asserts that technological creation is key for production dynamics and growth by the assumption of a New Keynesian dynamic stochastic general equilibrium (DSGE) model. Galí (1999) and Smets and Wouters (2003) have also explored endogenous shocks that can affect economic growth and fluctuations. They have demonstrated that endogenous shocks have a significant impact on the economy, and understanding them is crucial for policymakers. While Kolasa (2009), Galí (2014), and Kollmann et al. (2016) have studied how exogenous shocks and volatility factors in monetary terms impact economies in a two-country DSGE model, there are also various studies on endogenous dynamics and their transmission between two countries through the lens of the New Keynesian model as in Lubik and Schorfheide (2005) and Jang and Okano (2013).

This study is particularly relevant to economic policy and the outcome of variable shocks, and will based on some of above literature model construction and methodology. The study will focus on the endogenous dynamics and transmission of technological shocks between two countries through the Real Business Cycle (RBC) model. In addition, this study will analyse the effects of these shocks on economic growth, productivity, and fluctuations. By doing so, this study aims to contribute to the themes of endogenous technology as a key driver of growth and its determination.

It is widely acknowledged that technological innovation plays an important role in driving economic growth. However, the creation and impact of technology are complicated topics that require careful examination. There has been extensive research on the role of technology and its impact on production, which underlines the significant role of technological innovation in driving economic growth. For example, Acemoğlu (2003) and Caselli and Coleman II (2006) analysed the impact on the marginal productivity of capital and labour. Their insightful analysis shed light on the key drivers of economic growth and highlighted the significant role that technological progress can play in enhancing productivity and output. Other studies by Aghion and Howitt (1990), Romer (1996), and Acemoğlu (2002) have explored the relationship between productivity and endogenous technological response. Regarding endogenous technological change, those study indicates that it can significantly increase the marginal product of production, leading to biased marginal results. In addition, Acemoğlu (2010), Acemoğlu and Autor (2011), and Gancia et al. (2013) have examined the role of technological adoption as a substitution between technology and labour, with endogenous technological change is biased toward skilled labour and significantly affecting output growth.

On the other hand, Aghion and Howitt (2017) introduced innovation as a process of creative destruction that stimulates the marginal product of capital, determining the long-term growth rate. They noted that innovation plays a critical role in economic growth by driving creative destruction, which stimulates the marginal product of capital. Therefore, these studies underscore the pivotal part played by technological innovation in economic growth. By exploring the mechanisms of technology and its impact on production, focusing on these matters advances our understanding of how innovation drives economic growth and development.

Figure 1.3: Overview Theoretical Framework



Source: Extended framework based on theoretical study of Gancia et al. (2013) and Anzoategui et al. (2019)

This study delves into the creation of advanced technological systems through the process of R&D and the adoption of pre-existing technologies in a closed economic system. We focus on two regions that are identical and symmetrical in almost every aspect except for their methods of technological creation or adoption; see Figure 1.3 as the overview theoretical framework. The region which creates technology with R&D section is referred to as region R, while the region which adopts the technologies of region R is named region A. This study also takes into account the two types of households that exist in the economy: skilled and unskilled. Skilled households are responsible for providing their labour force to work in the technology sector and produce intermediate goods. In contrast, unskilled households work in the manufacturing sector to produce the final goods. This study uses an RBC model with heterogeneous households, allowing for additional analysis of the effects of the endogenous mechanism on the economy based on the theoretical framework of Gancia et al. (2013) and Anzoategui et al. (2019) to answer the questions of how does an economy perform under technology adoption in developing countries compared to technology creation in an advanced economy, how does economic growth respond to technology shock, and how much of economic adjustment does the endogenous mechanism account.

The structure of this study is as follows: Section 1.2 outlines a RBC model that takes into account households with distinct characteristics while incorporating diverse technology mechanisms within each region. Section 1.3 presents the estimation results and interprets the transmission of technology shocks on aggregate variables across both regions. The study concludes in Section 1.4, where the study also discusses potential avenues for further research.

1.2 The Model

This section discusses a model that combines a directed technical change framework developed by Gancia et al. (2013) and non-standard endogenous productivity and skilled labour features as proposed by Anzoategui et al. (2019). The main attribute of this model is the concept of endogenous productivity, which is performed through technology creation in two symmetric regions. The first region, called region R, represents the area where technology is created through research and development (R&D). The second region, region A, represents the area where technology is adopted.

This model assumes a closed economy and is based on Krugman's assumption (Krugman, 1991) with two productive sectors: manufacturing and technology creation. The manufacturing sector produces goods and services, while the technology creation sector is responsible for R&D and adopting new technology. Additionally, the model features two types of labour: unskilled and skilled. Unskilled labour is used in manufacturing, while skilled labour is employed in technology creation. These labour types are not allowed to move or migrate across regions.

1.2.1 Households

In each region A and R of two closed economy, there is a representative household for each skill level. These households contribute to the economy by supplying unskilled labour to good producers and skilled labour to the technology sector. As a result, they receive wages that are related to their respective types of labour. Each household possesses unique characteristics determining their lifetime utility for unskilled and skilled labour.

The current period utility of **unskilled households** is a function of their consumption $C_{Ui,t}$ and unskilled type of labour $N_{Ui,t}$ given by

$$U(C_{Ui,t}, N_{Ui,t}) = \log C_{Ui,t} + \chi_{Ui} \log(1 - N_{Ui,t}) \quad ,$$

where i stands for region in which $i \in \{R, A\}$ and χ_{Ui} denotes the unskilled labour weights in utility.

The representative unskilled household encounters with their utility maximisation problem,

$$\max_{C_{Ui,t}, N_{Ui,t}} E_t \sum_{t=0}^{\infty} \beta_{Ui}^t [U(C_{Ui,t}, N_{Ui,t})] \quad ,$$

subject to their budget and borrowing constraints,

$$C_{Ui,t} + R_{i,t-1}B_{i,t-1} = B_{i,t} + W_{Ui,t}N_{Ui,t} \quad ,$$
$$(R_{i,t} - 1 + \nu_i)B_{i,t} \leq \psi_i W_{Ui,t}N_{Ui,t} \quad ,$$

where $\beta_{Ui,t}$ is a borrowers' discount factor for the representative unskilled household in each region i. The term $R_{i,t-1}B_{i,t-1}$ is the amount of paying back money with interest rate $R_{i,t-1}$ in period $t-1$, $B_{i,t}$ is borrowed money, and $W_{Ui,t}$ is a wage of unskilled labour. In addition, a parameter ν_i is debt cost parameter and ψ_i is the exogenous payment-to-income (PTI) ratio.

Then, the maximisation problem can be rewritten as Lagrangian function as follows:

$$\begin{aligned}\max_{C_{Ui,t},N_{Ui,t}} E_t \sum_{t=0}^{\infty} \beta_{Ui}^t \{ & \log C_{Ui,t} + \chi_{Ui} \log(1 - N_{Ui,t}) \\ & + \Lambda_{Ui,t}[B_{i,t} + W_{Ui,t}N_{Ui,t} - C_{Ui,t} - R_{i,t-1}B_{i,t-1}] \\ & + \Lambda_{Ui,t}\mu_{Ui,t}[\psi_i W_{Ui,t}N_{Ui,t} - (R_{i,t} - 1 + \nu_i)B_{i,t}]\} \quad ,\end{aligned}$$

where $\Lambda_{Ui,t}$ is an unskilled labour's shadow price of budget and $\mu_{Ui,t}$ is an unskilled labour's shadow value of borrowing.

The optimality conditions for consumption of unskilled labour, the amount of unskilled labour, and borrowing are given by

$$C_{Ui,t}: \ \Lambda_{Ui,t} = \frac{1}{C_{Ui,t}} \quad , \tag{1.1}$$
$$N_{Ui,t}: \ (1 + \psi_i \mu_{Ui,t})W_{Ui,t}\Lambda_{Ui,t} = \frac{\chi_{Ui}}{1 - N_{Ui,t}} \quad , \tag{1.2}$$
$$B_{i,t}: \ \beta_{Ui} E_t \frac{\Lambda_{Ui,t+1}}{\Lambda_{Ui,t}} R_{i,t} + \mu_{Ui,t}(R_{i,t} - 1 + \nu_i) = 1 \tag{1.3}$$

respectively.

In addition, the current period utility of **skilled households** is a function of their consumption $C_{Si,t}$ and skilled type of labour $N_{Si,t}$ of the following form:

$$U(C_{Si,t}, N_{Si,t}) = \log C_{Si,t} + \chi_{Si} \log(1 - N_{Si,t}) \quad ,$$

where χ_{Si} denotes the skilled labour weights in utility.

The representative skilled households encounter the following maximisation problem,

$$\max_{C_{Si,t},N_{Si,t}} \quad E_t \sum_{t=0}^{\infty} \beta_{Si}^t [U(C_{Si,t}, N_{Si,t})] \quad ,$$

subject to their budget constraint,

$$C_{Si,t} + B_{i,t} = R_{i,t-1}B_{i,t-1} + W_{Si,t}N_{Si,t} \quad ,$$

where $\beta_{Si,t}$ is a savers' discount factor for the representative skilled household in each region i, $B_{i,t}$ is the amount of loans in period t, $R_{i,t-1}B_{i,t-1}$ is paying back money from the loans in period t with interest, $R_{i,t-1}$, and $W_{Si,t}$ is a wage of skilled labour.

Then, the maximisation problem for skilled households can be rewritten as Lagrangian function as follows

$$\begin{aligned} \max_{C_{Si,t},N_{Si,t}} \quad & E_t \sum_{t=0}^{\infty} \beta_{Si}^{t} \{\log C_{Si,t} + \chi_{Si} \log(1 - N_{Si,t}) \\ & \qquad + \Lambda_{Si,t}[R_{i,t-1}B_{i,t-1} + W_{Si,t}N_{Si,t} - C_{Si,t} - B_{i,t}]\} \quad , \end{aligned}$$

where $\Lambda_{Si,t}$ is a skilled labour's shadow price of budget.

The optimality conditions for consumption of skilled labour, the amount of skilled labour, and the loans are given by

$$C_{Si,t}: \ \Lambda_{Si,t} = \frac{1}{C_{Si,t}} \quad , \tag{1.4}$$

$$N_{Si,t}: \ \Lambda_{Si,t}W_{Si,t} = \frac{\chi_{Si}}{1 - N_{Si,t}} \quad , \tag{1.5}$$

$$B_{i,t}: \ \beta_{Si}E_t\frac{\Lambda_{Si,t+1}}{\Lambda_{Si,t}}R_{i,t} = 1 \tag{1.6}$$

respectively.

1.2.2 Firms

In each region a final good is produced by combining the manufacturing and the technology creation sectors. In region R, technology creation is produced through R&D, which requires skilled labour to work towards developing new technologies. In addition, region A requires skilled labour to adopt existing technology. Therefore, there is a need for skilled labour to work in both regions for the successful creation and adoption of technology.

The representative and competitive final good production for **region** R can be written as follows:

$$Y_{R,t} = \left[\int_0^{T_t} (y_{R,t}^{j})^{\frac{1}{\sigma_R}} dj\right]^{\sigma_R} \quad , \sigma_R > 1 \quad ,$$

where $Y_{R,t}$ is the numeric good with price $P_{R,t} = 1$, T_t denotes a stock of created technology, and σ_R stands for the final goods mark up in region R. The term $y^j_{R,t}$ represents the amount of variety goods j and the demand for variety $j \in [0, T_t]$ follows from the profit maximisation problem is as follows:

$$\max_{y^j_{R,t} \geq 0} \left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R} - \int_0^{T_t} (p^j_{R,t} y^j_{R,t}) dj \quad ,$$

which yields the inverse demand function which follows from the optimality condition for output:

$$\begin{aligned} y^j_{R,t}: \quad \sigma_R \left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R - 1} \frac{1}{\sigma_R} (y^j_{R,t})^{\frac{1}{\sigma_R} - 1} - p^j_{R,t} = 0 \\ p^j_{R,t} &= \left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R - 1} (y^j_{R,t})^{\frac{1}{\sigma_R} - 1} \\ &= \frac{\left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R}}{\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj} (y^j_{R,t})^{\frac{1}{\sigma_R} - 1} \\ &= \frac{Y_{R,t}}{(Y_{R,t})^{\frac{1}{\sigma_R}}} (y^j_{R,t})^{\frac{1}{\sigma_R} - 1} \\ &= \frac{1}{(Y_{R,t})^{\frac{1}{\sigma_R} - 1}} (y^j_{R,t})^{\frac{1}{\sigma_R} - 1} \\ \therefore p^j_{R,t} &= \left(\frac{y^j_{R,t}}{Y_{R,t}} \right)^{\frac{1}{\sigma_R} - 1} \equiv p^j_{R,t}(y^j_{R,t}) \quad , \end{aligned} \tag{1.7}$$

where $p^j_{R,t}$ also denotes a price level of variety goods j in region R.

Monopolistic intermediate good production of variety $j \in [0, T_t]$ can be described as

$$y^j_{R,t} = N^j_{UR,t} \quad . \tag{1.8}$$

Intermediate good producers demand unskilled labour to maximise their profits

$$\begin{aligned} \max_{N^j_{UR,t}} \; p^j_{R,t}(y^j_{R,t}) \cdot y^j_{R,t} - W_{UR,t} N^j_{UR,t} &\equiv \max_{N^j_{UR,t}} \left(\frac{y^j_{R,t}}{Y_{R,t}} \right)^{\frac{1}{\sigma_R} - 1} \cdot y^j_{R,t} - W_{UR,t} N^j_{UR,t} \\ &\equiv \max_{N^j_{UR,t}} \left(\frac{N^j_{UR,t}}{Y_{R,t}} \right)^{\frac{1}{\sigma_R} - 1} \cdot N^j_{UR,t} - W_{UR,t} N^j_{UR,t} \\ &\equiv \max_{N^j_{UR,t}} \frac{(N^j_{UR,t})^{\frac{1}{\sigma_R}}}{(Y_{R,t})^{\frac{1}{\sigma_R} - 1}} - W_{UR,t} N^j_{UR,t} \quad . \end{aligned}$$

The optimality condition for unskilled labour is given by

$$\begin{aligned}
\frac{1}{\sigma_R}\left(\frac{N_{UR,t}}{Y_{R,t}}\right)^{\frac{1}{\sigma_R}-1} - W_{UR,t} = 0 \\
W_{UR,t} &= \frac{1}{\sigma_R}\left(\frac{N_{UR,t}}{Y_{R,t}}\right)^{\frac{1}{\sigma_R}-1} \\
&= \frac{1}{\sigma_R}\left(\frac{y^j_{R,t}}{Y_{R,t}}\right)^{\frac{1}{\sigma_R}-1} \\
\therefore W_{UR,t} &= \frac{1}{\sigma_R} p^j_{R,t} \quad . \qquad (1.9)
\end{aligned}$$

However, the wages of unskilled workers are lowered because a value of σ_R is assumed to be greater than one, which causes $1/\sigma_R$ to be less than one, relative to a competitive economy. The producer of variety j therefore makes a profit:

$$\begin{aligned}
\pi^j_{R,t} &= p^j_{R,t}(y^j_{R,t}) \cdot y^j_{R,t} - W_{UR,t}N^j_{UR,t} \\
&= p^j_{R,t}y^j_{R,t} - \frac{1}{\sigma_R}p^j_{R,t}y^j_{R,t} \\
\therefore \pi^j_{R,t} &= \left(1 - \frac{1}{\sigma_R}\right) p^j_{R,t}y^j_{R,t} \quad . \qquad (1.10)
\end{aligned}$$

Note that the final good production can be expressed as

$$\begin{aligned}
Y_{R,t} &= \left[\int_0^{T_t} (N^j_{UR,t})^{\frac{1}{\sigma_R}} dj\right]^{\sigma_R} \\
&= \left[\int_0^{T_t} \left(\frac{N_{UR,t}}{T_t}\right)^{\frac{1}{\sigma_R}} dj\right]^{\sigma_R} \\
&= \frac{N_{UR,t}}{T_t}\left[\int_0^{T_t} (1) dj\right]^{\sigma_R} \\
&= \frac{N_{UR,t}}{T_t} T_t^{\sigma_R} \\
\therefore Y_{R,t} &= T_t^{\sigma_R - 1} N_{UR,t} \quad ,
\end{aligned}$$

where the aggregate unskilled labour demand $N^j_{UR,t} = N_{UR,t}/T_t$.

We apply the above final good production to rewrite the inverse demand function,

$$\begin{aligned} p^j_{R,t} &= \left(\frac{y^j_{R,t}}{Y_{R,t}}\right)^{\frac{1}{\sigma_R}-1} \\ &= \left(\frac{N^j_{UR,t}}{T_t^{\sigma_R-1}N_{UR,t}}\right)^{\frac{1}{\sigma_R}-1} \\ &= \left(\frac{1}{T_t^{\sigma_R}}\right)^{\frac{1}{\sigma_R}-1} \\ \therefore p^j_{R,t} &= T_t^{\sigma_R-1} \quad . \end{aligned}$$

Therefore, the profit function of the representative and competitive final good production can be written as

$$\begin{aligned} \pi_{R,t} &= \left(1-\frac{1}{\sigma_R}\right)p_{R,t}y_{R,t} \\ &= \left(1-\frac{1}{\sigma_R}\right)T_t^{\sigma_R-1}\frac{N_{UR,t}}{T_t} \\ \therefore \pi_{R,t} &= \left(1-\frac{1}{\sigma_R}\right)T_t^{\sigma_R-2}N_{UR,t} \quad . \end{aligned} \tag{1.11}$$

These are similar for **region** A where the representative and competitive final good production for region A can be written as

$$Y_{A,t} = \left[\int_0^{A_t}(y^j_{A,t})^{\frac{1}{\sigma_A}}dj\right]^{\sigma_A}, \sigma_A > 1 \quad ,$$

where $Y_{A,t}$ is the numeric good with price $P_{A,t} = 1$, A_t denotes a stock of adopted technology, and σ_A stands for the final goods mark up in region A. A term $y^j_{A,t}$ represents the amount of variety goods j and the demand for variety $j \in [0, A_t]$ follows from the profit maximisation problem is the following:

$$\max_{y^j_{A,t}\geq 0} \quad \left[\int_0^{A_t}(y^j_{A,t})^{\frac{1}{\sigma_A}}dj\right]^{\sigma_A} - \int_0^{A_t}(p^j_{A,t}y^j_{A,t})dj \quad ,$$

which also yields the inverse demand function which follows from the optimality condition for output:

$$p^j_{A,t} = \left(\frac{y^j_{A,t}}{Y_{A,t}}\right)^{\frac{1}{\sigma_A}-1} \equiv p^j_{A,t}(y^j_{A,t}) \quad , \tag{1.12}$$

where $p^j_{A,t}$ also denotes a price level of variety goods j in region A.

Since, the profit of competitive market is normal profit, $\pi_{A,t} = 0$, then

$$P_{A,t}Y_{A,t} = \int_0^{A_t} (p^j_{A,t} y^j_{A,t}) dj \quad .$$

Monopolistic intermediate good production of variety $j \in [0, A_t]$ can be described as

$$y^j_{A,t} = N^j_{UA,t} \quad .$$

Intermediate good producers demand unskilled labour to maximise their profits

$$\max_{N^j_{UA,t}} \quad p^j_{A,t}(y^j_{A,t}) \cdot y^j_{A,t} - W_{UA,t}N^j_{UA,t} \quad \Rightarrow \max_{N^j_{UA,t}} \quad \frac{(N^j_{UA,t})^{\frac{1}{\sigma_A}}}{(Y_{A,t})^{\frac{1}{\sigma_A}-1}} - W_{UA,t}N^j_{UA,t} \quad .$$

The optimality condition for unskilled labour is given by

$$W_{UA,t} = \frac{1}{\sigma_A} p^j_{A,t} \quad . \tag{1.13}$$

Because $1/\sigma_A$ is less than 1, then the unskilled wages are marked down relative to a competitive economy. The production of variety j therefore makes a profit:

$$\pi^j_{A,t} = \left(1 - \frac{1}{\sigma_A}\right) p^j_{A,t} y^j_{A,t} \quad .$$

Hence, the final good production function for the representative and competitive final good production in region A can be derived as

$$\begin{aligned} Y_{A,t} &= \left[\int_0^{A_t} (N^j_{UA,t})^{\frac{1}{\sigma_A}} dj\right]^{\sigma_A} \\ &= \left[\int_0^{A_t} \left(\frac{N_{UA,t}}{A_t}\right)^{\frac{1}{\sigma_A}} dj\right]^{\sigma_A} \\ &= \frac{N_{UA,t}}{A_t}\left[\int_0^{A_t} (1) dj\right]^{\sigma_A} \\ \therefore Y_{A,t} &= A_t^{\sigma_A - 1} N_{UA,t} \quad , \end{aligned}$$

where the aggregate unskilled labour demand $N^j_{UA,t} = N_{UA,t}/A_t$.

Applying the final good function to rewrite the inverse demand function as follows:

$$\begin{aligned}
p^j_{A,t} &= \left(\frac{y^j_{A,t}}{Y_{A,t}}\right)^{\frac{1}{\sigma_A}-1} = \left(\frac{N^j_{UA,t}}{A_t^{\sigma_A-1}N_{UA,t}}\right)^{\frac{1}{\sigma_A}-1} \\
&= \left(\frac{1}{A_t^{\sigma_A}}\right)^{\frac{1}{\sigma_A}-1} \\
p^j_{A,t} &= A_t^{\sigma_A-1} \quad .
\end{aligned}$$

Therefore, the profit function of the representative and competitive final good production can be written as

$$\begin{aligned}
\pi_{A,t} &= \left(1-\frac{1}{\sigma_A}\right)p_{A,t}y_{A,t} \\
&= \left(1-\frac{1}{\sigma_A}\right)A_t^{\sigma_A-1}\frac{N_{UA,t}}{A_t} \\
\therefore \pi_{A,t} &= \left(1-\frac{1}{\sigma_A}\right)A_t^{\sigma_A-2}N_{UA,t} \quad . \qquad (1.14)
\end{aligned}$$

1.2.3 Technology creators in region R

As mention previously, a final good is produced by combining the manufacturing and also the technology creation sectors. Specifically, in region R, the innovator (technology creator) produces new technologies through research and development (R&D), while the technology adopter (another type of technology creator) produces by adopting existing technologies in the region A. To develop new technologies, firms in the region R require skilled labour to work towards that objective. This study defines τ_t as the number of technologies that will be available at time $t+1$ that each unit of skilled labour can create.

Assuming that τ_t is produced by

$$\tau_t = \omega_t T_t N_{SR,t}^{\theta_R-1} \quad , \qquad (1.15)$$

which is the period creation of new technology function. The term $\theta_R - 1$ is the share of skill labour in new technology creation. Assuming that technology creating process is elastic with $\theta_R < 1$ which implies a diminishing aggregate level of technology creation. In addition, the term ω_t is the technology shocks which satisfies the law of motion,

$$\log\omega_t = (1-\rho_\omega)\log\bar{\omega} + \rho_\omega\log\omega_{t-1} + \epsilon_{\omega_t} \quad , \qquad (1.16)$$

where $\epsilon_{\omega_t} \sim i.i.d.N(0, \sigma_\omega)$ and ρ_ω states the degree of persistence of technology shocks and $\bar{\omega}$ is a steady state of shock to R&D technology.

Let $V_{R,t}$ be the value of a new technology then the maximisation problem of technology creation firm f is

$$\max_{N^f_{SR,t}} \theta_R \beta_{SR} E_t \frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \tau_t N^f_{SR,t} - W_{SR,t} N^f_{SR,t} \quad ,$$

yielding an optimality condition that determines the wage,

$$W_{SR,t} = \theta_R \beta_{SR} E_t \left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \tau_t \right] \quad . \tag{1.17}$$

Let ξ_R be the survival rate of any existing technology for region R. Then, the evolution of technologies can be expressed as follows:

$$T_{t+1} = \xi_R T_t + \tau_t N_{SR,t} \quad , \tag{1.18}$$

where a term $\tau_t N_{SR,t}$ is the creation of new technologies and $\xi_R T_t$ reflects the remaining technologies.

Suppose there is an existing stock of technology with multiple varieties available. If a new variety, defined as j, is introduced to this existing stock, then the producer of this new variety will have to buy its patent at a certain cost, denoted as $V_{R,t}$. However, the producer can expect to earn perpetual profits, represented by $\pi_{R,t}$, unless the technology becomes obsolete or dies out. If the technology does become outdated, however, the producer will no longer be able to generate any profits from it. Therefore,

$$V_{R,t} = -W_{SR,t} N_{SR,t} + \Omega_{R,t} N_{SR,t} + \xi_R \beta_{SR} E_t \left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} V_{R,t+1} \right] \quad , \tag{1.19}$$

where $\Omega_{R,t}$ is the value of created technology contribution and $\Omega_{R,t} = (1+\gamma_T)^t \eta_R (\tau_t / T_t)$ which η_R is a constant scaling parameter for periodic value of created technology.

1.2.4 Technology adopters in region A

For region A to thrive in the technology sector, it must implement new technologies and recruit skilled labour to work with these new technologies, much like the prosperous region R. Let us denote Φ_t as the number of newly adopted technologies available at $t+1$ that each unit of skilled labour in the region A is capable of producing. Assuming that Φ_t can be written as

$$\Phi_t = \frac{\kappa A_t T_{t-1} N_{SA,t}^{\theta_A - 1}}{\rho(1+\gamma_T)^{t-1}} \quad , \tag{1.20}$$

which is the period creation of newly adopted technology function. This period is determined by the degree of adopting ability, which is denoted by the parameter κ and takes values within the range of $\kappa \in (0,1)$. The parameter ρ is a scaling parameter for an interaction between the current adoption of technology and the previous creation of technology and γ_T denotes the growth rate of technology.

Let $V_{A,t}$ be the value of a new adopted technology then the maximisation problem of technology creation firm f is

$$\max_{N_{SA,t}^f} \theta_A \beta_{SA} E_t \frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \frac{V_{A,t+1}}{A_{t+1}} \Phi_t N_{SA,t}^f - W_{SA,t} N_{SA,t}^f \quad ,$$

yielding an optimality condition that provides the wage function as follows:

$$W_{SA,t} = \theta_A \beta_{SA} E_t \left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \frac{V_{A,t+1}}{A_{t+1}} \Phi_t \right] \quad . \tag{1.21}$$

Given ξ_A be the survival rate of any existing technology for region A which is the same rate as in region R. Then, the evolution of adopted technologies can be expressed as

$$A_{t+1} = \xi_A A_t + \Phi_t N_{SA,t} \quad , \tag{1.22}$$

where a term $\Phi_t N_{SA,t}$ is the adoption of additional new adopted technologies and $\xi_A A_t$ reflects the remaining adopted technologies.

If a new variety j is added to the existing stock of technology, the producer of this variety can expect a perpetual profit $\pi_{A,t}$ unless the technology dies. Hence,

$$V_{A,t} = -W_{SA,t} N_{SA,t} + \Omega_{A,t} N_{SA,t} + \xi_A \beta_{SA} E_t \left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} V_{A,t+1} \right] \quad , \tag{1.23}$$

where $\Omega_{A,t}$ is the value of adopted technology contribution and $\Omega_{A,t} = (1+\gamma_T)^t \eta_A (\Phi_t / A_t)$ which η_A is a constant scaling parameter for periodic value of adopted technology.

1.2.5 Aggregation for region R

The constant elasticity of substitution (CES) aggregation of the differentiated final goods yields:

$$Y_{R,t} = \left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R} \quad . \tag{1.24}$$

Intermediate goods production function is defined the following:

$$y^j_{R,t} = N^j_{UR,t} \quad . \tag{1.25}$$

From the definition of aggregate unskilled labour demand,

$$\begin{aligned} N_{UR,t} &= T_t N^j_{UR,t} \\ \therefore N^j_{UR,t} &= \frac{N_{UR,t}}{T_t} \quad . \end{aligned} \tag{1.26}$$

Thus, the aggregate production function can be written as

$$Y_{R,t} = T_t^{\sigma_R - 1} N_{UR,t} \quad . \tag{1.27}$$

The aggregate consumption can be expressed by

$$C_{R,t} = C_{SR,t} + C_{UR,t} \quad . \tag{1.28}$$

The aggregate skilled labour,

$$N_{SR,t} = N^f_{SR,t} \quad . \tag{1.29}$$

The aggregate labour can be written as

$$N_{SR,t} + N_{UR,t} = N_{R,t} = 1 \quad . \tag{1.30}$$

The aggregate intermediate producer profit,

$$\pi_{R,t} = T_t \pi^j_{R,t} \quad . \tag{1.31}$$

1.2.6 Aggregation for region A

The CES aggregation of the differentiated final goods yields:

$$Y_{A,t} = \left[\int_0^{A_t} (y^j_{A,t})^{\frac{1}{\sigma_A}} dj \right]^{\sigma_A} \quad . \tag{1.32}$$

Intermediate goods production function:

$$y^j_{A,t} = N^j_{UA,t} \quad . \tag{1.33}$$

From the definition of aggregate unskilled labour demand,

$$\begin{aligned} N_{UA,t} &= A_t N^j_{UA,t} \\ \therefore N^j_{UA,t} &= \frac{N_{UA,t}}{A_t} \quad . \end{aligned} \tag{1.34}$$

Thus, the aggregate production function can be written as

$$Y_{A,t} = A_t^{\sigma_A - 1} N_{UA,t} \quad . \tag{1.35}$$

The aggregate consumption can be expressed by

$$C_{A,t} = C_{SA,t} + C_{UA,t} \quad . \tag{1.36}$$

The aggregate skilled labour,

$$N_{SA,t} = N^f_{SA,t} \quad . \tag{1.37}$$

The aggregate labour can be written as

$$N_{SA,t} + N_{UA,t} = N_{A,t} = 1 \quad . \tag{1.38}$$

The aggregate intermediate producer profit,

$$\pi_{A,t} = A_t \pi^j_{A,t} \quad . \tag{1.39}$$

1.2.7 Market Clearing

The total outputs in each region i, $i \in \{R, A\}$, are allocated to the households' consumption. Therefore, goods market-clearing condition is given by

$$Y_{i,t} = C_{i,t} \quad . \tag{1.40}$$

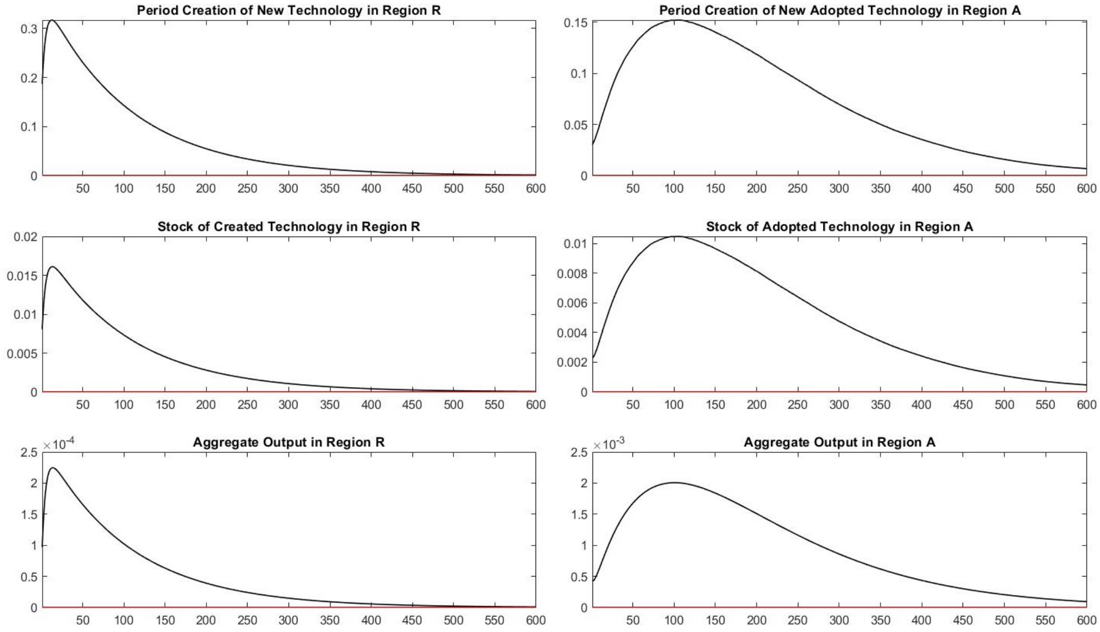
1.3 Results

This study focuses on analysing the impact of exogenous movements on endogenous productivity. It examines a shock to the technology R&D or technology creation shock. Before conducting the quantitative analysis using Dynare to evaluate the impact of a shock to technology R&D represented by a term ω_t on equilibrium variables, the model is solved by detrending the variables and then linearising around the certainty equivalent steady-state. The complete formation of model equations and their stationarised version can be found in Appendix 1.6.1 and 1.6.2. Numerical values used in this analysis are shown in Appendix 1.6.4, which were collected from Anzoategui et al. (2019), Emenogu and Michelis (2019), and a dissertation of Pathompituknukoon (2020). The research findings are presented in Figures 1.4, 1.5, and 1.6, which highlight selected variables that respond to a standard deviation technology R&D shock, ω_t. The left-hand side of these three figures shows the impulse response to one standard deviation technology R&D shock of region R, while the right-hand side is of region A.

The study found that a positive technology R&D shocks in region R resulted in a sudden increase in the number of new technologies, see the left side of Figure 1.4. This is because higher levels of R&D can enhance the number of newly created technologies or the marginal created technologies per skilled labour, leading to higher marginal benefits. Consequently, the technology creation sector employs more skilled labour, as shown in the left side of Figure 1.5. However, despite the increased demand, skilled households still face a labour supply shortage, as they prefer to work more due to the positive interest rate and expected future skilled wages.

When there is an excess demand for skilled labour due to a positive response to a technology R&D shock, several economic factors come into play. Firstly, the skilled wage increases, which incentivises skilled households to work more. Secondly, the skilled labour share also increases in the short run. This is because skilled households typically have a higher income level, which results in a higher consumption rate, as shown in the left-hand of Figure 1.5. They also tend to prefer saving more since the interest rate positively responds to the technology R&D shock. In addition, the technology level

Figure 1.4: Impulse response to one standard deviation positive technology R&D shock (a)



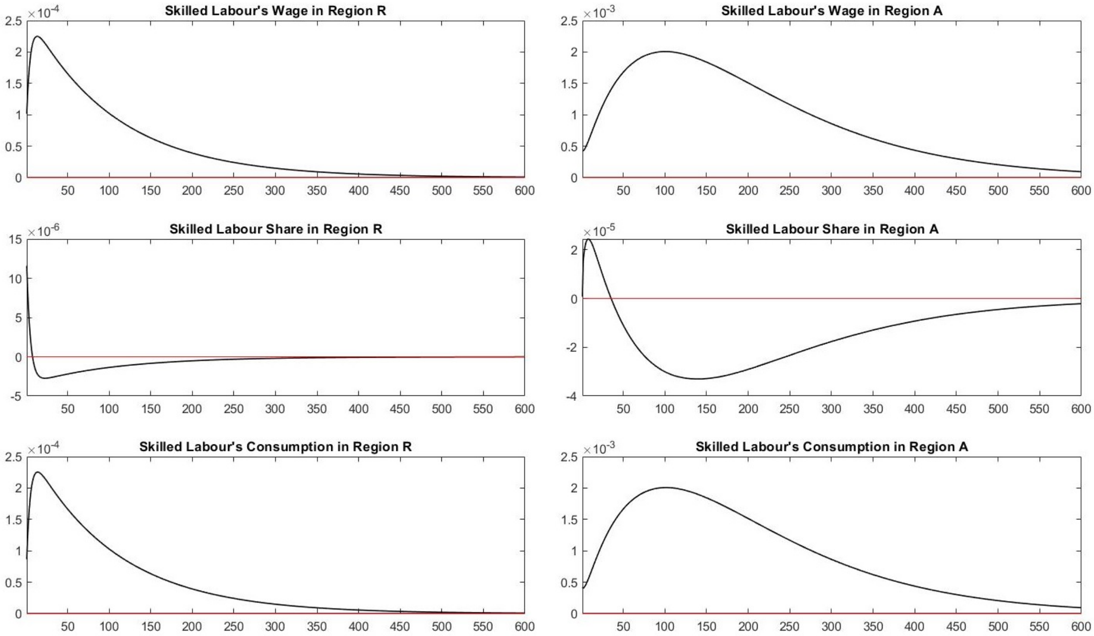
Source: Author's calculation

also experiences a positive response to the shock. This is because the creation of new technologies increases, leading to higher output in the region R, as shown in the left-hand of Figure 1.4.

The marginal product of unskilled labour also increases in response to the positive technology creation shock, which motivates firms to hire more unskilled labour, as shown in the left of Figure 1.6. This, in turn, creates an excess demand for unskilled labour. However, while the unskilled labour wage positively responds to the technology R&D shock, the unskilled labour share responds in the opposite direction. This is mainly due to the supply shortage of unskilled labour. Despite this, the consumption of unskilled labour remains positive because they receive higher incomes and can borrow to maintain a steady consumption rate. Overall, these economic factors work together to create a complex and dynamic system that responds to changes in technology and labour demand.

One of the transformative elements that significantly impact the result of technology creation shock on region R to region A is the delayed response of the technology adoption sector. This sector typically adopts new technologies by imitating them from another region or region R, which means that the benefits of adopting such technologies are not immediately realised. The adoption process takes some time to take effect, and thus, it is essential to understand the short-term impact of technology creation shock on the region, as shown in the right side of Figure 1.4.

Figure 1.5: Impulse response to one standard deviation positive technology R&D shock (b)



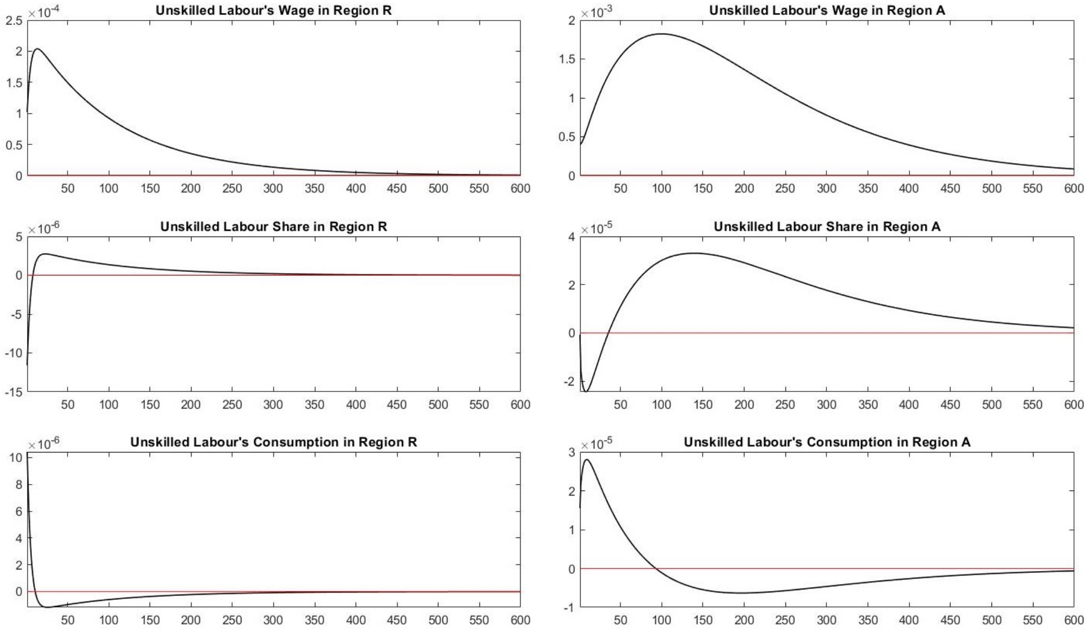
Source: Author's calculation

When a new technology is adopted, it leads to an increased marginal benefit, which in turn, drives up the demand for skilled labour. The technology adoption sector, being a significant player in this process, not only values but also depends heavily on the skills of its workforce, as shown in the right side of Figure 1.5. However, the supply of skilled labour remains constant, leading to excess demand. This excess demand creates a competitive environment where firms are willing to pay more elevated wages to attract skilled households, thereby highlighting the crucial role of skilled labour in the technology adoption sector.

Technological advancements not only lead to an increase in the wages of skilled labour but also elevate their share in the economy. This, in turn, triggers a rise in the consumption of skilled households due to their augmented income. Consequently, technology creation shock has a positive influence on the regional economy as a whole, stimulating an upsurge in the demand for skilled labour, higher wages, and increased consumption by skilled households.

Additionally, when firms adopt advanced technologies, it also leads to increased productivity and marginal output of unskilled labour, as presented in the right of Figure 1.6. This means that firms are able to hire more unskilled labour due to the higher demand for their services in the production process. However, unskilled households tend to have a lower supply of labour since they prefer to engage in more leisure activities and borrowing. This creates a situation where there is a higher wage for unskilled labour while their overall share in the labour market decreases. As a result of the higher wages, unskilled workers are able to earn more income and raise their consumption levels. This creates a positive cycle where increased productivity leads to higher wages and increased consumption, which in turn drives further economic growth.

FIGURE 1.6: Impulse response to one standard deviation positive technology R&D shock (c)



Source: Author's calculation

The process of the long-term adjustment mechanism can be visualised in Figures 1.4, 1.5, and 1.6. As shown in the figures, the region R experiences a sharp increase in the creation of new technologies, which is followed by a gradual decrease over time. Introducing these technologies results in a hike in both skilled and unskilled wages, which then converge to their steady-state values. The value of created technologies contribution in the R&D sector also experiences a sharp decrease initially before gradually increasing to its steady-state. This is because of the fact that the newly created technologies are initially in high demand, and their contribution to the R&D sector is significant. However, as time passes, the demand for these technologies decreases, leading to a decrease in their contribution to the R&D sector.

Simultaneously, the profits earned by good producers experience a sharp rise initially, which is then followed by a gradual decrease and converge to its steady-state. This is because the newly created technologies allow the good producers to reduce their production costs, which initially leads to an overflow in profits. However, as these technologies become more widespread, the cost reduction benefits decrease, leading to a gradual decrease in earnings over time. Therefore, the R&D sectors initially tend to hire less skilled labour and then gradually increase their workforce as the demand for creating new technologies decreases. On the other hand, the firms initially hire more unskilled labour and then gradually decrease their workforce as the cost reduction benefits of the new technologies become less significant. This adjustment process occurs over a long period, leading to a balanced and stable economy.

A decline in the interest rate can have a significant impact on the incentives for skilled and unskilled labours. Skilled labours tend to prefer more consumption, whereas unskilled labours prefer more work and less consumption. However, as the interest rate continues to decrease and eventually converges to zero or its steady state, the preferences of these groups will shift. Skilled labours will begin to prefer more work and less consumption as the interest rate approaches its steady-state. Conversely, unskilled labours will prefer less work and more consumption as the interest rate approaches zero. This shift in preferences will ultimately lead to a convergence of both groups towards their steady-state. As a result, the output of good producers will initially increase but will then gradually decrease as the interest rate continues to approach its steady-state. This is a complex economic phenomenon that can have widespread implications for both skilled and unskilled labours, as well as for those who rely on their products and services.

The region A has a unique long-term adjustment mechanism which controls the rate at which newly adopted technologies and the number of adopted technologies increase over time. This mechanism is influenced by the fact that skilled labour requires a significant amount of time to adopt these technologies from region R. The speed of technology adoption is then slow but steady. It is worth noting that the number of adopted technologies tends to decrease over time, eventually converging to its steady-state. While these technologies may lead to a substantial increase in skilled and unskilled wages in later periods, the wages will eventually decrease and converge to a steady state.

The contribution of adopted technologies to the sectors in which they are implemented is subject to a decrease over time due to the rising wages of skilled labour. However, the value of the adopted technologies' contribution will initially experience growth before eventually converging towards zero. Notably, the demand for skilled labour in these adopted sectors will sharply decrease, but it will increase before eventually converging towards its steady state. In response to the technology shock, the demand for unskilled labour will increase in the early periods for good producers. This is because the technology R&D shock leads to an increase in the demand for unskilled labour. However, the demand for unskilled labour by firms will eventually decrease and converge towards a steady state. It is also worth noting that the good producers' profit will slightly increase for a while before it turns to decrease and converge towards zero. This is because the firms will initially experience a boost in their productivity due to the adoption of new technologies. However, over time, the effect of this boost will begin to weaken and eventually fade, leading to a decline in profit to a steady state.

Over a period of time, the interest rate has experienced fluctuations in response to technology R&D shock. Initially, the interest rate started decreasing before it eventually increased and then converged to zero. On the other hand, the skilled labour supply initially responded negatively to the shock before turning positive. The skilled labour supply experienced a decline for some time before it eventually turned to increase and converged to zero. In contrast, the unskilled labour supply responded both positively and negatively to the shock. After the initial response, the supply then turned to increase and decrease until it eventually converged to its steady state over time.

The analysis indicates that there is a significant gap between the labour demands and labour supplies, resulting in an increase in employment opportunities. The skilled households initially experience a steep rise in consumption, which gradually declines and eventually reaches its steady-state after a period of time. On the other hand, the consumption behaviour of unskilled households responds positively to the shock, followed by a negative adjustment, and eventually converges to its steady state after an upward trend. Additionally, the output of good producers significantly increases in response to the technology R&D shock, followed by a decline in the growth rate, eventually converging to its steady state over time. These findings provide insights into the complex dynamics of the labour market, household consumption behaviour, and production output.

1.4 Conclusions

This chapter developed a Real Business Cycle (RBC) model with heterogeneous households and regions to study endogenous technology's role as the driving force of economic growth. The model has two regions: the technology creation (via research and development or R&D) region and the technology adoption region. Each region has similar sectors: households, technology sectors, and good producers. In addition, households are separated into skilled and unskilled types: skilled labour share is supplied to the technology sector, while unskilled labour share is supplied to good production. The model studies the effect, channel, and mechanical adjustment of technology creation or technology R&D shock on the economic growth in different regions. The parameter values are mainly collected from Anzoategui et al. (2019), and Emenugu and Michelis (2019) and some are calculated in the study.

The quantitative analysis established the following results. For the region R, the positive technology R&D shocks suddenly increase the amount of newly created technologies and then increase the stock of created technologies. This also pushes the output of the region R to grow. The more prominent created technologies imply the higher marginal benefit of skilled labour and the higher marginal product of unskilled labour. The labour wages and consumption are hence grown up. However, each type of labour share's response is in a different direction. The skilled labour share increases in response to the technology R&D shocks while the unskilled labour share decreases since the skilled labour seems to gain higher returns than the unskilled type.

Moreover, the positive technology shocks in the region R can affect the economy in the region A because the skilled labour in the region A can replicate or adopt the technology from another region. Thus, the more extensive stock of created technology causes a higher level of newly adopted technologies and a larger stock of adopted technologies. Then, the output is driven to a higher level such that the marginal benefit of skilled labour and the marginal product of unskilled labour are larger. These imply that they gain higher wages and they can then consume more. However, skilled labour will gain more wealth than unskilled labour. Then, there is more share of skilled labour while the share of unskilled labour is lessened. We notice that the direction of effect on most of the variables in the region A are similar to the region R. However, the size of changes in effect on the variable in the region A is larger because the economic variables in the region A are a more sensitive response to shocks than in the region R.

By the way, the results also present the long-run mechanism of adjustment. For the region R, the positive shock will continue increasing the amount of newly created technologies, the stock of created technologies, the aggregate output, the skilled labour's wage, the unskilled labour's wage, and the skilled household's consumption. However, those variables will decrease to a steady state in the long run. In the meantime, the skilled labour share will decrease from a positive value to a negative one. Then, it will increase to zero because the skilled household's return seems to reduce and converge to a steady state while the unskilled labour share responds to the shock in the opposite direction and then converges to a zero or steady state.

Additionally, unskilled consumption will decrease from positive to negative and then converge to zero over time because they are assumed to be borrowers who prefer to consume more in the present than in the future. For the region A, we can notice that the behaviour of variables is similar to the region R. However, there are time lags for the region A since the skilled labour in this region has to take time to replicate or adopt technology from the region R.

This study provides implications related to the endogenous technology mechanism and economic growth in two regions. The region with R$D or technology creation sector can boost its output, wages, consumption, and skilled labour share in the short term.

However, those variables will adjust themselves to respond to the positive technology shock convergence to their steady states in the long run since that shock is temporary. Meanwhile, the behaviour of variables in the region with the technology adoption sector also responds to the shock in the same direction, but they have lag movements and a larger scale of change in those variables. These results suggest that the technology improvement in R&D region should occur continually and permanently in order to drive economic growth in the long run. In contrast, the adopted technology region should accelerate technology improvement, for example, by training labour to be more skilled and increasing R&D funding to catch up and overcome another region.

In this model, there are some limitations as follows. First, the price is assumed to be fixed and normalised to be one. Second, the wage is considered to be a perfectly flexible adjustment. Those limitations can be relaxed by assuming assumptions of price and wage rigidities that might be employed in future studies.

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1.6 Appendix

1.6.1 Model Equations

The model equations are defined as follow:

$$\Lambda_{UR,t} = \frac{1}{C_{UR,t}} \tag{A.1}$$

$$\frac{\chi_{UR}}{1 - N_{UR,t}} = [1 + \psi_R \mu_{UR,t}]\Lambda_{UR,t} W_{UR,t} \tag{A.2}$$

$$\beta_{UR} \frac{E_t \Lambda_{UR,t+1}}{\Lambda_{UR,t}} R_{R,t} + \mu_{UR,t}(R_{R,t} - 1 + \nu_R) = 1 \tag{A.3}$$

$$\Lambda_{SR,t} = \frac{1}{C_{SR,t}} \tag{A.4}$$

$$\frac{\chi_{SR}}{1 - N_{SR,t}} = \Lambda_{SR,t} W_{SR,t} \tag{A.5}$$

$$\beta_{SR} E_t \frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} R_{R,t} = 1 \tag{A.6}$$

$$\Lambda_{UA,t} = \frac{1}{C_{UA,t}} \tag{A.7}$$

$$\frac{\chi_{UA}}{1 - N_{UA,t}} = (1 + \psi_A \mu_{UA,t})\Lambda_{UA,t} W_{UA,t} \tag{A.8}$$

$$\beta_{UA} E_t \frac{\Lambda_{UA,t+1}}{\Lambda_{UA,t}} R_{A,t} + \mu_{UA,t}(R_{A,t} - 1 + \nu_A) = 1 \tag{A.9}$$

$$\Lambda_{SA,t} = \frac{1}{C_{SA,t}} \tag{A.10}$$

$$\frac{\chi_{SA}}{1 - N_{SA,t}} = \Lambda_{SA,t} W_{SA,t} \tag{A.11}$$

$$\beta_{SA} E_t \frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} R_{A,t} = 1 \tag{A.12}$$

$$Y_{R,t} = T_t^{\sigma_R - 1} N_{UR,t} \tag{A.13}$$

$$W_{UR,t} = \frac{1}{\sigma_R} p_{R,t} \tag{A.14}$$

$$\pi_{R,t} = \left(1 - \frac{1}{\sigma_R}\right) T_t^{\sigma_R - 1} N_{UR,t} \tag{A.15}$$

$$p_{R,t} = T_t^{\sigma_R - 1} \tag{A.16}$$

$$\tau_t = \omega_t T_t N_{SR,t}^{\theta_R - 1} \tag{A.17}$$

$$\theta_R \beta_{SR} E_t \left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \cdot \tau_t \right] = W_{SR,t} \tag{A.18}$$

$$T_{t+1} = \xi_R T_t + \tau_t N_{SR,t} \tag{A.19}$$

$$V_{R,t} = -W_{SR,t} N_{SR,t} + \Omega_{R,t} N_{SR,t} + \xi_R \beta_{SR} E_t \frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} V_{R,t+1} \tag{A.20}$$

$$\Omega_{R,t} = (1+\gamma_T)^t \eta_R \frac{\tau_t}{T_t} \tag{A.21}$$

$$Y_{A,t} = A_t^{\sigma_A - 1} N_{UA,t} \tag{A.22}$$

$$W_{UA,t} = \frac{1}{\sigma_A} p_{A,t} \tag{A.23}$$

$$\pi_{A,t} = \left(1 - \frac{1}{\sigma_A}\right) A_t^{\sigma_A - 1} N_{UA,t} \tag{A.24}$$

$$p_{A,t} = A_t^{\sigma_A - 1} \tag{A.25}$$

$$\Phi_t = \frac{\kappa A_t T_{t-1} N_{SA,t}^{\theta_A - 1}}{\rho (1+\gamma_T)^{t-1}} \tag{A.26}$$

$$\theta_A \beta_{SA} E_t \left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \frac{V_{A,t+1}}{A_{t+1}} \cdot \Phi_t \right] = W_{SA,t} \tag{A.27}$$

$$A_{t+1} = \xi_A A_t + \Phi_t N_{SA,t} \tag{A.28}$$

$$V_{A,t} = -W_{SA,t} N_{SA,t} + \Omega_{A,t} N_{SA,t} + \xi_A \beta_{SA} E_t \frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} V_{A,t+1} \tag{A.29}$$

$$\Omega_{A,t} = (1+\gamma_T)^t \eta_A \frac{\Phi_t}{A_t} \tag{A.30}$$

$$C_{R,t} = C_{SR,t} + C_{UR,t} \tag{A.31}$$

$$C_{A,t} = C_{SA,t} + C_{UA,t} \tag{A.32}$$

$$N_{R,t} = N_{SR,t} + N_{UR,t} = 1 \tag{A.33}$$

$$N_{A,t} = N_{SA,t} + N_{UA,t} = 1 \tag{A.34}$$

$$Y_{R,t} = C_{R,t} \tag{A.35}$$

$$Y_{A,t} = C_{A,t} \tag{A.36}$$

$$\log(\omega_t) = (1-\rho_\omega) \log \bar{\omega} + \rho_\omega \log \omega_{t-1} + \epsilon_{\omega,t} \tag{A.37}$$

1.6.2 Stationarised Equations

The version of model stationary consists of thirty-seven equations as follow:

$$\tilde{\Lambda}_{UR,t} = \frac{1}{\tilde{C}_{UR,t}} \tag{A.1s}$$

$$\frac{\chi_{UR}}{1 - N_{UR,t}} = [1 + \psi_R \mu_{UR,t}] \tilde{\Lambda}_{UR,t} \tilde{W}_{UR,t} \tag{A.2s}$$

$$\beta_{UR} \frac{E_t \tilde{\Lambda}_{UR,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{UR,t}} R_{R,t} + \mu_{UR,t}(R_{R,t} - 1 + \nu_R) = 1 \tag{A.3s}$$

$$\tilde{\Lambda}_{SR,t} = \frac{1}{\tilde{C}_{SR,t}} \tag{A.4s}$$

$$\frac{\chi_{SR}}{1 - N_{SR,t}} = \tilde{\Lambda}_{SR,t} \tilde{W}_{SR,t} \tag{A.5s}$$

$$\beta_{SR} E_t \frac{\tilde{\Lambda}_{SR,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SR,t}} R_{R,t} = 1 \tag{A.6s}$$

$$\tilde{\Lambda}_{UA,t} = \frac{1}{\tilde{C}_{UA,t}} \tag{A.7s}$$

$$\frac{\chi_{UA}}{1 - N_{UA,t}} = (1 + \psi_A \mu_{UA,t}) \tilde{\Lambda}_{UA,t} \tilde{W}_{UA,t} \tag{A.8s}$$

$$\beta_{UA} E_t \frac{\tilde{\Lambda}_{UA,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{UA,t}} R_{A,t} + \mu_{UA,t}(R_{A,t} - 1 + \nu_A) = 1 \tag{A.9s}$$

$$\tilde{\Lambda}_{SA,t} = \frac{1}{\tilde{C}_{SA,t}} \tag{A.10s}$$

$$\frac{\chi_{SA}}{1 - N_{SA,t}} = \tilde{\Lambda}_{SA,t} \tilde{W}_{SA,t} \tag{A.11s}$$

$$\beta_{SA} E_t \frac{\tilde{\Lambda}_{SA,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SA,t}} R_{A,t} = 1 \tag{A.12s}$$

$$\tilde{Y}_{R,t} = \tilde{T}_t^{\sigma_R - 1} N_{UR,t} \tag{A.13s}$$

$$\tilde{W}_{UR,t} = \frac{1}{\sigma_R} \tilde{p}_{R,t} \tag{A.14s}$$

$$\tilde{\pi}_{R,t} = \left(1 - \frac{1}{\sigma_R}\right) \tilde{T}_t^{\sigma_R - 1} N_{UR,t} \tag{A.15s}$$

$$\tilde{p}_{R,t} = \tilde{T}_t^{\sigma_R - 1} \tag{A.16s}$$

$$\tilde{\tau}_t = \omega_t \tilde{T}_t N_{SR,t}^{\theta_R - 1} \tag{A.17s}$$

$$\theta_R \beta_{SR} E_t \left[\frac{\tilde{\Lambda}_{SR,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SR,t}} \frac{\tilde{V}_{R,t+1}}{\tilde{T}_{t+1}} \cdot \tilde{\tau}_t \right] = \tilde{W}_{SR,t} \tag{A.18s}$$

$$(1+\gamma_T)\tilde{T}_{t+1} = \xi_R \tilde{T}_t + \tilde{\tau}_t N_{SR,t} \tag{A.19s}$$

$$\tilde{V}_{R,t} = -\tilde{W}_{SR,t}N_{SR,t} + \tilde{\Omega}_{R,t}N_{SR,t} + \xi_R\beta_{SR}E_t\frac{\tilde{\Lambda}_{SR,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SR,t}}\tilde{V}_{R,t+1} \tag{A.20s}$$

$$\tilde{\Omega}_{R,t} = \eta_R\frac{\tilde{\tau}_t}{\tilde{T}_t} \tag{A.21s}$$

$$\tilde{Y}_{A,t} = \tilde{A}_t^{\sigma_A-1}N_{UA,t} \tag{A.22s}$$

$$\tilde{W}_{UA,t} = \frac{1}{\sigma_A}\tilde{p}_{A,t} \tag{A.23s}$$

$$\tilde{\pi}_{A,t} = \left(1-\frac{1}{\sigma_A}\right)\tilde{A}_t^{\sigma_A-1}N_{UA,t} \tag{A.24s}$$

$$\tilde{p}_{A,t} = \tilde{A}_t^{\sigma_A-1} \tag{A.25s}$$

$$\tilde{\Phi}_t = \frac{\kappa}{\rho}\tilde{A}_t\tilde{T}_{t-1}N_{SA,t}^{\theta_A-1} \tag{A.26s}$$

$$\theta_A\beta_{SA}E_t\{\frac{\tilde{\Lambda}_{SA,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SA,t}}\frac{\tilde{V}_{A,t+1}}{\tilde{A}_{t+1}}\cdot\tilde{\Phi}_t\} = \tilde{W}_{SA,t} \tag{A.27s}$$

$$(1+\gamma_T)\tilde{A}_{t+1} = \xi_A\tilde{A}_t + \tilde{\Phi}_tN_{SA,t} \tag{A.28s}$$

$$\tilde{V}_{A,t} = -\tilde{W}_{SA,t}N_{SA,t} + \tilde{\Omega}_{A,t}N_{SA,t} + \xi_A\beta_{SA}E_t\frac{\tilde{\Lambda}_{SA,t+1}}{(1+\gamma_T)\tilde{\Lambda}_{SA,t}}\tilde{V}_{A,t+1} \tag{A.29s}$$

$$\tilde{\Omega}_{A,t} = \eta_A\frac{\tilde{\Phi}_t}{\tilde{A}_t} \tag{A.30s}$$

$$\tilde{C}_{R,t} = \tilde{C}_{SR,t} + \tilde{C}_{UR,t} \tag{A.31s}$$

$$\tilde{C}_{A,t} = \tilde{C}_{SA,t} + \tilde{C}_{UA,t} \tag{A.32s}$$

$$N_{R,t} = N_{SR,t} + N_{UR,t} = 1 \tag{A.33s}$$

$$N_{A,t} = N_{SA,t} + N_{UA,t} = 1 \tag{A.34s}$$

$$\tilde{Y}_{R,t} = \tilde{C}_{R,t} \tag{A.35s}$$

$$\tilde{Y}_{A,t} = \tilde{C}_{A,t} \tag{A.36s}$$

$$\log(\omega_t) = (1-\rho_\omega)\log\bar{\omega} + \rho_\omega\log\omega_{t-1} + \epsilon_{\omega,t} \tag{A.37s}$$

1.6.3 Variable Descriptions

The model consists of thirty-seven equations related to thirty-seven variables (thirty-six endogenous variables and one variable of shock processes) described in the following table.

	Variable	**Description**
1	A_t	Stock of adopted technology in region A
2	$C_{A,t}$	Aggregate consumption in region A
3	$C_{R,t}$	Aggregate consumption in region R
4	$C_{SA,t}$	Skilled labour's consumption in region A
5	$C_{SR,t}$	Skilled labour's consumption in region R
6	$C_{UA,t}$	Unskilled labour's consumption in region A
7	$C_{UR,t}$	Unskilled labour's consumption in region R
8	$\Lambda_{SA,t}$	Skilled labour's shadow price of budget in region A
9	$\Lambda_{SR,t}$	Skilled labour's shadow price of budget in region R
10	$\Lambda_{UA,t}$	Unskilled labour's shadow price of budget in region A
11	$\Lambda_{UR,t}$	Unskilled labour's shadow price of budget in region R
12	$N_{SA,t}$	Skilled labour in region A
13	$N_{SR,t}$	Skilled labour in region R
14	$N_{UA,t}$	Unskilled labour in region A
15	$N_{UR,t}$	Unskilled labour in region R
16	$\mu_{UA,t}$	Unskilled labour's shadow value of borrowing in region A
17	$\mu_{UR,t}$	Unskilled labour's shadow value of borrowing in region R
18	ω_t	R&D productivity shocks
19	$\Omega_{A,t}$	Value of adopted technology contribution
20	$\Omega_{R,t}$	Value of created technology contribution

	Variable	**Description**
21	$p_{A,t}$	Price level (intermediate goods) in region A
22	$p_{R,t}$	Price level (intermediate goods) in region R
23	$\pi_{A,t}$	Firm's profit in region A
24	$\pi_{R,t}$	Firm's profit in region R
25	$R_{A,t}$	Interest rate in region A
26	$R_{R,t}$	Interest rate in region R
27	Φ_t	Period creation of new adopted technology in region A
28	T_t	Stock of created technology in region R
29	τ_t	Period creation of new technology in region R
30	$V_{A,t}$	Value of adopted technology in region A
31	$V_{R,t}$	Value of created technology in region R
32	$W_{SA,t}$	Skilled labour's wage in region A
33	$W_{SR,t}$	Skilled labour's wage in region R
34	$W_{UA,t}$	Unskilled labour's wage in region A
35	$W_{UR,t}$	Unskilled labour's wage in region R
36	$Y_{A,t}$	Output or goods in region A
37	$Y_{R,t}$	Output or goods in region R

1.6.4 Numerical Values for Parameters

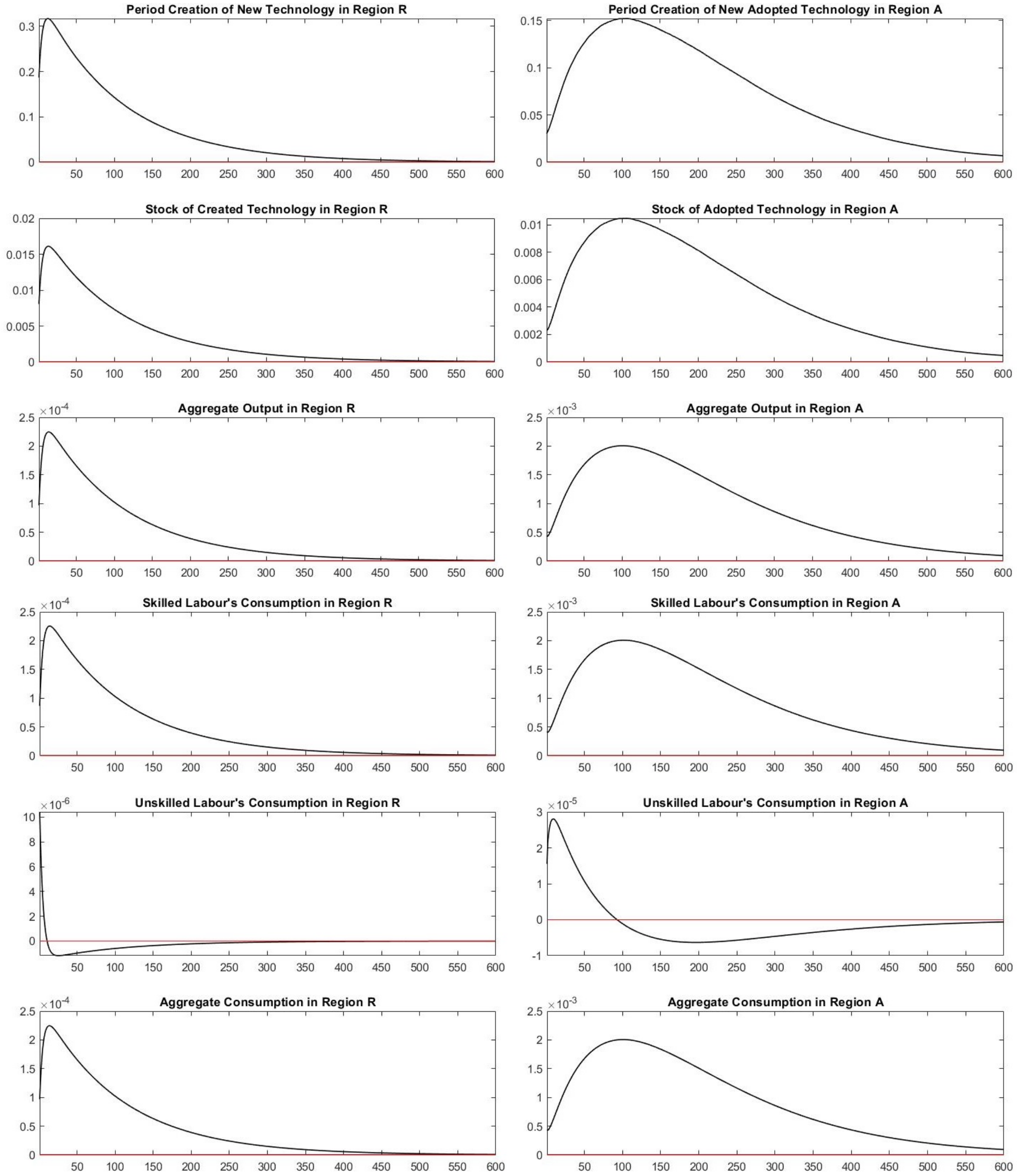
The set of parameters used in this model is collected from Anzoategui et al (2019), Emenogu and Michelis (2019), Pathompituknukoon's dissertation (2020) of Master of Research (MRes) in Economics at the University of Essex, and some parameters are calibrated. The model consists of 25 parameters as in the following table.

Parameters	**Definition**	**Value**
β_{UA}	Borrowers' discount factor of region A	0.985000
β_{UR}	Borrowers' discount factor of region R	0.985000
β_{SA}	Savers' discount factor of region A	0.995000
β_{SR}	Savers' discount factor of region R	0.995000
χ_{UA}	Unskilled labour weight of utilities of region A	1.000000
χ_{UR}	Unskilled labour weight of utilities of region R	1.000000
χ_{SA}	Skilled labour weight of utilities of region A	1.000000
χ_{SR}	Skilled labour weight of utilities of region R	1.000000
η_A	Scaling parameter for periodic value of adopted technology	0.100000
η_R	Scaling parameter for periodic value of created technology	0.100000
γ_T	The growth rate of technology	0.157000
κ	Ability of technology adoption where $\kappa \in (0, 1)$	0.800000
ν	Debt cost parameter	0.024000
$\bar{\omega}$	Steady state of shock to R&D technology	1.000000
ψ_A	Exogenous payment-to-income limit of region A	0.280000
ψ_R	Exogenous payment-to-income limit of region R	0.280000
ρ	Scaling parameter for interaction between current technology adoption and previous technology creation	0.000001
ρ_ω	Persistence of shock to R&D technology	0.803000
σ_A	Steady state of final goods mark up of region A	1.100000
σ_R	Steady state of final goods mark up of region R	1.100000
σ_ω	Standard deviation of shock to R&D technology	0.100000
θ_A	R&D elasticity of region A	0.376000
θ_R	R&D elasticity of region R	0.376000
ξ_A	Survival rate of technology of region A	0.980000
ξ_R	Survival rate of technology of region R	0.980000

1.6.5 Additional Results

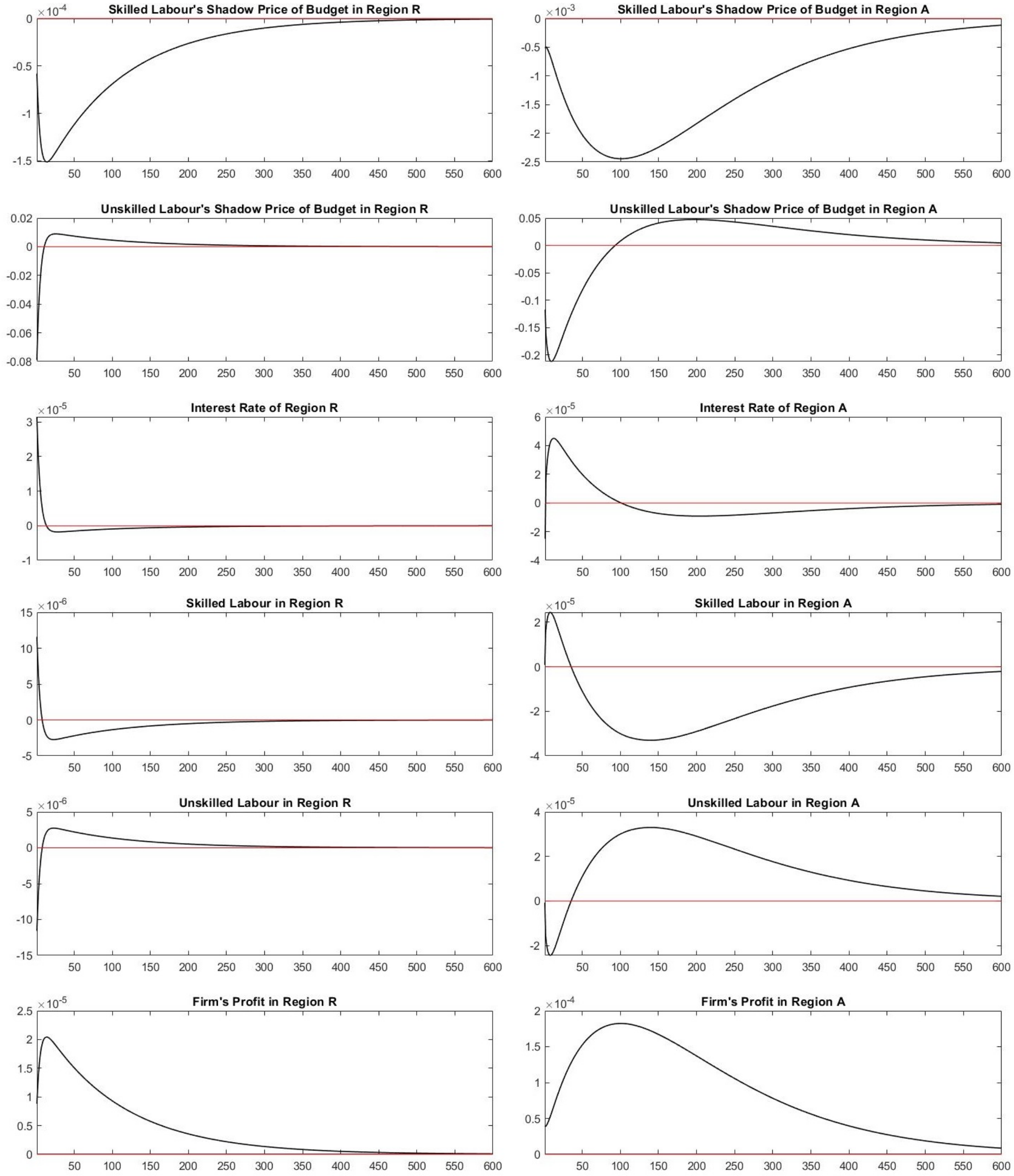
Impulse response to a one standard deviation of technology R&D shock in the region R are shown in Figure 1.7, 1.8, and 1.9 as follow:

FIGURE 1.7: Impulse response to one standard deviation positive technology R&D shocks (A.1)



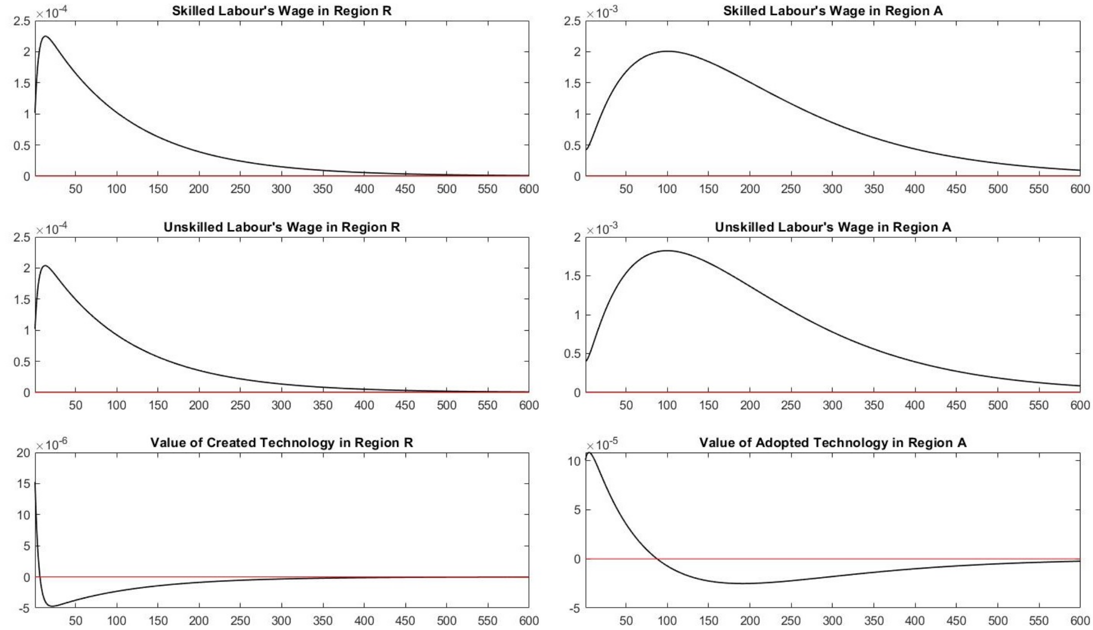
Source: Author's calculation

FIGURE 1.8: Impulse response to one standard deviation positive technology R&D shocks (A.2)



Source: Author's calculation

FIGURE 1.9: Impulse response to one standard deviation positive technology R&D shocks (A.3)



Source: Author's calculation

Chapter 2

Endogenous Technology, Inflation Dynamics, and Economic Growth

The previous chapter explored how productivity improvements and technological innovations interact in firms. In chapter 1, we aimed to create an endogenous growth model for two regions, a closed economy, where growth is driven by technology creation and adoption for each region. The quantitative results showed that the stock of both created and adopted technologies and the level of skilled labour cooperating with research and development (R&D) are important factors. A one-time positive shock of technology R&D affects the creation of new technology and newly adopted technology, which are endogenous factors determining long-run growth. Endogenous technology plays an essential role in stimulating economic growth. In addition, Chapter 1 demonstrated the results of a one-time positive technology shock on equilibrium productivity growth and how it affects the level of both skilled and unskilled labour, as it improves the economy.

Although the previous model mainly explains the growth driven by new endogenous technology, there is a limitation to addressing policy issues, i.e., monetary policy and fiscal policy, as it is based on the real business cycle (RBC) framework, which does not take into account changes in those policies. This means that technology R&D is one of many factors that play a central role in the economy. However, technology R&D can be crucial in shaping key macroeconomic variables' dynamic behaviour, but other factors might also be significant. This chapter 2 will develop a model that accounts for the effects of a dynamic change in policy, especially monetary policy. The study begins with a version of the standard New Keynesian (NK) model with nominal price and wage setting. Then, this study uses a version of this model for monetary policy analysis. The positive monetary policy shock will impede the overheated economy and the severity of inflation but negatively affect the stock of endogenous technology. This shock affects another economy similarly in later periods through the technology adoption channel.

2.1 Introduction

In monetary theory, the relationship between inflation and growth is a classic topic of discussion. One of the ways through which monetary policy can impact economic growth is through nominal rigidities in the economic system. Even a simple endogenous growth model can demonstrate that changes in the monetary expansion rate can have an impact on growth if inflation affects firm decisions. There are several approaches to monetary policy; one of the most well-known is the Taylor rule. Developed by John Taylor in 1993, it is a simple interest rate rule that helps manage inflation.

Another popular approach is inflation targeting, which has been endorsed by economists such as Bernanke and Mishkin (1997), Clarinda et al. (1999), and Hüpper and Kempa (2023). Inflation targeting involves setting a specific inflation rate target and using monetary policy to maintain it. Over the years, there have been many improvements to the theoretical frameworks for policy analysis. Many of these have incorporated the techniques of dynamic general equilibrium theory to take the lead in a real business cycle (RBC) frameworks. The dynamic general equilibrium framework differs from RBC because it recognises the importance of nominal price rigidities in evaluating monetary policy. It is a more complex framework that accounts for a broader range of economic factors, including the interactions between different markets and the effects of policy changes over time.

This study aims to expand the literature on a RBC model within a monetary New Keynesian (NK) framework. In the RBC models, money does not play any role and is inconsistent with the mainstream literature (Christiano et al., 2018), despite its significant role in various economic histories. For instance, Bernanke and Gertler (1995) illustrated how monetary policy significantly affected the severity of the recession in the early 1980s. Tight monetary policy directly weakens borrowers' financial position, which includes rising interest rates associated with extending floating-rate debt and reducing net cash flows. Higher interest rate levels also lead to the collapse of the reduction of asset prices and their values, contributing to the ensuing recession. However, the RBC framework implies that a monetary policy shock does not affect any real variables.

In contrast, simple NK models suggest that real variables respond to monetary policy shocks, as in Friedman and Schwartz (1965), Bernanke and Blinder (1992), Christiano et al. (2011), and Gertler and Karadi (2015). Consequently, many modern macroeconomic literature pieces desire to develop the NK models to analyse monetary policy and answer other related policy questions. This study, in particular, focuses on the monetary policy's impact on the NK model and how it can be used to address various policy-related issues.

This study aims to explore the concept of monetary policy within the NK model, which incorporates features such as nominal price and wage rigidities, endogenous technology growth, and adjustments in interest rates based on inflation and output. The framework is based on the pioneering work of economist Milton Friedman, published in 1968, which demonstrated that monetary policy has no lasting influence on real variables such as output and the real interest rate. However, in the short term, monetary policy can have an impact due to sticky prices and wage assumptions.

Using the NK model's impulse response functions, we can see that a positive monetary policy shock, such as a central bank using a tight or contractionary monetary policy to tackle rising inflation, will have several negative consequences. Firstly, a positive monetary policy shock will reduce both aggregate output and inflation in the innovating region. In addition, this shock will have a negative impact on the creation of new technology and the stock of endogenous technology. This is significant because the accumulation of new technology is a necessary factor in the growth and development of an economy. Thus, while monetary policy may not have long-term impacts on real variables, it can affect the economy in the short term. The NK model allows us to better understand the effects of monetary policy on the economy and highlights the importance of technological innovation in economic growth.

On the one hand, various papers related to the endogenous growth theory with a dynamic stochastic feature, such as in Kydland and Prescott (1982), Stadler (1994), Cooley and Prescott (1995) and Rebelo (2005), are modelled based on the RBC and growth. Technology, as a term for total factor productivity (TFP) shocks, played an important role in macroeconomic fluctuation in the RBC models. However, the endogenous growth channel enriches a standard NK model with significant supply-side features for determining long-term growth. For example, a study by Anzoategui et al. (2019) introduces endogenous growth through the technology sectors based on research and development (R&D) of the technology creation region while another region can adopt innovative technologies with a limited degree of adoption to expand the variety of goods in the economy.

On the other hand, there is various research on the development of the NK models that feature nominal price and wage rigidities to analyse how important monetary policy is. In a study conducted by Anzoategui et al. in 2019, the impact of endogenous productivity on the economy was analysed. The study also included the role of monetary policy in the growth mechanism, as well as models proposed by Christiano et al. (2005) and Smets and Wouters (2007). These models suggest that wages are sticky by assumption, as explained in literature of Bernanke and Blinder (1992) and Christiano et al. (1999). In addition, several studies show that prices and wage stickiness arise endogenously. The endogenous growth models with nominal price and wage rigidities features are modelled based on dynamic stochastic general equilibrium (DSGE) framework and growth (i.e., Evans and dos Santos, 2002; Hasumi et al., 2018; Christiano et al., 2018; and Abbritti et al., 2021) in which monetary policy shocks induce positive co-movement between measured productivity and inflation.

This chapter presents a model demonstrating how the interplay between an endogenous technology R&D channel and nominal price and wage rigidities in a NK framework can influence economic outcomes. The model highlights the importance of technological progress in driving economic growth and how it interacts with the rigidity of prices and wages. Anzoategui et al. (2019) contributed to the existing literature in this area. This study builds on that work and introduces endogenous growth in the model via an innovation sector that creates new technology to expand the variety of goods in the economy. Unlike the literature, this chapter's model does not include physical capital, but newly created technology is a factor in intermediate goods production. As in standard NK models, nominal rigidities arise from Calvo (1983), where firms and households can change prices and wages with some exogenous probability. This study uses this version of the NK model to address the monetary policy issue and analyse the interaction between monetary policy and volatility in aggregate economic variables.

Chapter 2 is structured as follows. Section 2.2 outlines a NK model with the basic features of the endogenous growth model that takes into account for nominal prices and wage rigidities. Section 2.3 illustrates the estimation results and their interpretation of monetary policy shock and preference shock on aggregate variables across two-region economy. Finally, section 2.4 concludes the chapter.

2.2 The Model

Based on Anzoategui et al. (2019), this study has developed a NK model that incorporates both standard and non-standard features. The non-standard feature is that the model includes a term representing endogenous technology for two symmetric regions, which this study refers to as regions R and A. The region R is the area where technology creation is carried out through R&D, while region A is the region where technology is created through adoption. The model also includes skilled households as inputs for the technology creation and adoption section. Moreover, the model assumes that nominal prices and wages drive inflation dynamics, which in turn have an endogenous effect on productivity and economic growth. Therefore, the monetary policy should respond to actual or expected inflation changes.

2.2.1 Households

For each region i, $i \in \{R, A\}$, of this two-region economy, the characteristics of the households are defined by their lifetime utility for skilled and unskilled labours. The representative households' preferences in each region are determined by their propensity to supply their labour to good producers as unskilled labour and to the technology sector as skilled labour. As a result, they earn different wages depending on their labour type. In addition, The households are characterised as patient and impatient, which divides the character of the skilled and unskilled types. This study assumes that the skilled type is a patient household that tends to save for future consumption, while the impatient household, unskilled labour, is the borrower in this economy. The characteristics of heterogeneous households are defined as their lifetime utility for unskilled and skilled labours.

- **Skilled Households**

The representative skilled households want to maximise their expected discounted utility function as follows:

$$E_t \sum_{t=0}^{\infty} \beta_{Si}^t [U(C_{Si,t}, N_{Si,t})] \quad ,$$

where $\beta_{Si,t} \in (0,1)$ is a savers' discount factor. The current period utility of skilled households is a function of their consumption $C_{Si,t}$ and skilled type of labour $N_{Si,t}$ for each region $i \in \{R, A\}$ given by

$$U(C_{Si,t}, N_{Si,t}) = \log C_{Si,t} + \chi_{Si} \log(1 - N_{Si,t}) \quad ,$$

subject to their budget constraint[1]

$$P_{i,t} C_{Si,t} + B_{i,t} = R_{i,t-1} B_{i,t-1} + W_{Si,t} N_{Si,t} + \pi_{i,t} \quad ,$$

where χ_{Si} denotes the skilled leisure weights in utility, $P_{i,t}$ is a price level for final goods, $B_{i,t}$ is the amount of loans, $R_{i,t-1}B_{i,t-1}$ is paying back money from the loans in period $t-1$ with real interest rate, $R_{i,t-1}$, $W_{Si,t}$ is a wage of skilled labour, and $\pi_{i,t}$ is an income of skilled households in term of firms' profit as they are the owner.

---

[1] This is written in terms of aggregate variables. See Appendix 2.6.5 for a full derivation and description.

Then, the maximisation problem for the representative skilled households can be written as Lagrangian function as follows:

$$\begin{aligned} \max_{C_{Si,t},N_{Si,t},B_{i,t}} \; & E_t \sum_{t=0}^{\infty} \beta_{Si}^t \{ \log C_{Si,t} + \chi_{Si} \log(1 - N_{Si,t}) \\ & + \Lambda_{Si,t}[R_{i,t-1}B_{i,t-1} + W_{Si,t}N_{Si,t} + \pi_{i,t} - P_{i,t}C_{Si,t} - B_{i,t}] \} \quad , \end{aligned}$$

where $\Lambda_{Si,t}$ is a skilled labour's shadow price of budget.

The optimality conditions for consumption of skilled labour, the amount of skilled labour, and the loans are given by

$$C_{Si,t} : \qquad \Lambda_{Si,t} = \frac{1}{P_{i,t}C_{Si,t}} \quad , \tag{2.1}$$

$$N_{Si,t} : \qquad \Lambda_{Si,t}W_{Si,t} = \frac{\chi_{Si}}{1 - N_{Si,t}} \quad , \tag{2.2}$$

$$B_{i,t} : \qquad \beta_{Si} E_t \frac{\Lambda_{Si,t+1}}{\Lambda_{Si,t}} R_{i,t} = 1 \quad . \tag{2.3}$$

• Unskilled Households

The representative unskilled households want to maximise their expected discounted utility function as follows:

$$E_t \sum_{t=0}^{\infty} \beta_{Ui}^t [U(C_{Ui,t}, N_{Ui,t})] \quad ,$$

where $\beta_{Ui,t} \in (0, 1)$ is a borrowers' discount factor. The current period utility of unskilled households is a function of their consumption $C_{Ui,t}$ and unskilled labour $N_{Ui,t}$ for each region i given by

$$U(C_{Ui,t}, N_{Ui,t}) = \log C_{Ui,t} + \chi_{Ui} \log(1 - N_{Ui,t}) \quad ,$$

subject to their budget and borrowing constraints[2]

$$\begin{aligned} P_{i,t}C_{Ui,t} + R_{i,t-1}B_{i,t-1} &= B_{i,t} + W_{Ui,t}N_{Ui,t} \quad , \\ (R_{i,t} - 1 + \nu_i)B_{i,t} &\leq \psi_i W_{Ui,t}N_{Ui,t} \quad , \end{aligned}$$

where χ_{Ui} denotes the unskilled leisure weights in utility, $R_{i,t-1}B_{i,t-1}$ is the amount of paying back money with real interest rate $R_{i,t-1}$, $B_{i,t}$ is borrowed money, $W_{Ui,t}$ is a wage of unskilled labour, ν_i is debt cost parameter, and ψ_i is the exogenous payment-to-income (PTI) ratio.

---

[2] See Appendix 2.6.5 for a full derivation and description.

Then, the maximisation problem for the representative unskilled households can be rewritten as Lagrangian function as follows:

$$
\begin{aligned}
\max_{C_{Ui,t}, N_{Ui,t}, B_{i,t}} E_t \sum_{t=0}^{\infty} \beta_{Ui}^{t} \{ & \log C_{Ui,t} + \chi_{Ui} \log(1 - N_{Ui,t}) \\
& + \Lambda_{Ui,t}[B_{i,t} + W_{Ui,t}N_{Ui,t} - P_{i,t}C_{Ui,t} - R_{i,t-1}B_{i,t-1}] \\
& + \Lambda_{Ui,t}\mu_{Ui,t}[\psi_i W_{Ui,t}N_{Ui,t} - (R_{i,t} - 1 + \nu_i)B_{i,t}]\} \quad ,
\end{aligned}
$$

where $\Lambda_{Ui,t}$ is an unskilled labour's shadow price of budget and $\mu_{Ui,t}$ is a Lagrange's multiplier for unskilled borrowing constraint or unskilled labour's shadow value of borrowing.

The optimality conditions for consumption of unskilled labour, the amount of unskilled labour, and borrowing are given by

$$
C_{Ui,t}: \qquad \Lambda_{Ui,t} = \frac{1}{P_{i,t}C_{Ui,t}} \quad , \tag{2.4}
$$

$$
N_{Ui,t}: \qquad (1 + \psi_i \mu_{Ui,t}) W_{Ui,t} \Lambda_{Ui,t} = \frac{\chi_{Ui}}{1 - N_{Ui,t}} \quad , \tag{2.5}
$$

$$
B_{i,t}: \qquad \beta_{Ui} E_t \frac{\Lambda_{Ui,t+1}}{\Lambda_{Ui,t}} R_{i,t} + \mu_{Ui,t}(R_{i,t} - 1 + \nu_i) = 1 \quad . \tag{2.6}
$$

2.2.2 Firms

Following the studies of Gancia et al. (2013) and Anzoategui et al. (2019), who examined the impact of technology creation and adoption on the productive sector, the firms' section constructed the productive sector by combining the manufacturing and technology creation sectors. The productive sector in region R has been achieved on technology creation through R&D, which involves the creation of new technology. This process requires highly skilled labour to carry out the research, development and implementation of new technologies. On the contrary, in region A, there is a need for skilled labour to work on technology adoption. This involves the adoption and integration of new technologies into existing systems. The process requires a team of skilled individuals who can analyse, implement and troubleshoot the new technology.

The representative and competitive final good production for **region** R can be written the following:

$$
Y_{R,t} = \left[\int_0^{T_t} (y_{R,t}^{j})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R}, \sigma_R > 1 \quad ,
$$

where $Y_{R,t}$ is the numeric goods with price $P_{R,t}$, T_t is stock of created technology in region R, and σ_R is a final goods mark up which is greater than one. The demand for variety $j \in [0, T_t]$ follows from the profit maximisation problem is

$$\max_{y^j_{R,t} \geq 0} \left[\int_0^{T_t} (y^j_{R,t})^{\frac{1}{\sigma_R}} dj \right]^{\sigma_R} - \int_0^{T_t} (p^j_{R,t} y^j_{R,t}) dj \quad ,$$

which yields the inverse demand function which follows from the optimality condition for output:

$$p^j_{R,t} = \left(\frac{y^j_{R,t}}{Y_{R,t}} \right)^{\frac{1}{\sigma_R} - 1} \equiv p^j_{R,t}(y^j_{R,t}) \quad .$$

Intermediate good production of variety $j \in [0, T_t]$ can be described the following:

$$y^j_{R,t} = N^j_{UR,t} \quad .$$

Intermediate good producers demand unskilled labour to maximise their profits can be described as follows:

$$\begin{aligned} &\max_{N^j_{UR,t}} p^j_{R,t}(y^j_{R,t}) \cdot y^j_{R,t} - W_{UR,t} N^j_{UR,t} - \frac{V_{R,t}}{T_t} \tau_{t-1} N_{SR,t-1} \\ &\qquad = \max_{N^j_{UR,t}} \left(\frac{N^j_{UR,t}}{Y_{R,t}} \right)^{\frac{1}{\sigma_R} - 1} \cdot N^j_{UR,t} - W_{UR,t} N^j_{UR,t} - \frac{V_{R,t}}{T_t} \tau_{t-1} N_{SR,t-1} \\ &\qquad = \max_{N^j_{UR,t}} \frac{(N^j_{UR,t})^{\frac{1}{\sigma_R}}}{(Y_{R,t})^{\frac{1}{\sigma_R} - 1}} - W_{UR,t} N^j_{UR,t} - \frac{V_{R,t}}{T_t} \tau_{t-1} N_{SR,t-1} \quad . \end{aligned}$$

The optimality condition for unskilled labour is given by

$$W_{UR,t} = \frac{1}{\sigma_R} p^j_{R,t} \quad . \tag{2.7}$$

Because $1/\sigma_R$ is less than one, then the unskilled wages are marked down relative to a competitive economy. The production of variety j therefore makes a profit:

$$\pi^j_{R,t} = \left(1 - \frac{1}{\sigma_R} \right) p^j_{R,t} y^j_{R,t} - \frac{V_{R,t}}{T_t} \tau_{t-1} N_{SR,t-1} \quad . \tag{2.8}$$

Hence, the final good production can be expressed as the following:

$$Y_{R,t} = T_t^{\sigma_R - 1} N_{UR,t} \quad . \tag{2.9}$$

Applying the above final good production to rewrite the inverse demand function,

$$p^j_{R,t} = T_t^{\sigma_R - 1} \quad ,$$

where the aggregate unskilled labour demand $N^j_{UR,t} = N_{UR,t}/T_t$.

Then, the optimal wage for unskilled type can be written as:

$$W_{UR,t} = \frac{1}{\sigma_R} p^j_{R,t} = \frac{1}{\sigma_R} T_t^{\sigma_R - 1} \quad . \tag{2.10}$$

Therefore, the profit function of the representative and competitive final good production can be written as follows:

$$\pi_{R,t} = \left(1 - \frac{1}{\sigma_R}\right) T_t^{\sigma_R - 2} N_{UR,t} - \frac{V_{R,t}}{T_t} \tau_{t-1} N_{SR,t-1} \quad . \tag{2.11}$$

These are similar for **region** A that the representative and competitive final good production for region A can be written as the following:

$$Y_{A,t} = \left[\int_0^{A_t} (y^j_{A,t})^{\frac{1}{\sigma_A}} dj \right]^{\sigma_A} , \sigma_A > 1 \quad ,$$

where $Y_{A,t}$ is the numeric goods with price $P_{A,t}$, A_t is stock of adopted technology in region A, and σ_A is a final goods mark up and is valued greater than 1. The demand for variety $j \in [0, A_t]$ follows from the profit maximisation problem as

$$\max_{y^j_{A,t} \geq 0} \left[\int_0^{A_t} (y^j_{A,t})^{\frac{1}{\sigma_A}} dj \right]^{\sigma_A} - \int_0^{A_t} (p^j_{A,t} y^j_{A,t}) dj \quad ,$$

which also yields the inverse demand function which follows from the optimality condition for output as follows:

$$p^j_{A,t} = \left(\frac{y^j_{A,t}}{Y_{A,t}} \right)^{\frac{1}{\sigma_A} - 1} \equiv p^j_{A,t}(y^j_{A,t}) \quad .$$

However, the profit of competitive market is normal profit, $\pi_{A,t} = 0$, hence

$$P_{A,t} Y_{A,t} = \int_0^{A_t} (p^j_{A,t} y^j_{A,t}) dj \quad .$$

Intermediate good production of variety $j \in [0, A_t]$ can be described as

$$y^j_{A,t} = N^j_{UA,t} \quad .$$

Intermediate good producers demand unskilled labour to maximise their profits

$$\begin{aligned}\max_{N^j_{UA,t}} & \, p^j_{A,t}(y^j_{A,t}) \cdot y^j_{A,t} - W_{UA,t}N^j_{UA,t} - \frac{V_{A,t}}{A_t}\phi_{t-1}N_{SA,t-1} \\ &= \max_{N^j_{UA,t}} \frac{(N^j_{UA,t})^{\frac{1}{\sigma_A}}}{(Y_{A,t})^{\frac{1}{\sigma_A}-1}} - W_{UA,t}N^j_{UA,t} - \frac{V_{A,t}}{A_t}\phi_{t-1}N_{SA,t-1} \quad .\end{aligned}$$

The optimality condition for unskilled labour is given by

$$W_{UA,t} = \frac{1}{\sigma_A}p^j_{A,t} \quad . \tag{2.12}$$

Then, the unskilled wages are marked down, due to the value of $1/\sigma_A$ is less than one, relative to a competitive economy.

The producer of variety j therefore makes a profit:

$$\pi^j_{A,t} = \left(1 - \frac{1}{\sigma_A}\right) p^j_{A,t}y^j_{A,t} - \frac{V_{A,t}}{A_t}\phi_{t-1}N_{SA,t-1} \quad . \tag{2.13}$$

Hence, the final good production function for the representative and competitive final good production in region A can be derived as the following:

$$Y_{A,t} = A_t^{\sigma_A - 1}N_{UA,t} \quad . \tag{2.14}$$

Applying the final good function to rewrite the inverse demand function,

$$p^j_{A,t} = A_t^{\sigma_A - 1} \quad ,$$

where the aggregate unskilled labour demand $N^j_{UA,t} = N_{UA,t}/A_t$.

Then, the optimal wage for unskilled type in region A can be written as follows:

$$W_{UA,t} = \frac{1}{\sigma_A}p^j_{A,t} = \frac{1}{\sigma_A}A_t^{\sigma_A - 1} \quad . \tag{2.15}$$

Therefore, the profit function of the representative and competitive final good production in region A can be written as the following:

$$\pi_{A,t} = \left(1 - \frac{1}{\sigma_A}\right) A_t^{\sigma_A - 2}N_{UA,t} - \frac{V_{A,t}}{A_t}\phi_{t-1}N_{SA,t-1} \quad . \tag{2.16}$$

2.2.3 Price Dynamics

Following Calvo (1983), all final goods firms face the demand for consumption goods j of household type x in region i,

$$C^j_{xi,t} = \left(\frac{P^j_{i,t}}{P_{i,t}}\right)^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}} C_{xi,t} \quad ,$$

taking the price $P_{i,t}$ and consumption $C_{xi,t}$ as given.

Each firm may re-optimise its price, $P^*_{i,t}$, only with probability $1-\zeta_i$ in any given period such that $\zeta_i \in [0,1]$ independent across firms (Yun, 1996). In this context, a term of ζ_i implies the index of price stickiness in region i and the average price duration is $(1-\zeta_i)^{-1}$. Then, the aggregate price can be expressed as followed:

$$P_{i,t} = \left[\zeta_i (P_{i,t-1})^{\frac{-1}{\nu_{p_i}-1}} + (1-\zeta_i)(P^*_{i,t})^{\frac{-1}{\nu_{p_i}-1}}\right]^{-(\nu_{p_i}-1)} \quad . \tag{2.17}$$

The firms will choose their prices by taking the demand for goods derived from all demand for consumption in the region i as given. However, assuming that all firms have the same cost structure, they will set their prices to the same. Thus, the price maximisation problem is given as follows:

$$\max_{P^*_{i,t}} E_t \left\{ \sum_{k=0}^{\infty} (\zeta_{pi}\beta_x)^k \cdot \frac{\Lambda_{x,t+k}}{\Lambda_{x,t}} \left[\frac{P^*_{i,t}}{P_{i,t+k}} \cdot Y_{i,t+k|t} - \frac{MC_{i,t+k}}{P_{i,t+k}} \cdot Y^j_{i,t+k|t} \right] \right\} \quad ,$$

where $MC_{i,t+k}$ is the marginal cost for producing one unit of goods and $\Lambda_{x,t}$ denotes a shadow price of household type x, subject to the demand facing each firm when it chooses price $P^*_{i,t}$,

$$Y^j_{i,t} = \left(\frac{P^*_{i,t}}{P_{i,t}}\right)^{\frac{-\nu_{p_i}}{\nu_{p_{i,t}}-1}} Y_{i,t} \quad ,$$

where ν_{p_i} is a steady state final goods mark up price in each region i.

Then, the maximisation problem can be rewritten as Lagrangian function as follows:

$$\max_{P^*_{i,t}} E_t \left\{ \sum_{k=0}^{\infty} (\zeta_{pi}\beta_x)^k \cdot \frac{\Lambda_{x,t+k}}{\Lambda_{x,t}} \left[\left(\frac{P^*_{i,t}}{P_{i,t+k}}\right)^{\frac{-1}{\nu_{p_i}-1}} \cdot Y_{i,t+k} - \frac{MC_{i,t+k}}{(P_{i,t+k})^{\frac{-1}{\nu_{p_i}-1}}} \cdot (P^*_{i,t})^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}} \cdot Y_{i,t+k} \right] \right\} .$$

Each firm will respectively choose their optimal price $P^*_{i,t}$ in each period t to maximise their profits while prices remain effective. They gain the optimality condition for price in the region i as follows:

$$
\begin{aligned}
E_t\{ \sum_{k=0}^{\infty} (\zeta_{pi}\beta_x)^k \cdot \frac{\Lambda_{x,t+k}}{\Lambda_{x,t}} [\left(\frac{-1}{\nu_{p_i}-1}\right) & \frac{(P^*_{i,t})^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}}}{(P_{i,t+k})^{\frac{-1}{\nu_{p_i}-1}}} Y_{i,t+k} \\
& - \frac{MC_{i,t+k}}{(P_{i,t+k})^{\frac{-1}{\nu_{p_i}-1}}} \left(\frac{-\nu_{p_i}}{\nu_{p_i}-1}\right) (P^*_{i,t})^{\frac{-2\nu_{p_i}+1}{\nu_{p_i}-1}} Y_{i.t+k}] \ \} = 0 \quad ,
\end{aligned}
$$

$$
P^*_{i,t} = \nu_{p_i} \frac{E_t \sum_{k=0}^{\infty} (\zeta_{p_i}\beta_x)^k \cdot \frac{\Lambda_{x,t+k}}{\Lambda_{x,t}} \cdot (P_{i,t+k})^{\frac{1}{\nu_{p_i}-1}} \cdot MC_{i,t+k} Y_{i,t+k}}{E_t \sum_{k=0}^{\infty} (\zeta_{p_i}\beta_x)^k \cdot \frac{\Lambda_{x,t+k}}{\Lambda_{x,t}} \cdot (P_{i,t+k})^{\frac{1}{\nu_{p_i}-1}} Y_{i,t+k}} \quad . \tag{2.18}
$$

We can define the numerator and denominator of optimal price setting conditions for goods as $H_{p1i,t}$ and $H_{p2i,t}$, respectively. Thus, Equation 2.18 can be rewritten as follows:

$$
\frac{P^*_{i,t}}{P_{i,t}} = \nu_{p_i} \frac{H_{p1i,t}}{H_{p2i,t}} \quad , \tag{2.19}
$$

where the numerator and denominator can be written in recursive forms as the following:

$$
H_{p1i,t} = \frac{MC_i Y_{i,t}}{P_{i,t}} + \zeta_{pi}\beta_x E_t \left(\frac{\Lambda_{x,t+1}}{\Lambda_{x,t}}\right) \left(\frac{P_{i,t+1}}{P_{i,t}}\right)^{\frac{\nu_{p_i}}{\nu_{p_i}-1}} H_{p1i,t+1} \tag{2.20}
$$

and

$$
H_{p2i,t} = Y_{i,t} + \zeta_{pi}\beta_x E_t \left(\frac{\Lambda_{x,t+1}}{\Lambda_{x,t}}\right) \left(\frac{P_{i,t+1}}{P_{i,t}}\right)^{\frac{1}{\nu_{p_i}-1}} H_{p2i,t+1} \quad . \tag{2.21}
$$

2.2.4 Wage Dynamics

Similar to the price setting, the wage of household type x in the region i may be re-optimised to $W^*_{xi,t}$ with probability $1-\zeta_{wxi}$ in each period t such that a term ζ_{wxi} is independent across workers. Thus, ζ_{wxi} indicates the index of wage stickiness of labour type x in region i, and the average wage duration is $(1-\zeta_{wxi})^{-1}$, then the aggregate wage for labour type x in region i can be expressed as follows:

$$
W_{xi,t} = \left[\zeta_{wxi}(W_{xi,t})^{\frac{-1}{\nu_{wxi}-1}} + (1-\zeta_{wxi})(W^*_{xi,t})^{\frac{-1}{\nu_{wxi}-1}}\right]^{-(\nu_{wxi}-1)} \quad , \tag{2.22}
$$

where ν_{wxi} is a steady state mark up wage for labour type x in each region i.

The household will choose the wage for their labour type x in the region i by taking the demand for labour as given. However, we assume that all households have the same preference, and then they will set their wages to the same wage. Thus, the wage maximisation problem is constructed by,

$$\max_{W^*_{xi,t}} E_t \left\{ \sum_{k=0}^{\infty} (\zeta_{wxi}\beta_{xi})^k \left[\log C_{xi,t+k} + \chi_{xi} \log(1 - N^h_{xi,t+k}) \right] \right\} \quad .$$

Subject to the demand for labour type x,

$$N^h_{xi,t} = \left(\frac{W^*_{xi,t}}{W_{xi,t}} \right)^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \cdot N_{xi,t} \quad ,$$

where χ_{xi} denotes a labour weight of utilities for each labour type x in region i.

Each household will choose their optimal wage $W^*_{xi,t}$ in each period t respectively to maximise their utility while wages remain effective, then they get the optimality condition for wages for labour type x in the region i as follows:

$$E_t\{ \sum_{k=0}^{\infty} (\zeta_{wxi}\beta_{xi})^k \; [\; \frac{1}{C_{xi,t+k}} \left(\frac{-1}{\nu_{wxi}-1} \right) (W^*_{xi,t})^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \left[\frac{N_{xi,t+k}}{P_{i,t+k}(W_{xi,t})^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}}} \right]$$
$$+ \chi_{xi} \frac{1}{1 - N^h_{xi,t+k}} (-1) \left(\frac{-\nu_{wxi}}{\nu_{wxi}-1} \right) \left(\frac{W^*_{xi,t}}{W_{xi,t+k}} \right)^{\frac{-2\nu_{wxi}+1}{\nu_{wxi}-1}} \frac{N_{xi,t+k}}{W_{xi,t+k}} \;] \; \} = 0,$$

$$W^*_{xi,t} = \nu_{wxi} \frac{E_t \sum_{k=0}^{\infty} (\zeta_{wxi}\beta_{xi})^k \cdot N_{xi,t+k} \cdot MRS_{xi,t+k} P_{i,t+k}}{E_t \sum_{k=0}^{\infty} (\zeta_{wxi}\beta_{xi})^k \cdot N_{xi,t+k}} \quad , \tag{2.23}$$

where $MRS_{xi,t+k}$ denotes the marginal rate of substitution between consumption and working hours.

We can define the numerator and denominator of optimal wage setting condition for labour as $H_{wx1i,t}$ and $H_{wx2i,t}$, respectively. Thus, Equation 2.23 can be rewritten as follows:

$$W^*_{xi,t} = \nu_{wxi} \frac{H_{wx1i,t}}{H_{wx2i,t}} \quad , \tag{2.24}$$

where the numerator and denominator can be written in the recursive forms as the following:

$$H_{wx1i,t} = N_{xi,t} MRS_{xi,t} P_{i,t} + \zeta_{wxi}\beta_{xi} E_t \left(\frac{\Lambda_{xi,t+1}}{\Lambda_{xi,t}} \right) H_{wx1i,t+1} \tag{2.25}$$

and

$$H_{wx2i,t} = N_{xi,t} + \zeta_{wxi}\beta_{xi} E_t \left(\frac{\Lambda_{xi,t+1}}{\Lambda_{xi,t}} \right) H_{wx2i,t+1} \quad . \tag{2.26}$$

2.2.5 Technology creators in region R

This section will discuss the productive sector, which consists of the manufacturing and technology creation sectors. In region R, technology creation is carried out by technology creators or innovators through R&D, while technology creators or adopters in region A do technology adoption. For firms in region R to create new technologies, they require skilled labour to work towards that goal.

Considering the number of technologies, τ_t, available at time $t+1$ that each unit of skilled labour can create as τ_t. The production for τ_t is given by:

$$\tau_t = \omega_t T_t N_{SR,t}^{\theta_R - 1} \quad , \tag{2.27}$$

which represents the period of the creation of new technology. ω_t is a scale of ability on technology creation, which is also defined as an R&D productivity shock, T_t is the available technology stock at time t, and $N_{SR,t}$ is the number of skilled labours in the region R. A term $\theta_R - 1$ represents the share of skilled labour in new technology creation. Assuming that the technology-creating process is elastic, we can infer that θ_R is less than one, which implies a diminishing aggregate level of technology creation.

Let $V_{R,t}$ be the value of a new technology then the maximisation problem of technology creation firm f is

$$\max_{N_{SR,t}^f} \theta_R \beta_{SR} E_t \frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \tau_t N_{SR,t}^f - W_{SR,t} N_{SR,t}^f \quad ,$$

yielding an optimality condition that provides the wage as follows:

$$W_{SR,t} = \theta_R \beta_{SR} E_t \left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \tau_t \right] \quad . \tag{2.28}$$

Given a parameter ξ_R be the survival rate of any existing technology for region R. Then, the evolution of technologies can be expressed as the following:

$$T_{t+1} = \xi_R T_t + \tau_t N_{SR,t} \quad , \tag{2.29}$$

where a term $\xi_R T_t$ reflects the remaining technologies and $\tau_t N_{SR,t}$ is the creation of new technologies.

If a new technology is added to the existing stock of technology, represented by a variety j, the producer who buys the patent at a price $V_{R,t}$ can expect to generate a perpetual profit, represented by $\pi_{R,t}$, for as long as the technology remains viable. This means that the producer can expect to earn a profit indefinitely, unless the technology becomes obsolete or is replaced by a newer, more advanced technology. Therefore, the value function of technology creation in region R can be expressed as follows:

$$V_{R,t} = -W_{SR,t}N_{SR,t} + \Omega_{R,t}N_{SR,t} + \xi_R\beta_{SR}E_t\left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}}V_{R,t+1}\right] \quad , \tag{2.30}$$

where $\Omega_{R,t}$ is the value of created technology contribution and

$$\Omega_{R,t} = (1+\gamma_T)^t\eta_R\left(\frac{\tau_t}{T_t}\right) \quad , \tag{2.31}$$

which η_R is a constant scaling parameter for periodic value of created technology.

2.2.6 Technology adopters in region A

In region A, the technology sector produces new technology through technology adoption. To work with this new technology, skilled labour is required, just like in region R. Assuming that Φ_t is the number of newly adopted technologies available at period $t+1$ that each unit of skilled labour in the region A can produce and the production for Φ_t can be written as follows:

$$\Phi_t = \frac{\kappa A_t T_{t-1} N_{SA,t}^{\theta_A - 1}}{\rho(1+\gamma_T)^{t-1}} \quad . \tag{2.32}$$

This Equation 2.32 represents the period of creation of a newly adopted technology function. The parameter κ is a degree of adopting ability, where κ belongs to the range between 0 and 1, $\kappa \in (0,1)$, and ρ is a scaling parameter for interaction between current technology adoption and previous technology creation. In addition, A_t is stock of adopted technology at time t and $N_{SA,t}$ is the number of skilled labours in the region A. A term $\theta_A - 1$ represents the share of skilled labour in newly adopted technology. Assuming that the adoption technology process is elastic, we can infer that θ_A is less than one, which implies a diminishing aggregate level of technology adoption.

Let $V_{A,t}$ be the value of a new adopted technology then the maximisation problem of technology creation firm f is

$$\max_{N_{SA,t}^f} \theta_A\beta_{SA}E_t\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}}\frac{V_{A,t+1}}{A_{t+1}}\Phi_t N_{SA,t}^f - W_{SA,t}N_{SA,t}^f \quad ,$$

yielding an optimality condition that provides the wage

$$W_{SA,t} = \theta_A\beta_{SA}E_t\left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}}\frac{V_{A,t+1}}{A_{t+1}}\Phi_t\right] \quad . \tag{2.33}$$

Consider a scenario where the survival rate of any existing technology in region A, denoted by the parameter ξ_A, is at the same rate as in region R. In such a case, the evolution of adopted technologies can be expressed as the following equation:

$$A_{t+1} = \xi_A A_t + \Phi_t N_{SA,t} \quad , \tag{2.34}$$

where a term $\xi_A A_t$ reflects the remaining adopted technologies and $\Phi_t N_{SA,t}$ represents the adoption of additional new technologies.

When a new variety, denoted as j, is added to the current technology stock, the producer of this variety j can expect to earn a perpetual profit, represented by $\pi_{A,t}$. This profit is expected to continue indefinitely, unless the technology dies. The perpetual profit indicates that the producer can earn a continuous income stream from the new variety without any predetermined expiration date. Therefore, the value function of technology adoption in region A can be expressed as follows:

$$V_{A,t} = -W_{SA,t} N_{SA,t} + \Omega_{A,t} N_{SA,t} + \xi_A \beta_{SA} E_t \left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} V_{A,t+1} \right] \quad , \tag{2.35}$$

where $\Omega_{A,t}$ is the value of adopted technology contribution and

$$\Omega_{A,t} = (1 + \gamma_T)^t \eta_A \left(\frac{\Phi_t}{A_t} \right) \quad . \tag{2.36}$$

A parameter η_A is a constant scaling parameter for periodic value of adopted technology.

2.2.7 Inflation and Fisher Rule

Back in 1930, Irving Fisher introduced the theory of interest, which proposed that the nominal interest rate could be calculated by adding up the real interest rate and the expected inflation rate (Fisher, 1930). This Fisher rule can be expressed as a gross rate formula as the following:

$$R_{ni,t} = R_{i,t} E_t \Pi_{Pi,t+1} \quad . \tag{2.37}$$

In this Equation 2.37, $R_{ni,t}$ denotes the nominal interest rate for each region i, $R_{i,t}$ represents the real interest rate, and $\Pi_{Pi,t+1}$ stands for inflation.

To calculate the gross rate of inflation, this study uses a formula that compares present prices with previous-period prices or the ratio of those two terms, which is given as follows:

$$\Pi_{Pi,t} = \frac{P_{i,t}}{P_{i,t-1}} \quad . \tag{2.38}$$

2.2.8 Monetary Policy

The central bank employs the interest rate policy as a means of stabilising inflation and output whenever they deviate from their usual levels or steady-state values. The interest rate reaction function for region R, derived from the research of Herbst and Schorfheide (1984), Galí (2007), and Anzoategui et al. (2019), can be expressed mathematically through the following equation:

$$R_{nR,t} = \iota_{RnR,t} \left[\left(\frac{\Pi_{PR,t+1}}{\bar{\Pi}_{PR}} \right)^{\rho_{\Pi PR}} \left(\frac{\tilde{Y}_{R,t}}{\bar{Y}_R} \right)^{\rho_{YR}} \bar{R}_{nR} \right]^{(1-\rho_{RnR})} (R_{nR,t-1})^{\rho_{RnR}} \quad , \tag{2.39}$$

where $\iota_{RnR,t}$ denotes the interest rate policy shock, $\Pi_{PR,t+1}$ is the gross inflation rate, and $\bar{\Pi}_{PR}$ stands for the target inflation rate. In addition, $\tilde{Y}_{R,t}$ represents the level of aggregate output that already detrend using the endogenous steady-state growth rate, $\bar{Y}_R$ stands for the target level of output, and $\bar{R}_{nR}$ denotes the nominal target rate.

The parameter $\rho_{\Pi PR}$ is a degree of contraction monetary policy when inflation exceeds its target value, ρ_{YR} denotes a degree of contraction monetary policy when the economy is overgrowth, ρ_{RnR} is a degree of interest rate smoothing, and is range between 0 and 1, $0 < \rho_{RnR} < 1$, and the parameters $\rho_{\Pi PR}$ and ρ_{YR} are greater than zero.

The interest rate policy shock $\iota_{RnR,t}$ is assumed to be $AR(1)$ process and is expressed as follows:

$$\log \iota_{RnR,t} = (1 - \rho_{\iota_{RnR}}) \log (\bar{\iota}_{RnR}) + \rho_{\iota_{RnR}} \log (\iota_{RnR,t-1}) + \epsilon_{\iota_{RnR}} \quad , \tag{2.40}$$

where $\rho_{\iota_{RnR}}$ is persistence of nominal interest rate policy shock and $\epsilon_{\iota_{RnR}}$ is interest rate policy shock that assumed to be serially uncorrelated and normally distributed with mean zero and standard deviation $\sigma_{\iota RnR}$ or $\epsilon_{\iota_{RnR}} \sim N(0, \sigma_{\iota RnR})$.

Conversely, the interest rate reaction function for region A is defined the following:

$$R_{nA,t} = \left[\left(\frac{\Pi_{PA,t+1}}{\bar{\Pi}_{PA}} \right)^{\rho_{\Pi PA}} \left(\frac{\tilde{Y}_{A,t}}{\bar{Y}_A} \right)^{\rho_{YA}} \bar{R}_{nA} \right]^{(1-\rho_{RnA})} (R_{nA,t-1})^{\rho_{RnA}} \quad . \tag{2.41}$$

2.2.9 Aggregation for region R

The aggregate consumption can be expressed as follows:

$$C_{R,t} = C_{SR,t} + C_{UR,t} \quad . \tag{2.42}$$

The aggregate labour can be written as follows:

$$N_{R,t} = N_{SR,t} + N_{UR,t} \quad . \tag{2.43}$$

2.2.10 Aggregation for region A

The aggregate consumption can be expressed as follows:

$$C_{A,t} = C_{SA,t} + C_{UA,t} \quad . \tag{2.44}$$

The aggregate labour can be written as follows:

$$N_{A,t} = N_{SA,t} + N_{UA,t} \quad . \tag{2.45}$$

2.2.11 Market Clearing

The total outputs in each region i, $i \in \{R, A\}$, are allocated to the households' consumption. Therefore, goods market-clearing conditions are given by,

$$Y_{i,t} = C_{i,t} \quad . \tag{2.46}$$

2.3 Results

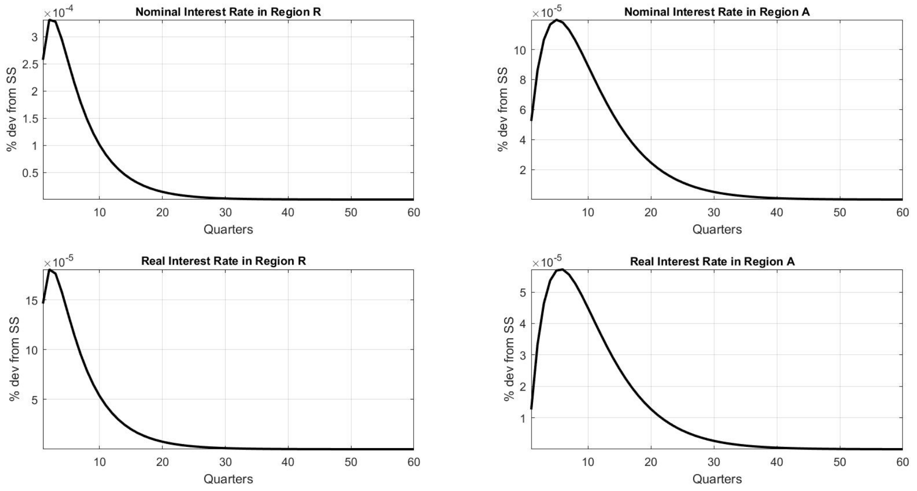
Within the framework of the endogenous growth study, there are several endogenous factors that could impact economic growth. This study examines a simple yet widely utilised model concerning the monetary transmission mechanism that facilitates precise results regarding growth. The problems that households and firms must solve and examine the necessary conditions describe the standard dynamic equilibrium under the assumption that all are interior and assume that the dynamic equilibrium converges to a steady state growth path. Those give a system of seventy-one nonlinear equations describing seventy-one endogenous variables of the model.

The equations that describe the system can be found in Appendix 2.6.1, and their stationary version detrends the dynamic equilibrium using the endogenous steady-state growth rate. This is demonstrated in Appendix 2.6.2. Since this chapter is mainly interested in the growth consequences of inflationary monetary policy in this framework, the results section will start with the impulse response to one standard deviation of monetary policy shock or a positive monetary policy shock using the software Dynare to evaluate the impact and followed by the impulse response to one standard deviation of skilled household preference shock.

2.3.1 Monetary Policy Shock

In the economic region R, when there is a positive monetary policy shock, the nominal interest rate increases sufficiently to ensure that the real interest rate becomes positive, following Taylor's principle, as depicted on the left side of Figure 2.1. This means that the real interest rate will be higher than the inflation rate, which has a significant impact on the economy. Due to this increase in real interest rates, there is a subsequent decrease in aggregate output and inflation, as shown on the left side of Figure 2.2. This decrease in aggregate output and inflation is due to the perception of the final goods producers that inflation will significantly decrease in the near future, leading to a decline in their profits. The rise in real interest rates makes borrowing more expensive, which leads to a decrease in investment and, in turn, results in reduced aggregate demand. As a result, the prices of goods and services decrease, leading to a drop in inflation.

FIGURE 2.1: Impulse response to a one standard deviation of monetary policy shock (a)

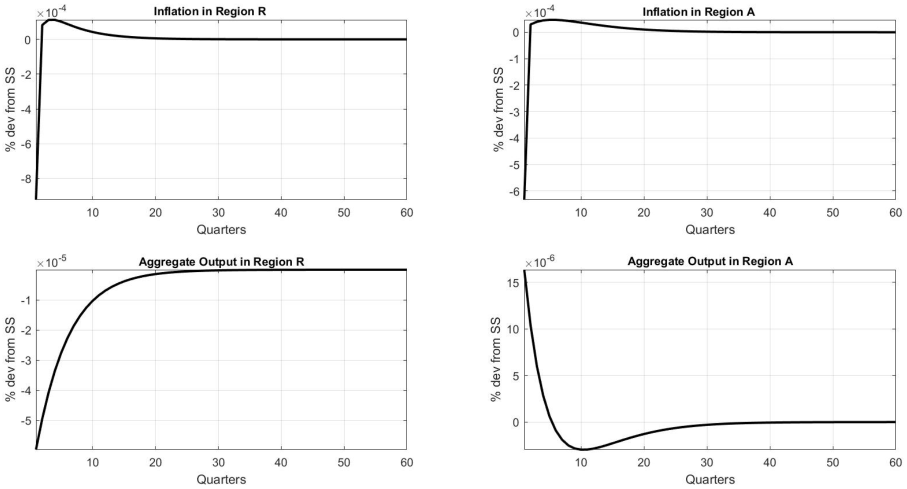


Source: Author's calculation

In response to a one-time positive monetary policy shock, the final goods production in region R reacted by adjusting their operations. Specifically, they opted to reduce the wages of unskilled workers. This decision consequently led to a reduction in financial support to the research and development sector. The decrease in support caused a decline in skilled wages as well. This reduction in wages was not only affected to the unskilled workforce; it also impacted skilled workers. As a result of these changes, the inputs of final goods producers were affected. This included the quantity of unskilled labour

($N_{UR,t}$) and technology level (T_t), both of which decreased. The decline in unskilled labour was a direct result of the reduction in wages that followed the monetary policy shock. The decrease in technology level was due to the reduction in funding to the R&D sector. This reduction in support led to a decline in technological advancements, which ultimately impacted the technology level of final goods producers. This is shown in the left-hand side of Figure 2.3.

FIGURE 2.2: Impulse response to a one standard deviation of monetary policy shock (b)

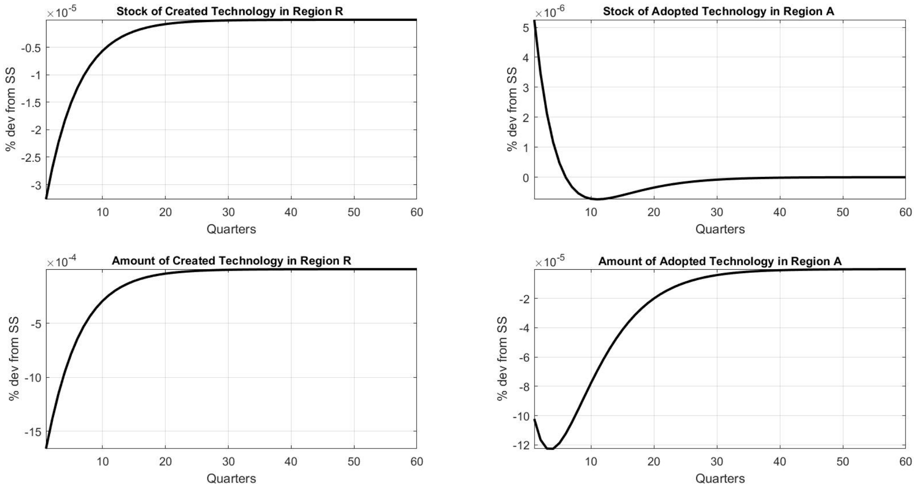


Source: Author's calculation

Households with skilled workers tend to exhibit a greater degree of financial prudence, with a focus on saving and investing for the future. These households tend to work and consume less, prioritising lending money to earn a higher return on the increasing interest rate. This saving and investing strategy helps them build wealth over time and provides a cushion against unexpected expenses or emergencies. On the other hand, households with unskilled workers tend to indicate a higher degree of impulsivity and short-term thinking. These households tend to borrow more money to consume more, even though they may prefer to work less due to the lower unskilled wage. This behaviour can be attributed to their lower propensity to save, which makes them more reliant on borrowing to meet their immediate spending needs.

In comparison to the short response of some variables in region R, region A experienced a delayed response of most macroeconomic variables to the positive monetary policy shock. The impulse responses to this shock in region A are shown on the right-hand sides of Figures 2.1, 2.2 and 2.3. This delay can be attributed to the technology gap between the two regions. Despite this delay, the economy of region A, which has adopted technology, has been experiencing consistent growth for a while, as depicted on the right of Figure 2.2. This growth is due to the comprehensive adoption of technology, which

Figure 2.3: Impulse response to a one standard deviation of monetary policy shock (c)



Source: Author's calculation

has significantly increased aggregate output. However, this increase in output has led to a decrease in the number of unskilled labours. As a result, producers of final goods have a higher marginal product of unskilled labour, which has led to an increase in unskilled wages in the short term. Therefore, while the adoption of technology has been beneficial for the overall economy of region A in the short run, it has also resulted in some unintended consequences, such as a reduction in the number of unskilled labours.

However, there is a significant increase in the overall output, it has both direct and indirect effects on the Taylor rule. The direct effect is that when the aggregate output deviates positively from its target, it increases both the nominal and real interest rates. This means that a higher output of goods and services creates an increase in demand for these outputs. This higher level of demand can lead to an increase in prices as the market responds to the higher demand. However, the increase in prices can also lead to an increase in nominal interest rates as lenders seek to protect their returns in the face of inflation. In addition, the increase in output also leads to a rise in the real interest rates as firms demand higher rates of return on their investments.

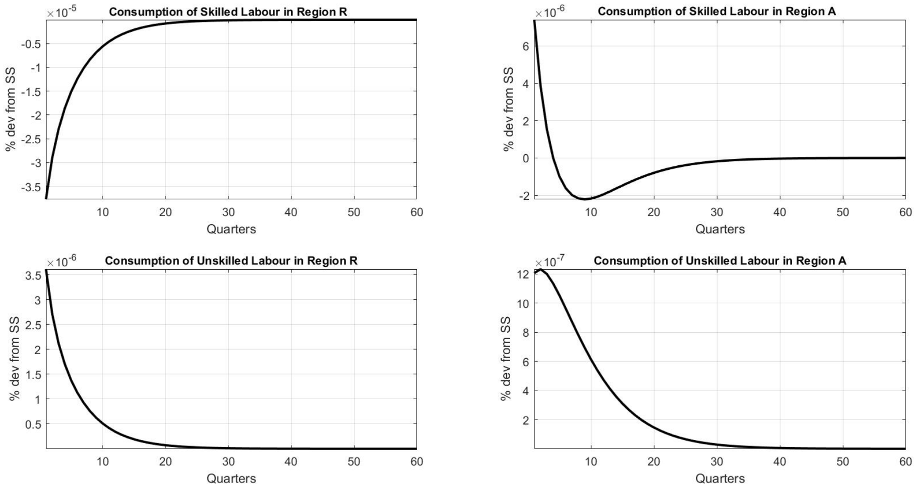
On the other hand, the indirect effect of a larger output on the Taylor rule is that it implies excess supply, leading to a decline in both price and inflation. This decline in inflation impedes both the nominal and real interest rates as inflation deviates from its target. However, the indirect effect seems to dominate, leading to an increase in both the nominal and real interest rates, as shown on the right side of Figure 2.1. It is important to note that this rise in both kinds of interest rates helps adjust the macro variables to their steady state in the long run. This means that the increase in interest rates helps stabilise the economy by reducing inflationary pressures and bringing the economy back to its equilibrium level.

2.3.2 Preference Shock

According to the additional results obtained from the positive preference shock of skilled households in the region R, it has been observed that skilled households tend to work more but consume less so that they can lend more money. On the other hand, unskilled households tend to work less but consume more by borrowing more money. Consequently, the shock causes a sudden decrease in skilled consumption and a sharp increase in skilled labour while unskilled consumption increases and unskilled labour decreases, as illustrated on the left-hand side in Figure 2.4.

Figure 2.4: Impulse response to a one standard deviation of skilled preference shock

(a)



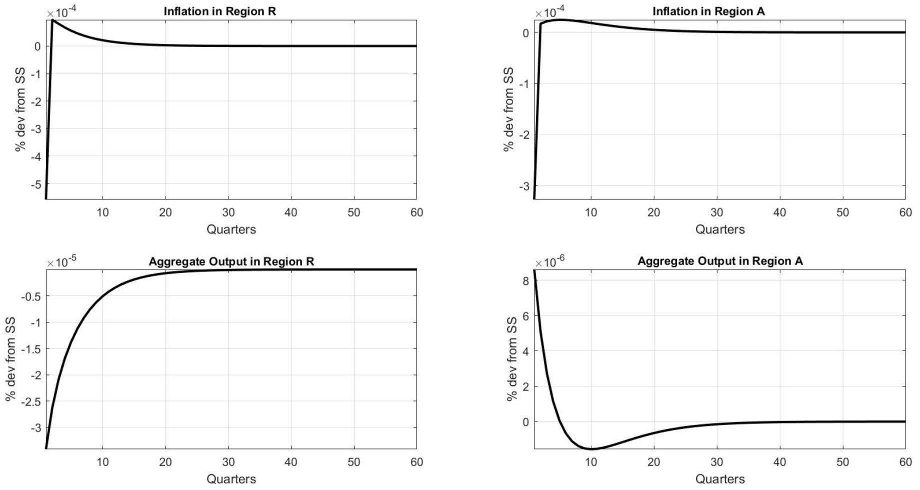
Source: Author's calculation

It has been observed that a shock to skilled consumption tends to have a greater negative impact on skilled consumption than an unskilled one. As a result, the overall level of aggregate consumption in the economy decreases. This decline in consumption leads to an increase in both nominal and real interest rates, as unskilled households tend to borrow more than skilled households lend. The decrease in aggregate consumption also leads to a temporary decrease in aggregate output. This, in turn, results in an increase in prices and inflation, as presented on the left-hand side of Figure 2.5.

However, firms operating in the economy will expect a decrease in future profits due to this decline in consumption. As a result, they will adjust their operations by reducing their aggregate output, inputs, and financial support for R&D activities. This reduction in aggregate output leads to a decrease in both skilled and unskilled wages. Moreover, it also leads to a decrease in R&D technology, which is essential for long-term economic growth and development. This can be seen in Figures 2.6 and 2.7, which illustrate the impact of the shock to skilled consumption on the overall economy.

In the long run, economic variables are expected to adjust to their steady-state values through the implementation of the Taylor rule by the central bank's monetary policy reaction. As seen in the left-hand side of Figure 2.5, negative deviations in aggregate output and inflation will prompt the central bank to reduce the nominal interest rate, leading to a decrease in the real interest rate according to the Taylor principle. This decrease in the real interest rate will stimulate the economy as firms expect inflation to increase. Consequently, firms will begin to hire more unskilled labour and employ more R&D technologies to produce more aggregate output. The economy is expected to recover and stabilise by implementing such measures in the long run.

Figure 2.5: Impulse response to a one standard deviation of skilled preference shock (b)

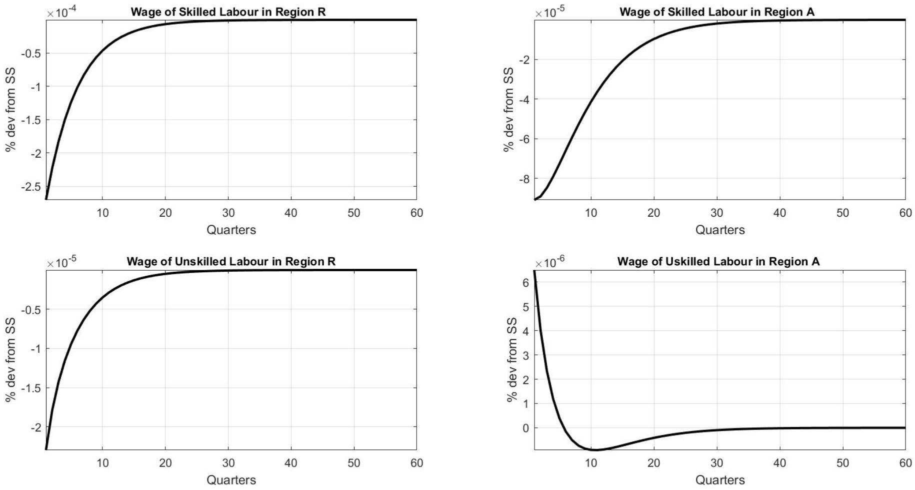


Source: Author's calculation

As a result of a positive skilled preference shock, both unskilled and skilled wages are increasing. This is because the marginal products of labour are rising, leading to an increase in the number of unskilled labours but a decrease in their consumption. Skilled households, on the other hand, are consuming more but working less due to the lower real interest rate, which results in a smaller return on lending. Additionally, there is an increase in aggregate consumption as skilled consumption dominates over unskilled consumption. The demand for aggregate consumption responds more than the aggregate output, leading to an excess demand for production that will push the price and inflation up. Finally, all economic variables will eventually adjust to their steady-state values in the long run.

Additionally, in the region A, a decrease in R&D technologies in the region R leads to a smaller number of adopted technologies. However, there are technology gaps that region A can fill up and catch up with the region R. The technology adopter has identified these gaps and then hires more skilled labours. This hiring of skilled labour outweighs the decrease in the number of adopted technologies and leads to a higher level of adopted technologies in the initial periods. The increase in the level of adopted technologies causes an increase in aggregate output, shown on the right-hand side in Figures 2.5 and 2.7. However, firms may end up hiring less unskilled labour because they expect slight inflation and a smaller profit in the future.

FIGURE 2.6: Impulse response to a one standard deviation of skilled preference shock (c)

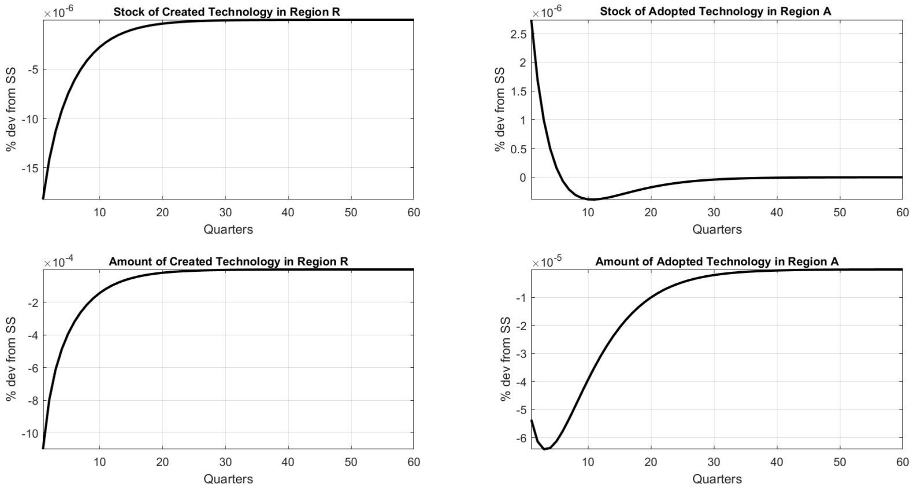


Source: Author's calculation

The right-hand side in Figure 2.6 demonstrates that a skilled preference shock in the region R significantly impacts the skilled wage in the region A. The reason for this is that the marginal adopted technologies of skilled labour decrease, leading to a negative response in the skilled wage. At the same time, the unskilled wage increases because of an increase in the marginal product of unskilled labour. This difference in the response of the skilled and unskilled wages can be attributed to the varying degrees of skill preference shocks in different regions. When skilled households experience a decrease in wages, they tend to save and lend less money. This is because they consume more to maintain their standard of living. On the other hand, unskilled households tend to borrow more loans because they want to work less. This results in an excess demand for loans, which pushes up both the real and nominal interest rates.

In response to a preference shock, both skilled and unskilled consumption in the region A increase, as does aggregate consumption, as indicated in Figure 2.4. However, the change in aggregate output is greater than the change in aggregate consumption. Consequently, there is excess production supply, leading to a decrease in prices and inflation in the short run. The monetary policy will react with the positive deviation of aggregate output by increasing the nominal interest rate. Conversely, the nominal interest rate will also decrease in response to the negative deviation of inflation. However, the central bank prioritises inflation targeting over output targeting, resulting in a lower adjustment of the nominal interest rate. Since the return on lending decreases, skilled households will lend less money and prefer lower consumption and work levels.

Figure 2.7: Impulse response to a one standard deviation of skilled preference shock (d)



Source: Author's calculation

In regions where households are defined as unskilled, access to loans may be limited, resulting in reduced consumption and increased work. Despite the increase in the number of adopted technologies in region A, due to advancements in R&D technologies from region R, the level of adopted technologies remains lower due to a decrease or shortage of skilled labour, as seen on the right-hand side of Figure 2.7. This indicates that although the technology is available, there needs to be more skilled labour to utilise it effectively.

Consequently, the lower level of adopted technologies leads to a decrease in aggregate output, meaning that the total amount of goods and services produced is less than what could be produced if the technology was used effectively. Moreover, this decrease in aggregate production dominates a decrease in aggregate consumption, implying that people are consuming less than they could be if the technology were used effectively.

In the long run, the excess supply of output will cause the price level and inflation to decrease. This happens because the lower aggregate output means that there is more supply than demand for goods and services. This excess supply will eventually lead to a decrease in prices as businesses attempt to attract customers by selling their goods and services at lower prices. As a result, inflation will also decrease in the long run.

2.4 Conclusions

Chapter 2 develops a New Keynesian DSGE model that features price and nominal wage stickiness. The model is used for monetary policy analysis to understand the interaction between monetary policy and volatility in aggregate economic variables. Using the software Dynare to evaluate the impact of a shock to nominal interest rate, $\iota_{RnR,t}$, on equilibrium variables or a positive monetary policy shock, the impulse response functions show the deviation from the steady-state for each macroeconomic variable. The nominal interest rate increases much enough to push the real interest rate to have positive values in response to a monetary policy shock, which follows Taylor's principle. Meanwhile, the aggregate output, inflation, the creation of new technology, and the stock of created technology in the innovating region, the region R, are negative responses to the shock since the positive real interest rate negatively affects the firms' decision as they expect the lower profit in the future as the shock sharply reduces the inflation. With a technology gap between the two regions, however, there is a lag effect from this monetary policy shock in the region A.

The quantitative results also include the impact of a skilled preference shock, $\beta_{SR,t}$, on the economy, which causes a sudden decrease in skilled consumption and a sharp increase in skilled labour while unskilled consumption increases and unskilled labour decreases. This shock leads to a decrease in aggregate consumption, an increase in both nominal and real interest rates, and a temporary decrease in aggregate output, resulting in a decrease in both skilled and unskilled wages, as well as R&D technology. However, in the long run, economic variables are expected to adjust to their steady-state values through the implementation of the Taylor rule by the central bank's monetary policy reaction. Additionally, a decrease in R&D technologies in region R leads to a smaller number of adopted technologies in region A, but there are technology gaps that region A can catch up with for a while. Finally, the response of skilled and unskilled wages to a skilled preference shock can be attributed to varying degrees of skill preference shocks in different regions.

In conclusion, monetary policy typically affects not only one region or country but also other regions. The effect of policy implementation can be transmitted to other regions through various channels, and the transmission channels between regions are the key to the economy's growth, especially in developing areas. However, this study only focuses on the impact of monetary policy through the technology adoption channel from one region to another. This study suggests that the monetary authorities in developing regions should monitor this channel more to support economic growth and stabilise economic volatility. The policy in the advanced regions also affects the entrepreneurs in developing regions through the technology adoption channel. Thus, the firm owners should understand the consequences of the effect on this channel (and other transmission channels) to manage their business to grow smoothly in the long run.

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2.6 Appendix

2.6.1 Model Equations

The model consists of 71 equations as follow:

$$\Lambda_{UR,t} = \frac{1}{P_{R,t}C_{UR,t}} \tag{B.1}$$

$$\frac{\chi_{UR}}{1-N_{UR,t}} = [1+\psi_R\mu_{UR,t}](1+\gamma_T)^t\Lambda_{UR,t}W_{UR,t} \tag{B.2}$$

$$\beta_{UR}\frac{E_t\Lambda_{UR,t+1}}{\Lambda_{UR,t}}R_{R,t} + \mu_{UR,t}(R_{R,t}-1+\nu_R) = 1 \tag{B.3}$$

$$\Lambda_{SR,t} = \frac{1}{P_{R,t}C_{SR,t}} \tag{B.4}$$

$$\frac{\chi_{SR}}{1-N_{SR,t}} = (1+\gamma_T)^t\Lambda_{SR,t}W_{SR,t} \tag{B.5}$$

$$\beta_{SR}E_t\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}}R_{R,t} = 1 \tag{B.6}$$

$$\begin{aligned} P_{R,t} &= [\zeta_{PR}((1+\gamma_T)P_{R,t-1})^{\frac{-1}{\nu_{PR}-1}} \\ &\quad + (1-\zeta_{PR})(P^*_{R,t})^{\frac{-1}{\nu_{PR}-1}}]^{-(\nu_{PR}-1)} \end{aligned} \tag{B.7}$$

$$\frac{P^*_{R,t}}{P_{R,t}} = \nu_{PR}\frac{H_{P1R,t}}{H_{P2R,t}} \tag{B.8}$$

$$\begin{aligned} H_{P1R,t} &= \frac{(1+\gamma_T)^t MC_{R,t}Y_{R,t}}{P_{R,t}} \\ &\quad + \zeta_{PR}\beta_{UR}E_t\left(\frac{(1+\gamma_T)\Lambda_{UR,t+1}}{\Lambda_{UR,t}}\right)\left(\frac{P_{R,t+1}}{(1+\gamma_T)P_{R,t}}\right)^{\frac{\nu_{PR}}{\nu_{PR}-1}} H_{P1R,t+1} \end{aligned} \tag{B.9}$$

$$\begin{aligned} H_{P2R,t} &= Y_{R,t} \\ &\quad + \zeta_{PR}\beta_{UR}E_t\left(\frac{(1+\gamma_T)\Lambda_{UR,t+1}}{\Lambda_{UR,t}}\right)\left(\frac{P_{R,t+1}}{(1+\gamma_T)P_{R,t}}\right)^{\frac{1}{\nu_{PR}-1}} H_{P2R,t+1} \end{aligned} \tag{B.10}$$

$$\Lambda_{UA,t} = \frac{1}{P_{A,t}C_{UA,t}} \tag{B.11}$$

$$\frac{\chi_{UA}}{1-N_{UA,t}} = (1+\psi_A\mu_{UA,t})(1+\gamma_T)^t\Lambda_{UA,t}W_{UA,t} \tag{B.12}$$

$$\beta_{UA} E_t \frac{\Lambda_{UA,t+1}}{\Lambda_{UA,t}} R_{A,t} + \mu_{UA,t}(R_{A,t} - 1 + \nu_A) = 1 \tag{B.13}$$

$$\Lambda_{SA,t} = \frac{1}{P_{A,t} C_{SA,t}} \tag{B.14}$$

$$\frac{\chi SA}{1 - N_{SA,t}} = (1+\gamma_T)^t \Lambda_{SA,t} W_{SA,t} \tag{B.15}$$

$$\beta_{SA} E_t \frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} R_{A,t} = 1 \tag{B.16}$$

$$\begin{aligned} P_{A,t} &= [\zeta_{PA}((1+\gamma_T)P_{A,t-1})^{\frac{-1}{\nu_{PA}-1}} \\ &\quad + (1-\zeta_{PA})(P^*_{A,t})^{\frac{-1}{\nu_{PA}-1}}]^{-(\nu_{PA}-1)} \end{aligned} \tag{B.17}$$

$$\frac{P^*_{A,t}}{P_{A,t}} = \nu_{PA} \frac{H_{P1A,t}}{H_{P2A,t}} \tag{B.18}$$

$$\begin{aligned} H_{P1A,t} &= \frac{(1+\gamma_T)^t MC_{A,t} Y_{A,t}}{P_{A,t}} \\ &\quad + \zeta_{PA}\beta_{UA} E_t \left(\frac{(1+\gamma_T)\Lambda_{UA,t+1}}{\Lambda_{UA,t}}\right) \left(\frac{P_{A,t+1}}{(1+\gamma_T)P_{A,t}}\right)^{\frac{\nu_{PA}}{\nu_{PA}-1}} H_{P1A,t+1} \end{aligned} \tag{B.19}$$

$$\begin{aligned} H_{P2A,t} &= Y_{A,t} + \zeta_{PA}\beta_{UA} E_t \left(\frac{(1+\gamma_T)\Lambda_{UA,t+1}}{\Lambda_{UA,t}}\right) \\ &\quad \cdot \left(\frac{P_{A,t+1}}{(1+\gamma_T)P_{A,t}}\right)^{\frac{1}{\nu_{PA}-1}} H_{P2A,t+1} \end{aligned} \tag{B.20}$$

$$Y_{R,t} = T_t^{\sigma_R - 1} N_{UR,t} \tag{B.21}$$

$$W_{UR,t} = \frac{1}{\sigma_R} T^{\sigma_R - 1} \tag{B.22}$$

$$\pi_{R,t} = \left(1 - \frac{1}{\sigma_R}\right) T_t^{\sigma_R - 2} N_{UR,t} - \frac{V_{R,t}}{T_t}(1+\gamma_T)\tau_{t-1} N_{SR,t-1} \tag{B.23}$$

$$\begin{aligned} W_{UR,t} &= \{\zeta_{WUR}[(1+\gamma_T)W_{UR,t-1}]^{\frac{-1}{\nu_{WUR}-1}} \\ &\quad + (1-\zeta_{WUR})(W^*_{UR,t})^{\frac{-1}{\nu_{WUR}-1}}\}^{-(\nu_{WUR}-1)} \end{aligned} \tag{B.24}$$

$$W^*_{UR,t} = \nu_{WUR} \frac{H_{WU1R,t}}{H_{WU2R,t}} \tag{B.25}$$

$$\begin{aligned} H_{WU1R,t} &= (1+\gamma_T) N_{UR,t} MRS_{UR,t} P_{R,t} \\ &\quad + \zeta_{WUR}\beta_{UR} E_t \left(\frac{(1+\gamma_T)^t \Lambda_{UR,t+1}}{\Lambda_{UR,t}}\right) H_{WU1R,t+1} \end{aligned} \tag{B.26}$$

$$\begin{aligned} H_{WU2R,t} &= (1+\gamma_T)^t N_{UR,t} \\ &\quad + \zeta_{WUR}\beta_{UR} E_t \left(\frac{(1+\gamma_T)\Lambda_{UR,t+1}}{\Lambda_{UR,t}}\right) H_{WU2R,t+1} \end{aligned} \tag{B.27}$$

$$\tau_t = \omega_t T_t N_{SR,t}^{\theta_R - 1} \tag{B.28}$$

$$W_{SR,t} = \theta_R \beta_{SR} E_t \left[\frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \frac{V_{R,t+1}}{T_{t+1}} \cdot \tau_t\right] \tag{B.29}$$

$$T_{t+1} = \xi_R T_t + \tau_t N_{SR,t} \tag{B.30}$$

$$\begin{aligned} V_{R,t} = &-W_{SR,t}N_{SR,t} + \Omega_{R,t}N_{SR,t} \\ &+ \xi_R \beta_{SR} E_t \frac{\Lambda_{SR,t+1}}{\Lambda_{SR,t}} V_{R,t+1} \end{aligned} \tag{B.31}$$

$$\Omega_{R,t} = (1+\gamma_T)^t \eta_R \frac{\tau_t}{T_t} \tag{B.32}$$

$$\begin{aligned} W_{SR,t} = &\{\zeta_{WSR}[(1+\gamma_T)W_{SR,t-1}]^{\frac{-1}{\nu_{WUR}-1}} \\ &+ (1-\zeta_{WUR})(W^*_{UR,t})^{\frac{-1}{\nu_{WUR}-1}}\}^{-(\nu_{WSR}-1)} \end{aligned} \tag{B.33}$$

$$W^*_{SR,t} = \nu_{WSR} \frac{H_{WS1R,t}}{H_{WS2R,t}} \tag{B.34}$$

$$\begin{aligned} H_{WS1R,t} = &N_{SR,t} MRS_{SR,t} P_{R,t} \\ &+ \zeta_{WSR} \beta_{SR} E_t \left(\frac{(1+\gamma_T)\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \right) H_{WS1R,t+1} \end{aligned} \tag{B.35}$$

$$\begin{aligned} H_{WS2R,t} = &(1+\gamma_T)^t N_{SR,t} \\ &+ \zeta_{WSR} \beta_{SR} E_t \left(\frac{(1+\gamma_T)\Lambda_{SR,t+1}}{\Lambda_{SR,t}} \right) H_{WS2R,t+1} \end{aligned} \tag{B.36}$$

$$Y_{A,t} = A_t^{\sigma_A - 1} N_{UA,t} \tag{B.37}$$

$$W_{UA,t} = \frac{1}{\sigma_A} A_t^{\sigma_A - 1} \tag{B.38}$$

$$\pi_{A,t} = \left(1 - \frac{1}{\sigma_A}\right) A_t^{\sigma_A - 2} N_{UA,t} - \frac{V_{A,t}}{A_t}(1+\gamma_T)\Phi_{t-1} N_{SA,t-1} \tag{B.39}$$

$$\begin{aligned} W_{UA,t} = &\{\zeta_{WUA}((1+\gamma_T)W_{UA,t-1})^{\frac{-1}{\nu_{WUA}-1}} \\ &+ (1-\zeta_{WUA})(W^*_{UA,t})^{\frac{-1}{\nu_{WUA}-1}}\}^{-(\nu_{WUA}-1)} \end{aligned} \tag{B.40}$$

$$W^*_{UA,t} = \nu_{WUA} \frac{H_{WU1A,t}}{H_{WU2A,t}} \tag{B.41}$$

$$\begin{aligned} H_{WU1A,t} = &(1+\gamma_T)^t N_{UA,t} MRS_{UA,t} P_{A,t} \\ &+ \zeta_{WUA} \beta_{UA} E_t \left(\frac{(1+\gamma_T)\Lambda_{UA,t+1}}{\Lambda_{UA,t}} \right) H_{WU1A,t+1} \end{aligned} \tag{B.42}$$

$$\begin{aligned} H_{WU2A,t} = &(1+\gamma_T)^t N_{UA,t} \\ &+ \zeta_{WUA} \beta_{UA} E_t \left(\frac{(1+\gamma_T)\Lambda_{UA,t+1}}{\Lambda_{UA,t}} \right) H_{WU2A,t+1} \end{aligned} \tag{B.43}$$

$$\Phi_t = \frac{\kappa}{\rho} \cdot \frac{A_t T_{t-1} N_{SA,t}^{\theta_A - 1}}{(1+\gamma_T)^{t-1}} \tag{B.44}$$

$$W_{SA,t} = \theta_A \beta_{SA} E_t \left[\frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \frac{V_{A,t+1}}{A_{t+1}} \cdot \Phi_t \right] \tag{B.45}$$

$$A_{t+1} = \xi_A A_t + \Phi_t N_{SA,t} \tag{B.46}$$

$$V_{A,t} = -W_{SA,t}N_{SA,t} + \Omega_{A,t}N_{SA,t} + \xi_A \beta_{SA} E_t \frac{\Lambda_{SA,t+1}}{\Lambda_{SA,t}} V_{A,t+1} \tag{B.47}$$

$$\Omega_{A,t} = \eta_A (1+\gamma_T)^t \frac{\Phi_t}{A_t} \tag{B.48}$$

$$\begin{aligned} W_{SA,t} = \{ & \zeta_{WSA}[(1+\gamma_T)W_{SA,t-1}]^{\frac{-1}{\nu_{WSA}-1}} \\ & + (1-\zeta_{WSA})(W^*_{SA,t})^{\frac{-1}{\nu_{WSA}-1}} \}^{-(\nu_{WSA}-1)} \end{aligned} \tag{B.49}$$

$$W^*_{SA,t} = \nu_{WSA} \frac{H_{WS1A,t}}{H_{Ws2A,t}} \tag{B.50}$$

$$\begin{aligned} H_{WS1A,t} = & (1+\gamma_T)^t N_{SA,t} MRS_{SA,t} P_{A,t} \\ & + \zeta_{WSA} \beta_{SA} E_t \left(\frac{(1+\gamma_T)\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \right) H_{WS1A,t+1} \end{aligned} \tag{B.51}$$

$$\begin{aligned} H_{WS2A,t} = & (1+\gamma_T)^t N_{SA,t} \\ & + \zeta_{WSA} \beta_{SA} E_t \left(\frac{(1+\gamma_T)\Lambda_{SA,t+1}}{\Lambda_{SA,t}} \right) H_{WS2A,t+1} \end{aligned} \tag{B.52}$$

$$\Pi_{PR,t} = \frac{P_{R,t}}{(1+\gamma_T)P_{R,t-1}} \tag{B.53}$$

$$\Pi_{PA,t} = \frac{P_{A,t}}{(1+\gamma_T)P_{A,t-1}} \tag{B.54}$$

$$R_{nR,t} = R_{R,t} E_t \Pi_{PR,t+1} \tag{B.55}$$

$$R_{nA,t} = R_{A,t} E_t \Pi_{PA,t+1} \tag{B.56}$$

$$R_{nR,t} = \iota_{RnR} \left[\left(\frac{\Pi_{PR,t+1}}{\bar{\Pi}_{PR}} \right)^{\rho_{\Pi_{PR}}} \left(\frac{Y_{R,t}}{(1+\gamma_T)^t \bar{Y}_R} \right)^{\rho_{YR}} \bar{R}_{nR} \right]^{(1-\rho_{RnR})} R_{nR,t-1}^{\rho_{RnR}} \tag{B.57}$$

$$R_{nA,t} = \left[\left(\frac{\Pi_{PA,t+1}}{\bar{\Pi}_{PA}} \right)^{\rho_{\Pi_{PA}}} \left(\frac{Y_{A,t}}{(1+\gamma_T)^t \bar{Y}_A} \right)^{\rho_{YA}} \bar{R}_{nA} \right]^{(1-\rho_{RnA})} R_{nA,t-1}^{\rho_{RnA}} \tag{B.58}$$

$$C_{R,t} = C_{SR,t} + C_{UR,t} \tag{B.59}$$

$$C_{A,t} = C_{SA,t} + C_{UA,t} \tag{B.60}$$

$$N_{R,t} = N_{SR,t} + N_{UR,t} \tag{B.61}$$

$$N_{A,t} = N_{SA,t} + N_{UA,t} \tag{B.62}$$

$$Y_{R,t} = C_{R,t} \tag{B.63}$$

$$Y_{A,t} = C_{A,t} \tag{B.64}$$

$$\log \iota_{RnR,t} = (1-\rho_{\iota_{RnR}}) \log(\bar{\iota}_{RnR}) + \rho_{\iota_{RnR}} \log(\iota_{RnR,t-1}) + \epsilon_{\iota_{RnR}} \tag{B.65}$$

$$\log \beta_{SR,t} = (1-\rho_{\beta_{SR}}) \log(\bar{\beta}_{SR}) + \rho_{\beta_{SR}} \log(\beta_{SR,t-1}) + \epsilon_{\beta_{SR}} \tag{B.66}$$

$$\log \beta_{UR,t} = (1-\rho_{\beta_{UR}}) \log(\bar{\beta}_{UR}) + \rho_{\beta_{UR}} \log(\beta_{UR,t-1}) + \epsilon_{\beta_{UR}} \tag{B.67}$$

$$\log(\omega_t) = (1-\rho_\omega) \log \overline{\omega} + \rho_\omega \log \omega_{t-1} + \epsilon_{\omega,t} \tag{B.68}$$

$$\log \nu_{PR,t} = (1-\rho_{\nu_{PR}}) \log(\bar{\nu}_{PR}) + \rho_{\nu_{PR}} \log(\nu_{PR,t-1}) + \epsilon_{\nu_{PR}} \tag{B.69}$$

$$\log \nu_{W_{SR},t} = (1-\rho_{\nu_{W_{SR}}}) \log(\bar{\nu}_{W_{SR}}) + \rho_{\nu_{W_{SR}}} \log(\nu_{W_{SR},t-1}) + \epsilon_{\nu_{W_{SR}}} \tag{B.70}$$

$$\log \nu_{W_{UR},t} = (1-\rho_{\nu_{W_{UR}}}) \log(\bar{\nu}_{W_{UR}}) + \rho_{\nu_{W_{UR}}} \log(\nu_{W_{UR},t-1}) + \epsilon_{\nu_{W_{UR}}} \tag{B.71}$$

2.6.2 Stationarised Equations

The version of model stationary consists of 71 equations as follow:

$$\hat{\Lambda}_{UR,t} = \frac{1}{\tilde{P}_{R,t}\tilde{C}_{UR,t}} \qquad ; \hat{\Lambda}_{UR,t} = (1+\gamma_T)^{2t}\Lambda_{UR,t} \tag{B.1s}$$

$$\frac{\chi_{UR}}{1-N_{UR,t}} = [1+\psi_R\mu_{UR,t}]\hat{\Lambda}_{UR,t}\tilde{W}_{UR,t} \tag{B.2s}$$

$$\beta_{UR}\frac{E_t\hat{\Lambda}_{UR,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{UR,t}}R_{R,t} + \mu_{UR,t}(R_{R,t} - 1 + \nu_R) = 1 \tag{B.3s}$$

$$\hat{\Lambda}_{SR,t} = \frac{1}{\tilde{P}_{R,t}\tilde{C}_{SR,t}} \tag{B.4s}$$

$$\frac{\chi_{SR}}{1-N_{SR,t}} = \hat{\Lambda}_{SR,t}\tilde{W}_{SR,t} \tag{B.5s}$$

$$\beta_{SR}E_t\frac{\hat{\Lambda}_{SR,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{SR,t}}R_{R,t} = 1 \tag{B.6s}$$

$$\tilde{P}_{R,t} = [\zeta_{PR}(\tilde{P}_{R,t-1})^{\frac{-1}{\nu_{PR}-1}} + (1-\zeta_{PR})(\tilde{P}^*_{R,t})^{\frac{-1}{\nu_{PR}-1}}]^{-(\nu_{PR}-1)} \tag{B.7s}$$

$$\frac{\tilde{P}^*_{R,t}}{\tilde{P}_{R,t}} = \nu_{PR}\frac{\tilde{H}_{P1R,t}}{\tilde{H}_{P2R,t}} \tag{B.8s}$$

$$\tilde{H}_{P1R,t} = \frac{MC_{R,t}\tilde{Y}_{R,t}}{\tilde{P}_{R,t}} + \zeta_{PR}\beta_{UR}E_t\left(\frac{\hat{\Lambda}_{UR,t+1}}{\hat{\Lambda}_{UR,t}}\right)\left(\frac{\tilde{P}_{R,t+1}}{\tilde{P}_{R,t}}\right)^{\frac{\nu_{PR}}{\nu_{PR}-1}}\tilde{H}_{P1R,t+1} \tag{B.9s}$$

$$\tilde{H}_{P2R,t} = \tilde{Y}_{R,t} + \zeta_{PR}\beta_{UR}E_t\left(\frac{\hat{\Lambda}_{UR,t+1}}{\hat{\Lambda}_{UR,t}}\right)\left(\frac{\tilde{P}_{R,t+1}}{\tilde{P}_{R,t}}\right)^{\frac{1}{\nu_{PR}-1}}\tilde{H}_{P2R,t+1} \tag{B.10s}$$

$$\hat{\Lambda}_{UA,t} = \frac{1}{\tilde{P}_{A,t}\tilde{C}_{UA,t}} \tag{B.11s}$$

$$\frac{\chi_{UA}}{1-N_{UA,t}} = (1+\psi_A\mu_{UA,t})\hat{\Lambda}_{UA,t}\tilde{W}_{UA,t} \tag{B.12s}$$

$$\beta_{UA}E_t\frac{\hat{\Lambda}_{UA,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{UA,t}}R_{A,t} + \mu_{UA,t}(R_{A,t} - 1 + \nu_A) = 1 \tag{B.13s}$$

$$\hat{\Lambda}_{SA,t} = \frac{1}{\tilde{P}_{A,t}\tilde{C}_{SA,t}} \tag{B.14s}$$

$$\frac{\chi_{SA}}{1-N_{SA,t}} = \hat{\Lambda}_{SA,t}\tilde{W}_{SA,t} \tag{B.15s}$$

$$\beta_{SA}E_t\frac{\hat{\Lambda}_{SA,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{SA,t}}R_{A,t} = 1 \tag{B.16s}$$

$$\begin{aligned}\tilde{P}_{A,t} &= [\zeta_{PA}(\tilde{P}_{A,t-1})^{\frac{-1}{\nu_{PA}-1}} \\ &\quad + (1-\zeta_{PA})(\tilde{P}^*_{A,t})^{\frac{-1}{\nu_{PA}-1}}]^{-(\nu_{PA}-1)}\end{aligned} \tag{B.17s}$$

$$\frac{\tilde{P}^*_{A,t}}{\tilde{P}_{A,t}} = \nu_{PA}\frac{\tilde{H}_{P1A,t}}{\tilde{H}_{P2A,t}} \tag{B.18s}$$

$$\begin{aligned}\tilde{H}_{P1A,t} &= \frac{MC_{A,t}\tilde{Y}_{A,t}}{\tilde{P}_{A,t}} \\ &\quad + \zeta_{PA}\beta_{UA}E_t\left(\frac{\hat{\Lambda}_{UA,t+1}}{\hat{\Lambda}_{UA,t}}\right)\left(\frac{\tilde{P}_{A,t+1}}{\tilde{P}_{A,t}}\right)^{\frac{\nu_{PA}}{\nu_{PA}-1}}\tilde{H}_{P1A,t+1}\end{aligned} \tag{B.19s}$$

$$\begin{aligned}\tilde{H}_{P2A,t} &= \tilde{Y}_{A,t} + \zeta_{PA}\beta_{UA}E_t\left(\frac{\hat{\Lambda}_{UA,t+1}}{\hat{\Lambda}_{UA,t}}\right) \\ &\quad \cdot \left(\frac{\tilde{P}_{A,t+1}}{\tilde{P}_{A,t}}\right)^{\frac{1}{\nu_{PA}-1}}\tilde{H}_{P2A,t+1}\end{aligned} \tag{B.20s}$$

$$\tilde{Y}_{R,t} = \tilde{T}_t^{\sigma_R-1}N_{UR,t} \tag{B.21s}$$

$$\tilde{W}_{UR,t} = \frac{1}{\sigma_R}\tilde{T}^{\sigma_R-1} \tag{B.22s}$$

$$\tilde{\pi}_{R,t} = \left(1-\frac{1}{\sigma_R}\right)\tilde{T}_t^{\sigma_R-2}N_{UR,t} - \frac{\tilde{V}_{R,t}}{\tilde{T}_t}\tilde{\tau}_{t-1}N_{SR,t-1} \tag{B.23s}$$

$$\begin{aligned}\tilde{W}_{UR,t} &= \{\zeta_{WUR}(\tilde{W}_{UR,t-1})^{\frac{-1}{\nu_{WUR}-1}} \\ &\quad + (1-\zeta_{WUR})(\tilde{W}^*_{UR,t})^{\frac{-1}{\nu_{WUR}-1}}\}^{-(\nu_{WUR}-1)}\end{aligned} \tag{B.24s}$$

$$\tilde{W}^*_{UR,t} = \nu_{WUR}\frac{\tilde{H}_{WU1R,t}}{\tilde{H}_{WU2R,t}} \tag{B.25s}$$

$$\begin{aligned}\tilde{H}_{WU1R,t} &= MRS_{UR,t}\tilde{P}_{R,t}N_{UR,t} \\ &\quad + \zeta_{WUR}\beta_{UR}E_t\left(\frac{\hat{\Lambda}_{UR,t+1}}{\hat{\Lambda}_{UR,t}}\right)\tilde{H}_{WU1R,t+1}\end{aligned} \tag{B.26s}$$

$$\tilde{H}_{WU2R,t} = N_{UR,t} + \zeta_{WUR}\beta_{UR}E_t\left(\frac{\hat{\Lambda}_{UR,t+1}}{\hat{\Lambda}_{UR,t}}\right)\tilde{H}_{WU2R,t+1} \tag{B.27s}$$

$$\tilde{\tau}_t = \omega_t\tilde{T}_tN_{SR,t}^{\theta_R-1} \tag{B.28s}$$

$$\tilde{W}_{SR,t} = \theta_R\beta_{SR}E_t\left[\frac{\hat{\Lambda}_{SR,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{SR,t}}\frac{\tilde{V}_{R,t+1}}{\tilde{T}_{t+1}}\cdot\tilde{\tau}_t\right] \tag{B.29s}$$

$$(1+\gamma_T)\tilde{T}_{t+1} = \xi_R\tilde{T}_t + \tilde{\tau}_tN_{SR,t} \tag{B.30s}$$

$$\begin{aligned}\tilde{V}_{R,t} &= -\tilde{W}_{SR,t}N_{SR,t} + \tilde{\Omega}_{R,t}N_{SR,t} \\ &\quad + \xi_R\beta_{SR}E_t\frac{\hat{\Lambda}_{SR,t+1}}{(1+\gamma_T)\hat{\Lambda}_{SR,t}}\tilde{V}_{R,t+1}\end{aligned} \tag{B.31s}$$

$$\tilde{\Omega}_{R,t} = \eta_R\frac{\tilde{\tau}_t}{\tilde{T}_t} \tag{B.32s}$$

$$\begin{aligned}\tilde{W}_{SR,t} &= \{\zeta_{WSR}(W_{SR,t-1})^{\frac{-1}{\nu_{WSR}-1}} \\ &\quad + (1-\zeta_{WSR})(\tilde{W}^*_{SR,t})^{\frac{-1}{\nu_{WSR}-1}}\}^{-(\nu_{WSR}-1)}\end{aligned} \tag{B.33s}$$

$$\tilde{W}^*_{SR,t} = \nu_{WSR}\frac{\tilde{H}_{WS1R,t}}{\tilde{H}_{WS2R,t}} \tag{B.34s}$$

$$\begin{aligned}\tilde{H}_{WS1R,t} &= MRS_{SR,t}\tilde{P}_{R,t}N_{SR,t} \\ &\quad + \zeta_{WSR}\beta_{SR}E_t\left(\frac{\hat{\Lambda}_{SR,t+1}}{\hat{\Lambda}_{SR,t}}\right)\tilde{H}_{WS1R,t+1}\end{aligned} \tag{B.35s}$$

$$\tilde{H}_{WS2R,t} = N_{SR,t} + \zeta_{WSR}\beta_{SR}E_t\left(\frac{\hat{\Lambda}_{SR,t+1}}{\hat{\Lambda}_{SR,t}}\right)\tilde{H}_{WS2R,t+1} \tag{B.36s}$$

$$\tilde{Y}_{A,t} = \tilde{A}_t^{\sigma_A-1}N_{UA,t} \tag{B.37s}$$

$$\tilde{W}_{UA,t} = \frac{1}{\sigma_A}\tilde{A}_t^{\sigma_A-1} \tag{B.38s}$$

$$\tilde{\pi}_{A,t} = \left(1-\frac{1}{\sigma_A}\right)\tilde{A}_t^{\sigma_A-2}N_{UA,t} - \frac{\tilde{V}_{A,t}}{\tilde{A}_t}\tilde{\Phi}_{t-1}N_{SA,t-1} \tag{B.39s}$$

$$\begin{aligned}\tilde{W}_{UA,t} &= [\zeta_{WUA}(\tilde{W}_{UA,t-1})^{\frac{-1}{\nu_{WUA}-1}} \\ &\quad + (1-\zeta_{WUA})(\tilde{W}^*_{UA,t})^{\frac{-1}{\nu_{WUA}-1}}]^{-(\nu_{WUA}-1)}\end{aligned} \tag{B.40s}$$

$$\tilde{W}^*_{UA,t} = \nu_{WUA}\frac{\tilde{H}_{WU1A,t}}{\tilde{H}_{WU2A,t}} \tag{B.41s}$$

$$\begin{aligned}\tilde{H}_{WU1A,t} &= MRS_{UA,t}\tilde{P}_{A,t}N_{UA,t} \\ &\quad + \zeta_{WUA}\beta_{UA}E_t\left(\frac{\hat{\Lambda}_{UA,t+1}}{\hat{\Lambda}_{UA,t}}\right)\tilde{H}_{WU1A,t+1}\end{aligned} \tag{B.42s}$$

$$\begin{aligned}\tilde{H}_{WU2A,t} &= N_{UA,t} \\ &\quad + \zeta_{WUA}\beta_{UA}E_t\left(\frac{(\hat{\Lambda}_{UA,t+1}}{\hat{\Lambda}_{UA,t}}\right)\tilde{H}_{WU2A,t+1}\end{aligned} \tag{B.43s}$$

$$\tilde{\Phi}_t = \frac{\kappa}{\rho}\cdot\tilde{A}_t\tilde{T}_{t-1}N_{SA,t}^{\theta_A-1} \tag{B.44s}$$

$$\tilde{W}_{SA,t} = \theta_A\beta_{SA}E_t\left[\frac{\hat{\Lambda}_{SA,t+1}}{(1+\gamma_T)^2\hat{\Lambda}_{SA,t}}\frac{\tilde{V}_{A,t+1}}{\tilde{A}_{t+1}}\cdot\tilde{\Phi}_t\right] \tag{B.45s}$$

$$(1+\gamma_T)^2\tilde{A}_{t+1} = \xi_A\tilde{A}_t + \tilde{\Phi}_tN_{SA,t} \tag{B.46s}$$

$$\tilde{V}_{A,t} = -\tilde{W}_{SA,t}N_{SA,t} + \tilde{\Omega}_{A,t}N_{SA,t} + \xi_A\beta_{SA}E_t\frac{\hat{\Lambda}_{SA,t+1}}{(1+\gamma_T)\hat{\Lambda}_{SA,t}}\tilde{V}_{A,t+1} \tag{B.47s}$$

$$\tilde{\Omega}_{A,t} = \eta_A\frac{\tilde{\Phi}_t}{\tilde{A}_t} \tag{B.48s}$$

$$\begin{aligned}\tilde{W}_{SA,t} &= [\zeta_{WSA}(\tilde{W}_{SA,t-1})^{\frac{-1}{\nu_{WSA}-1}} \\ &\quad + (1-\zeta_{WSA})(\tilde{W}^*_{SA,t})^{\frac{-1}{\nu_{WSA}-1}}]^{-(\nu_{WSA}-1)}\end{aligned} \tag{B.49s}$$

$$\tilde{W}^*_{SA,t} = \nu_{WSA}\frac{\tilde{H}_{WS1A,t}}{\tilde{H}_{Ws2A,t}} \tag{B.50s}$$

$$\begin{aligned}\tilde{H}_{WS1A,t} &= MRS_{SA,t}\tilde{P}_{A,t}N_{SA,t} \\ &\quad + \zeta_{WSA}\beta_{SA}E_t\left(\frac{\hat{\Lambda}_{SA,t+1}}{\hat{\Lambda}_{SA,t}}\right)\tilde{H}_{WS1A,t+1}\end{aligned} \tag{B.51s}$$

$$\tilde{H}_{WS2A,t} = N_{SA,t} + \zeta_{WSA}\beta_{SA}E_t\left(\frac{\hat{\Lambda}_{SA,t+1}}{\hat{\Lambda}_{SA,t}}\right)\tilde{H}_{WS2A,t+1} \tag{B.52s}$$

$$\Pi_{PR,t} = \frac{\tilde{P}_{R,t}}{\tilde{P}_{R,t-1}} \tag{B.53s}$$

$$\Pi_{PA,t} = \frac{\tilde{P}_{A,t}}{\tilde{P}_{A,t-1}} \tag{B.54s}$$

$$R_{nR,t} = R_{R,t}E_t\Pi_{PR,t+1} \tag{B.55s}$$

$$R_{nA,t} = R_{A,t}E_t\Pi_{PA,t+1} \tag{B.56s}$$

$$R_{nR,t} = \iota_{RnR}\left[\left(\frac{\Pi_{PR,t+1}}{\bar{\Pi}_{PR}}\right)^{\rho_{\Pi_{PR}}}\left(\frac{\tilde{Y}_{R,t}}{\bar{Y}_R}\right)^{\rho_{YR}}\bar{R}_{nR}\right]^{(1-\rho_{RnR})}R_{nR,t-1}^{\rho_{RnR}} \tag{B.57s}$$

$$R_{nA,t} = \left[\left(\frac{\Pi_{PA,t+1}}{\bar{\Pi}_{PA}}\right)^{\rho_{\Pi_{PA}}}\left(\frac{\tilde{Y}_{A,t}}{\bar{Y}_A}\right)^{\rho_{YA}}\bar{R}_{nA}\right]^{(1-\rho_{RnA})}R_{nA,t-1}^{\rho_{RnA}} \tag{B.58s}$$

$$\tilde{C}_{R,t} = \tilde{C}_{SR,t} + \tilde{C}_{UR,t} \tag{B.59s}$$

$$\tilde{C}_{A,t} = \tilde{C}_{SA,t} + \tilde{C}_{UA,t} \tag{B.60s}$$

$$N_{R,t} = N_{SR,t} + N_{UR,t} \tag{B.61s}$$

$$N_{A,t} = N_{SA,t} + N_{UA,t} \tag{B.62s}$$

$$\tilde{Y}_{R,t} = \tilde{C}_{R,t} \tag{B.63s}$$

$$\tilde{Y}_{A,t} = \tilde{C}_{A,t} \tag{B.64s}$$

$$\log\iota_{RnR,t} = (1-\rho_{\iota_{RnR}})\log(\bar{\iota}_{RnR}) + \rho_{\iota_{RnR}}\log(\iota_{RnR,t-1}) + \epsilon_{\iota_{RnR}} \tag{B.65s}$$

$$\log\beta_{SR,t} = (1-\rho_{\beta_{SR}})\log(\bar{\beta}_{SR}) + \rho_{\beta_{SR}}\log(\beta_{SR,t-1}) + \epsilon_{\beta_{SR}} \tag{B.66s}$$

$$\log\beta_{UR,t} = (1-\rho_{\beta_{UR}})\log(\bar{\beta}_{UR}) + \rho_{\beta_{UR}}\log(\beta_{UR,t-1}) + \epsilon_{\beta_{UR}} \tag{B.67s}$$

$$\log(\omega_t) = (1-\rho_\omega)\log\overline{\varpi} + \rho_\omega\log\omega_{t-1} + \epsilon_{\omega,t} \tag{B.68s}$$

$$\log\nu_{PR,t} = (1-\rho_{\nu_{PR}})\log(\bar{\nu}_{PR}) + \rho_{\nu_{PR}}\log(\nu_{PR,t-1}) + \epsilon_{\nu_{PR}} \tag{B.69s}$$

$$\log\nu_{W_{SR},t} = (1-\rho_{\nu_{W_{SR}}})\log(\bar{\nu}_{W_{SR}}) + \rho_{\nu_{W_{SR}}}\log(\nu_{W_{SR},t-1}) + \epsilon_{\nu_{W_{SR}}} \tag{B.70s}$$

$$\log\nu_{W_{UR},t} = (1-\rho_{\nu_{W_{UR}}})\log(\bar{\nu}_{W_{UR}}) + \rho_{\nu_{W_{UR}}}\log(\nu_{W_{UR},t-1}) + \epsilon_{\nu_{W_{UR}}} \tag{B.71s}$$

2.6.3 Variable Descriptions

The model consists of 71 equations related to 71 variables (64 endogenous variables and 7 variable of exogenous shock processes) described in the following table.

	Variable	**Description**
1	A_t	Stock of adopted technology in region A
2	$\beta_{SR,t}$	Savers' discount factor of region R
3	$\beta_{UR,t}$	Borrowers' discount factor of region R
4	$C_{A,t}$	Aggregate consumption in region A
5	$C_{R,t}$	Aggregate consumption in region R
6	$C_{SA,t}$	Skilled labour's consumption in region A
7	$C_{SR,t}$	Skilled labour's consumption in region R
8	$C_{UA,t}$	Unskilled labour's consumption in region A
9	$C_{UR,t}$	Unskilled labour's consumption in region R
10	$H_{p1A,t}$	Numerator of the optimal price setting in region A
11	$H_{p1R,t}$	Numerator of the optimal price setting in region R
12	$H_{p2A,t}$	Denominator of the optimal price setting in region A
13	$H_{p2R,t}$	Denominator of the optimal price setting in region R
14	$H_{ws1A,t}$	Numerator of the optimal skilled wage setting in region A
15	$H_{ws1R,t}$	Numerator of the optimal skilled wage setting in region R
16	$H_{ws2A,t}$	Denominator of the optimal skilled wage setting in region A
17	$H_{ws2R,t}$	Denominator of the optimal skilled wage setting in region R
18	$H_{wu1A,t}$	Numerator of the optimal unskilled wage setting in region A
19	$H_{wu1R,t}$	Numerator of the optimal unskilled wage setting in region R
20	$H_{wu2A,t}$	Denominator of the optimal unskilled wage setting in region A
21	$H_{wu2R,t}$	Denominator of the optimal unskilled wage setting in region R
22	$\iota_{RnR,t}$	Interest rate policy shock
23	$\Lambda_{SA,t}$	Skilled labour's shadow price of budget in region A
24	$\Lambda_{SR,t}$	Skilled labour's shadow price of budget in region R
25	$\Lambda_{UA,t}$	Unskilled labour's shadow price of budget in region A
26	$\Lambda_{UR,t}$	Unskilled labour's shadow price of budget in region R

	Variable	**Description**
27	$MC_{A,t}$	Marginal cost of final goods in region A
28	$MC_{R,t}$	Marginal cost of final goods in region R
29	MRS_{SA}	Marginal rate of substitution of skilled households in region A
30	MRS_{SR}	Marginal rate of substitution of skilled households in region R
31	MRS_{UA}	Marginal rate of substitution of unskilled households in region A
32	MRS_{UR}	Marginal rate of substitution of skilled households in region R
33	$\mu_{UA,t}$	Unskilled labour's shadow value of borrowing in region A
34	$\mu_{UR,t}$	Unskilled labour's shadow value of borrowing in region R
35	$N_{SA,t}$	Skilled labour in region A
36	$N_{SR,t}$	Skilled labour in region R
37	$N_{UA,t}$	Unskilled labour in region A
38	$N_{UR,t}$	Unskilled labour in region R
39	ν_{PR}	Mark up price
40	ν_{WSR}	Mark up skilled-wages
41	ν_{WUR}	Mark up unskilled-wages
42	ω_t	R&D productivity shocks
43	$\Omega_{A,t}$	Value of adopted technology contribution
44	$\Omega_{R,t}$	Value of created technology contribution
45	$P_{A,t}$	Price level for final goods in region A
46	$P^*_{A,t}$	Optimal price level for final goods in region A
47	$P_{R,t}$	Price level for final goods in region R
48	$P^*_{R,t}$	Optimal price level for final goods in region R
49	π_A	Profit of firms in region A
50	π_R	Profit of firms in region R
51	Π_{PA}	Gross rate of inflation in region A
52	Π_{PR}	Gross rate of inflation in region R
53	Φ_t	Period creation of new adopted technology in region A
54	$R_{A,t}$	Real interest rate of region A
55	$R_{R,t}$	Real interest rate of region R

	Variable	Description
56	$R_{nA,t}$	Nominal interest rate of region A
57	$R_{nR,t}$	Nominal interest rate of region R
58	T_t	Stock of created technology in region R
59	τ_t	Period creation of new technology in region R
60	$V_{A,t}$	Value of adopted technology in region A
61	$V_{R,t}$	Value of created technology in region R
62	$W_{SA,t}$	Skilled labour's wage in region A
63	$W^*_{SA,t}$	Optimal skilled labour's wage in region A
64	$W_{SR,t}$	Skilled labour's wage in region R
65	$W^*_{SR,t}$	Optimal skilled labour's wage in region R
66	$W_{UA,t}$	Unskilled labour's wage in region A
67	$W^*_{UA,t}$	Optimal unskilled labour's wage in region A
68	$W_{UR,t}$	Unskilled labour's wage in region R
69	$W^*_{UR,t}$	Optimal unskilled labour's wage in region R
70	$Y_{A,t}$	Final output or goods in region A
71	$Y_{R,t}$	Final output or goods in region R

2.6.4 Numerical Values for Parameters

The set of parameters used in this model are collected from Anzoategui et al (2019), Bosworth and Ellis (1979) and Caballero and Jaffe (1996) cited in Anzoategui et al (2019), Emenogu and Michelis (2019), Galí's Handbook (2007), Pathompituknukoon's dissertation (2020) of Master of Research (MRes) in Economics at the University of Essex, some parameters are calibrated in the first chapter, and some parameters are calibrated in this chapter. The model consists of 62 parameters as in the following table.

Parameters	**Definition**	**Value**
β_{SA}	Savers' discount factor of region A	0.9950
$\bar{\beta}_{SR}$	Savers' discount factor of region R	0.9950
β_{UA}	Borrowers' discount factor of region A	0.9850
$\bar{\beta}_{UR}$	Borrowers' discount factor of region R	0.9850
χ_{SA}	Skilled labour weight of utilities of region A	1.0000
χ_{SR}	Skilled labour weight of utilities of region R	1.0000
χ_{UA}	Unskilled labour weight of utilities of region A	1.0000
χ_{UR}	Unskilled labour weight of utilities of region R	1.0000
η_A	Scaling parameter for periodic value of adopted technology	0.1000
η_R	Scaling parameter for periodic value of created technology	0.1000
γ_T	The growth rate of technology	0.15700
$\bar{\iota}_{RnR}$	Steady state of shock to monetary policy	1.00000
κ	Ability of technology adoption where $\kappa \in (0, 1)$	0.80000
ν	Debt cost parameter	0.02400
ν_{PA}	Steady state final goods mark up price in region A	1.10000
$\bar{\nu}_{PR}$	Steady state final goods mark up price in region R	1.10000
ν_{WSA}	Steady state skilled labour mark up wage in region A	0.14900
$\bar{\nu}_{WSR}$	Steady state skilled labour mark up wage in region R	0.14900
ν_{WUA}	Steady state unskilled labour mark up wage in region A	0.14900
$\bar{\nu}_{WUR}$	Steady state unskilled labour mark up wage in region R	0.14900
$\bar{\omega}$	Steady state of shock to R&D technology	1.00000

Parameters	**Definition**	**Value**
$\bar{\Pi}_{PA}$	Target rate of inflation at steady state of region A	1.00000
$\bar{\Pi}_{PR}$	Target rate of inflation at steady state of region R	1.00000
ψ_A	Exogenous payment-to-income limit of region A	0.28000
ψ_R	Exogenous payment-to-income limit of region R	0.28000
$\bar{R}_{nA}$	Nominal interest rate at a steady state of region A	1.34538
$\bar{R}_{nR}$	Nominal interest rate at a steady state of region R	1.34538
ρ	Scaling parameter for interaction between current technology adoption and previous technology creation	0.08000
$\rho_{\beta SR}$	Persistence of skilled households' preference shock	0.40000
$\rho_{\beta UR}$	Persistence of unskilled households' preference shock	0.40000
$\rho_{\iota_{RnR}}$	Persistence of nominal interest rate policy shock	0.46500
$\rho_{\nu_{PR}}$	Persistence of markup price shock of region R	0.40600
$\rho_{\nu_{WSR}}$	Persistence of markup skilled wages' shock of region R	0.27300
$\rho_{\nu_{WUR}}$	Persistence of markup unskilled wages' shock of region R	0.27300
$\rho_{\Pi_P A}$	Degree of contraction monetary policy when the inflation exceeds its target value of region A	1.94000
$\rho_{\Pi_P R}$	Degree of contraction monetary policy when the inflation exceeds its target value of region R	1.94000
ρ_{RnA}	Degree of interest rate smoothing of region A	0.37000
ρ_{RnR}	Degree of interest rate smoothing of region R	0.37000
ρ_{YA}	Degree of contraction monetary policy when the economy is overgrowth of region A	0.13000
ρ_{YR}	Degree of contraction monetary policy when the economy is overgrowth of region R	0.13000
ρ_ω	Persistence of shock to R&D technology	0.80300
σ_A	Steady state of final goods mark up of region A	1.35000
σ_R	Steady state of final goods mark up of region R	1.35000
$\sigma_{\beta SR}$	Standard deviation of skilled labour preference shock	0.00010
$\sigma_{\beta UR}$	Standard deviation of unskilled labour preference shock	0.00010

Parameters	**Definition**	**Value**
$\sigma_{\iota_{RnR}}$	Standard deviation of interest rate policy shock	0.00010
$\sigma_{\nu_{PR}}$	Standard deviation of markup price shock	0.00010
$\sigma_{\nu_{WSR}}$	Standard deviation of markup skilled wages' shock	0.00010
$\sigma_{\nu_{WUR}}$	Standard deviation of markup unskilled wages' shock	0.00010
σ_{ω}	Standard deviation of technology R&D shock	0.00010
θ_A	R&D elasticity of region A	0.37600
θ_R	R&D elasticity of region R	0.37600
ξ_A	Survival rate of technology in region A	0.98000
ξ_R	Survival rate of technology in region R	0.98000
$\bar{Y}_A$	Target level of output at steady state of region A	0.29934
$\bar{Y}_R$	Target level of output at steady state of region R	0.42265
ζ_{PA}	Degree of price Stickiness in region A	0.93500
ζ_{PR}	Degree of price Stickiness in region R	0.93500
ζ_{WSA}	Degree of skilled wage stickiness in region A	0.90800
ζ_{WSR}	Degree of skilled wage stickiness in region R	0.90800
ζ_{WUA}	Degree of unskilled wage stickiness in region A	0.90800
ζ_{WUR}	Degree of unskilled wage stickiness in region R	0.90800

2.6.5 Households' Problem Description

Skilled Households - The current period utility of skilled households is the function of their consumption $C_{Si,t}$ and skilled labour $N_{Si,t}$ as follows:

$$E_t \sum_{t=0}^{\infty} \beta_{Si}^t U(C_{Si,t}, N_{Si,t}) \quad ,$$

where $U(C_{Si,t}, N_{Si,t}) \equiv \log C_{Si,t} + \chi_{Si} \log(1 - N_{Si,t})$ and $C_{Si,t} \equiv \left[\int_0^1 (C_{Si,t}^j)^{\frac{1}{\nu_{pi}}} dj\right]^{\nu_{pi}}$ represents consumption index, which $j \in [0,1]$ and $C_{Si,t}^j$ represents the quantity of goods j consumed by skilled types of consumer in region $i \in \{R, A\}$ at period t, ν_{pi} is a final goods mark up price, and χ_{Si} denotes the skilled labour weights of labour in utility.

Their budget constraint is given by

$$\int_0^1 P_{i,t}^j C_{Si,t}^j dj + B_{i,t} = R_{i,t-1} B_{i,t-1} + \int_0^1 W_{Si,t}^h N_{Si,t}^h dh + \pi_{i,t} \quad ,$$

where $P_{i,t}^j$ is the price of goods j, $R_{i,t}$ is the interest rate, $B_{i,t}$ is an amount of money that household lend, $N_{Si,t} \equiv \left[\int_0^1 (N_{Si,t}^h)^{\frac{1}{\nu_{wsi}}} dh\right]^{\nu_{wsi}}$ is an aggregated version of skilled type, $h \in [0,1]$ represents the skilled labour index which $N_{Si,t}^h$ denotes the quantity of skilled labour employed by good-producer in region $i \in \{R, A\}$ in period t, and $W_{Si,t}^h$ denotes the nominal wage of each types of labour for all individual $h \in [0,1]$.

Unskilled Households - The current period utility of unskilled households is the function of their consumption $C_{Ui,t}$, $x \in \{U, S\}$ and unskilled type of labour $N_{Ui,t}$ as follows:

$$E_t \sum_{t=0}^{\infty} \beta_{Ui}^t U(C_{Ui,t}, N_{Ui,t}) \quad ,$$

where $U(C_{Ui,t}, N_{Ui,t}) \equiv \log C_{Ui,t} + \chi_{Ui} \log(1 - N_{Ui,t})$ and $C_{Ui,t} \equiv \left[\int_0^1 (C_{Ui,t}^j)^{\frac{1}{\nu_{pi}}} dj\right]^{\nu_{pi}}$ represents consumption index, which $j \in [0,1]$ and $C_{Ui,t}^j$ represents the quantity of goods j consumed by unskilled households in period t, and χ_{Ui} denotes the labour weights for unskilled labour in utility.

Their budget constraint is given by

$$\int_0^1 P_{i,t}^j C_{Ui,t}^j dj + R_{i,t-1} B_{i,t-1} = B_{i,t} + \int_0^1 W_{Ui,t}^h N_{Ui,t}^h dh \quad ,$$

where $P^j_{i,t}$ is the price of goods j, $R_{i,t}$ is the interest rate. $B_{i,t}$ is an amount of money that households borrow and their borrowing constraint is given by

$$(R_{i,t} - 1 + \nu_i)B_{i,t} \leq \psi_i \int_0^1 W^h_{Ui,t} N^h_{Ui,t} dh \quad ,$$

where ν_i is a debt cost parameter, ψ_i is an exogenous payment-to-income limit, $N^h_{Ui,t}$ denotes the quantity of unskilled labour employed by good-producer in region $i \in \{R, A\}$ in period t, and $W^h_{Ui,t}$ denotes the nominal wage of unskilled labour for all individual $h \in [0, 1]$.

Households' maximisation problem - Beginning with solving the optimal allocation of the expenditure on consumption that maximisation of $C_{xi,t},\ x \in \{U, S\}$, where U and S denote for unskilled and skilled types of labour respectively, for any given expenditure level $\int_0^1 P^j_{i,t} C^j_{xi,t} dj = Z_{xi,t}$ by setting the Lagrangian as

$$\mathcal{L} \equiv \left[\int_0^1 (C^j_{xi,t})^{\frac{1}{\nu_{p_i}}}\right]^{\nu_{p_i}} - \lambda \left[\int_0^1 P^j_{i,t} C^j_{xi,t} dj - Z_{xi,t}\right] \quad .$$

The optimality condition for consumption of each types of labour is given by

$$\begin{aligned} C^j_{xi,t} : \nu_{pi} \left[\int_0^1 (C^j_{xi,t})^{\frac{1}{\nu_{p_i}}} dj\right]^{\nu_{p_i}} \left(\frac{1}{\nu_{p_i}}\right) (C^j_{xi,t})^{\frac{1-\nu_{p_i}}{\nu_{p_i}}} - \lambda P^j_{i,t} &= 0 \\ \left[(C_{xi,t})^{\frac{1}{\nu_{p_i}}}\right]^{\nu_{p_i}-1} \cdot (C^j_{xi,t})^{\frac{1-\nu_{p_i}}{\nu_{p_i}}} &= \lambda P^j_{i,t} \quad . \end{aligned}$$

For good j,

$$(C_{xi,t})^{\frac{\nu_{p_i}-1}{\nu_{p_i}}} \cdot (C^j_{xi,t})^{\frac{1-\nu_{p_i}}{\nu_{p_i}}} = \lambda P^j_{i,t} \quad .$$

For any good ℓ,

$$(C_{xi,t})^{\frac{\nu_{p_i}-1}{\nu_{p_i}}} \cdot (C^\ell_{xi,t})^{\frac{1-\nu_{p_i}}{\nu_{p_i}}} = \lambda P^\ell_{i,t} \quad .$$

Dividing good j by good ℓ

$$\begin{aligned} \left(\frac{C^j_{xi,t}}{C^\ell_{xi,t}}\right)^{\frac{1-\nu_{p_i}}{\nu_{p_i}}} &= \frac{P^j_{i,t}}{P^\ell_{i,t}} \\ C^j_{xi,t} &= C^\ell_{xi,t} \left(\frac{P^j_{i,t}}{P^\ell_{i,t}}\right)^{\frac{\nu_{p_i}}{1-\nu_{p_i}}} \quad , \end{aligned} \tag{B.5.1}$$

which can be plugged in to the expression for expenditure of each types of labour on consumption,

$$(P_{i,t}^{\ell})^{\frac{\nu_{p_i}}{\nu_{p_i}-1}} C_{xi,t}^{\ell} \int_0^1 (P_{i,t}^{j})^{\frac{-1}{\nu_{p_i}-1}} dj = Z_{xi,t} \quad . \tag{B.5.2}$$

Since the consumption price index in region i is

$$P_{i,t} = \left[\int_0^1 (P_{i,t})^{\frac{-1}{\nu_{p_i}-1}} dj \right]^{-(\nu_{p_i}-1)} \quad . \tag{B.5.3}$$

This can be rewritten as,

$$\int_0^1 (P_{i,t}^{j})^{\frac{-1}{\nu_{p_i}-1}} dj = (P_{i,t})^{\frac{-1}{\nu_{p_i}-1}} \quad .$$

Using this assumption for Equation B.5.2, hence,

$$(P_{i,t}^{\ell})^{\frac{\nu_{p_i}}{\nu_{p_i}-1}} \cdot C_{xi,t}^{\ell} \cdot (P_{i,t})^{\frac{-1}{\nu_{p_i}-1}} = Z_{xi,t} \quad ,$$

yielding the demand for consumption good ℓ as

$$C_{xi,t}^{\ell} = \left(\frac{P_{i,t}^{\ell}}{P_{i,t}} \right)^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}} \cdot \frac{Z_{xi,t}}{P_{i,t}} \qquad , \forall \ell \quad ,$$

and the demand for consumption good j is

$$C_{xi,t}^{j} = \left(\frac{P_{i,t}^{j}}{P_{i,t}} \right)^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}} \cdot \frac{Z_{xi,t}}{P_{i,t}} \qquad , \forall j \quad .$$

Substituting the demand for consumption good j into the consumption index for each skilled types,

$$\begin{aligned} C_{xi,t} &= \left[\int_0^1 \left\{ \left(\frac{P_{i,t}^{j}}{P_{i,t}} \right)^{\frac{-\nu_{p_i}}{\nu_{p_i}-1}} \cdot \frac{Z_{xi,t}}{P_{i,t}} \right\}^{\frac{1}{\nu_{p_i}}} dj \right]^{\nu_{p_i}} \\ C_{xi,t} &= \frac{Z_{xi,t}}{P_{i,t}} \\ \therefore Z_{xi,t} &= P_{i,t} C_{xi,t} \quad . \end{aligned} \tag{B.5.4}$$

Therefore,

$$\int_0^1 P_{i,t}^{j} C_{xi,t}^{j} dj = P_{i,t} C_{xi,t} \quad . \tag{B.5.5}$$

Now, we have to solve for the cost minimisation for good producers to obtain the demand for each types of labour in region i. The minimisation of $N_{xi,t}^{h}$ at any given cost level,

$\int_0^1 W^h_{xi,t} N^h_{xi,t} dh = Z_{wxi,t}$, by formalising the Lagrangian function as

$$\mathcal{L} \equiv \left[\int_0^1 (N^h_{xi,t})^{\frac{1}{\nu_{wxi}}} dh\right]^{\nu_{wxi}} - \lambda \left[\int_0^1 W^h_{xi,t} N^h_{xi,t} dh - Z_{wxi,t}\right] \quad .$$

The optimality condition for the amount of each types of labour is given by

$$\begin{aligned} N^h_{xi,t} : \nu_{wxi} \left[\int_0^1 (N^h_{xi,t})^{\frac{1}{\nu_{wxi}}} dh\right]^{\nu_{wxi}-1} \left(\frac{1}{\nu_{wxi}}\right) (N^h_{xi,t})^{\frac{1-\nu_{wxi}}{\nu_{wxi}}} - \lambda W^h_{xi,t} &= 0 \\ \left[N_{xi,t}^{\frac{1}{\nu_{wxi}}}\right]^{\nu_{wxi}-1} \cdot (N^h_{xi,t})^{\frac{1-\nu_{wxi}}{\nu_{wxi}}} &= \lambda W^h_{xi,t} \quad . \end{aligned}$$

For labour h,

$$N_{xi,t}^{\frac{\nu_{wxi}-1}{\nu_{wxi}}} \cdot (N^h_{xi,t})^{\frac{1-\nu_{wxi}}{\nu_{wxi}}} = \lambda W^h_{xi,t} \quad .$$

For any labour m,

$$N_{xi,t}^{\frac{\nu_{wxi}-1}{\nu_{wxi}}} \cdot (N^m_{xi,t})^{\frac{1-\nu_{wxi}}{\nu_{wxi}}} = \lambda W^m_{xi,t} \quad .$$

Dividing labour h by labour m,

$$\begin{aligned} \left(\frac{N^h_{xi,t}}{N^m_{xi,t}}\right)^{\frac{1-\nu_{wxi}}{\nu_{wxi}}} &= \frac{W^h_{xi,t}}{W^m_{xi,t}} \\ N^h_{xi,t} &= N^m_{xi,t} \left(\frac{W^h_{xi,t}}{W^m_{xi,t}}\right)^{\frac{\nu_{wxi}}{1-\nu_{wxi}}} \quad , \end{aligned} \tag{B.5.6}$$

which can be plugged in the expression for cost of good producer in region i,

$$(W^m_{xi,t})^{\frac{\nu_{wxi}}{\nu_{wxi}-1}} \cdot N^m_{xi,t} \int_0^1 (W^h_{xi,t})^{\frac{-1}{\nu_{wxi}-1}} dh = Z_{wxi,t} \quad . \tag{B.5.7}$$

Since the each skilled labour wage index in region i is

$$W_{xi,t} = \left[\int_0^1 (W^h_{xi,t})^{\frac{-1}{\nu_{wxi}-1}} dh\right]^{-(\nu_{wxi}-1)} \quad , \tag{B.5.8}$$

then,

$$\int_0^1 (W^h_{xi,t})^{\frac{-1}{\nu_{wxi}-1}} dh = W_{xi,t}^{\frac{-1}{\nu_{wxi}-1}} \quad .$$

Using this assumption for Equation B.5.7. Hence,

$$\begin{aligned}(W^m_{xi,t})^{\frac{\nu_{wxi}}{\nu_{wxi}-1}} \cdot N^m_{xi,t} \cdot W_{xi,t}^{\frac{-1}{\nu_{wxi}-1}} &= Z_{wxi,t} \\ N^m_{xi,t} = (W^m_{xi,t})^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \cdot Z_{wxi,t} \cdot W_{xi,t}^{\frac{1}{\nu_{wxi}-1}} & \quad .\end{aligned}$$

Then, we yield the demand for each skilled types of labour m,

$$N^m_{xi,t} = \left(\frac{W^m_{xi,t}}{W_{xi,t}}\right)^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \cdot \frac{Z_{wxi,t}}{W_{xi,t}} \qquad ,\forall m \quad ,$$

and the demand for each skilled types of labour h,

$$N^h_{xi,t} = \left(\frac{W^h_{xi,t}}{W_{xi,t}}\right)^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \cdot \frac{Z_{wxi,t}}{W_{xi,t}} \qquad ,\forall h \quad .$$

Substituting the demand for each skilled types of labour h into the each skilled types of labour index,

$$\begin{aligned}N_{xi,t} &= \left[\int_0^1 \left\{\left(\frac{W^h_{xi,t}}{W_{xi,t}}\right)^{\frac{-\nu_{wxi}}{\nu_{wxi}-1}} \cdot \frac{Z_{wxi,t}}{W_{xi,t}}\right\}^{\frac{1}{\nu_{wxi}}} dh\right]^{\nu_{wxi}} \\ N_{xi,t} &= \frac{Z_{wxi,t}}{W_{xi,t}} \\ \therefore Z_{wxi,t} &= W_{xi,t}N_{xi,t} \quad . \qquad \text{(B.5.9)}\end{aligned}$$

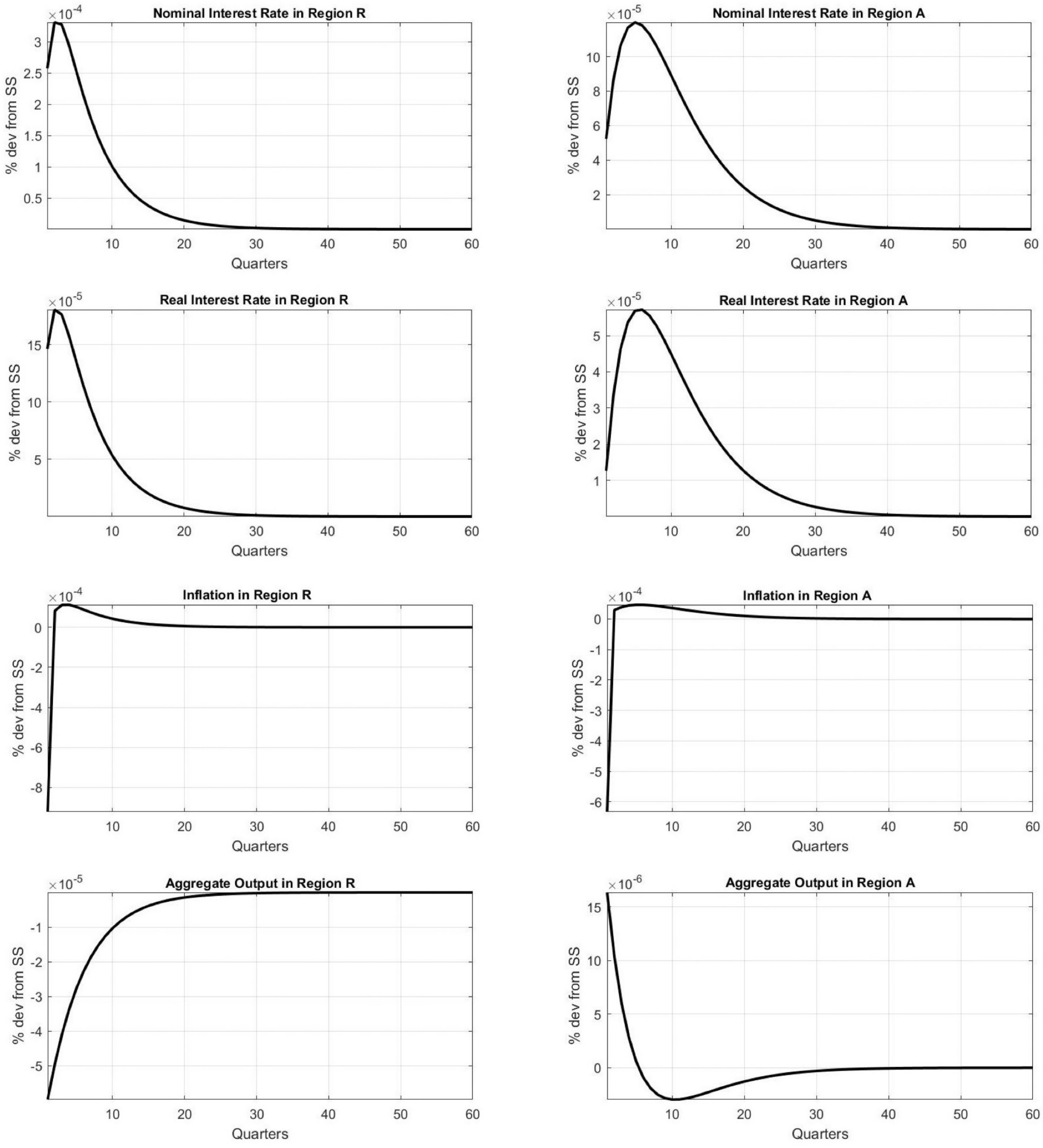
Therefore,

$$\int_0^1 W^h_{xi,t}N^h_{xi,t}dh \quad = \quad W_{xi,t}N_{xi,t} \quad . \qquad \text{(B.5.10)}$$

2.6.6 Additional Results

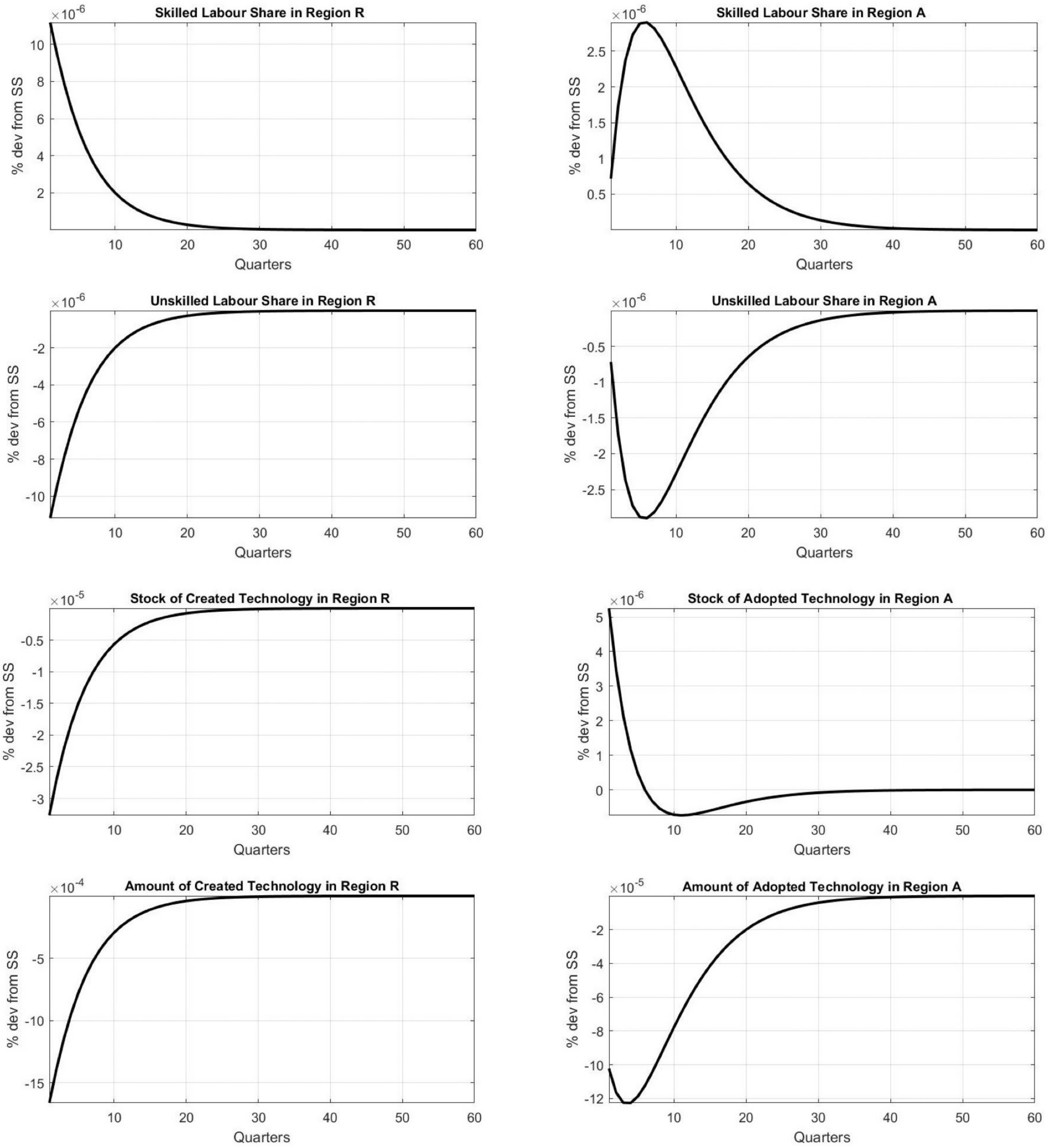
Impulse response to a one standard deviation of monetary policy shock in the region R are shown in Figure 2.8, 2.9, and 2.10, and impulse response to a one standard deviation of skilled preference shock in the region R are shown in Figure 2.11, 2.12, and 2.13 as follow:

FIGURE 2.8: Impulse response to a one standard deviation of monetary policy shock (A.1)



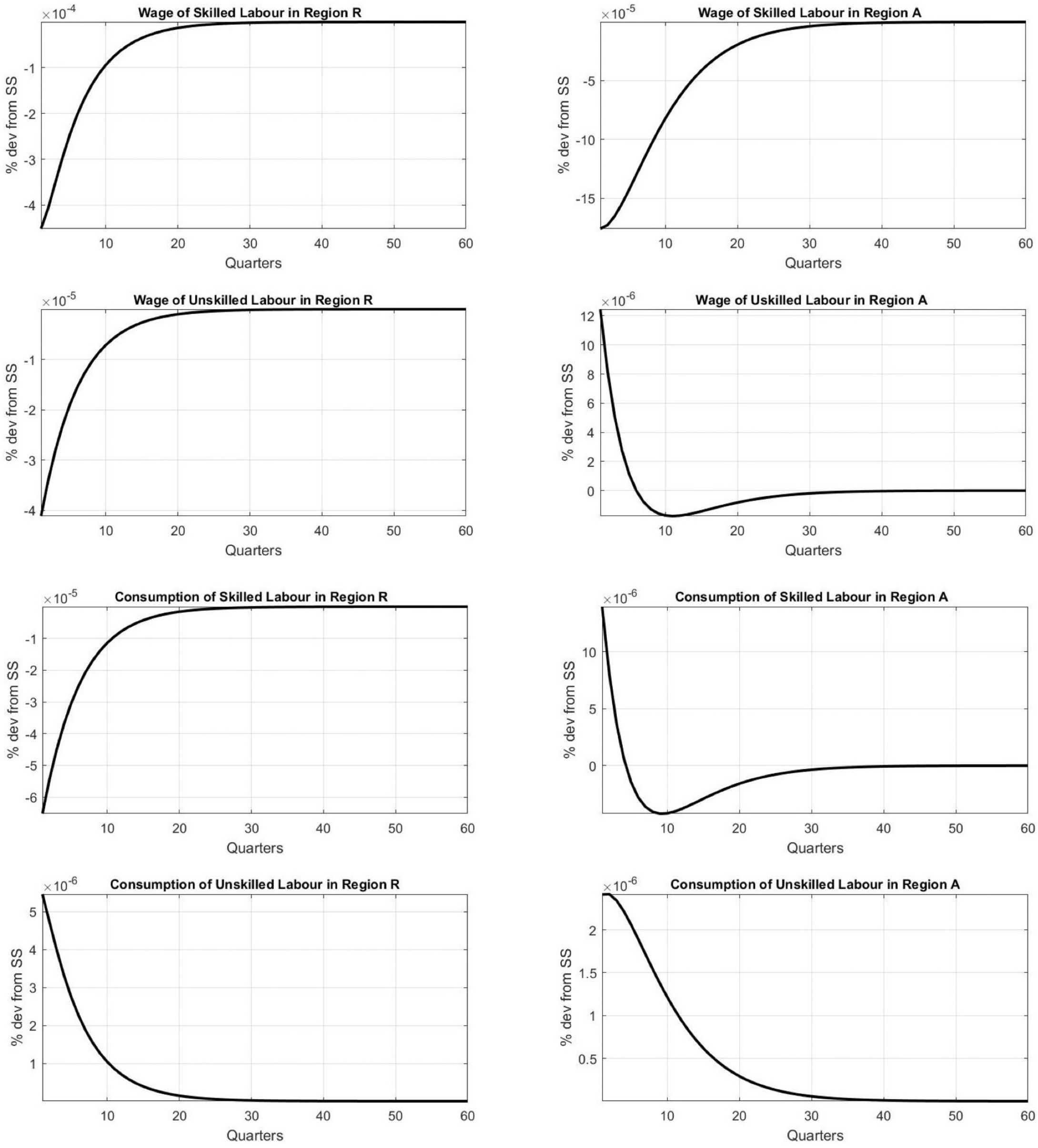
Source: Author's calculation

FIGURE 2.9: Impulse response to a one standard deviation of monetary policy shock (A.2)



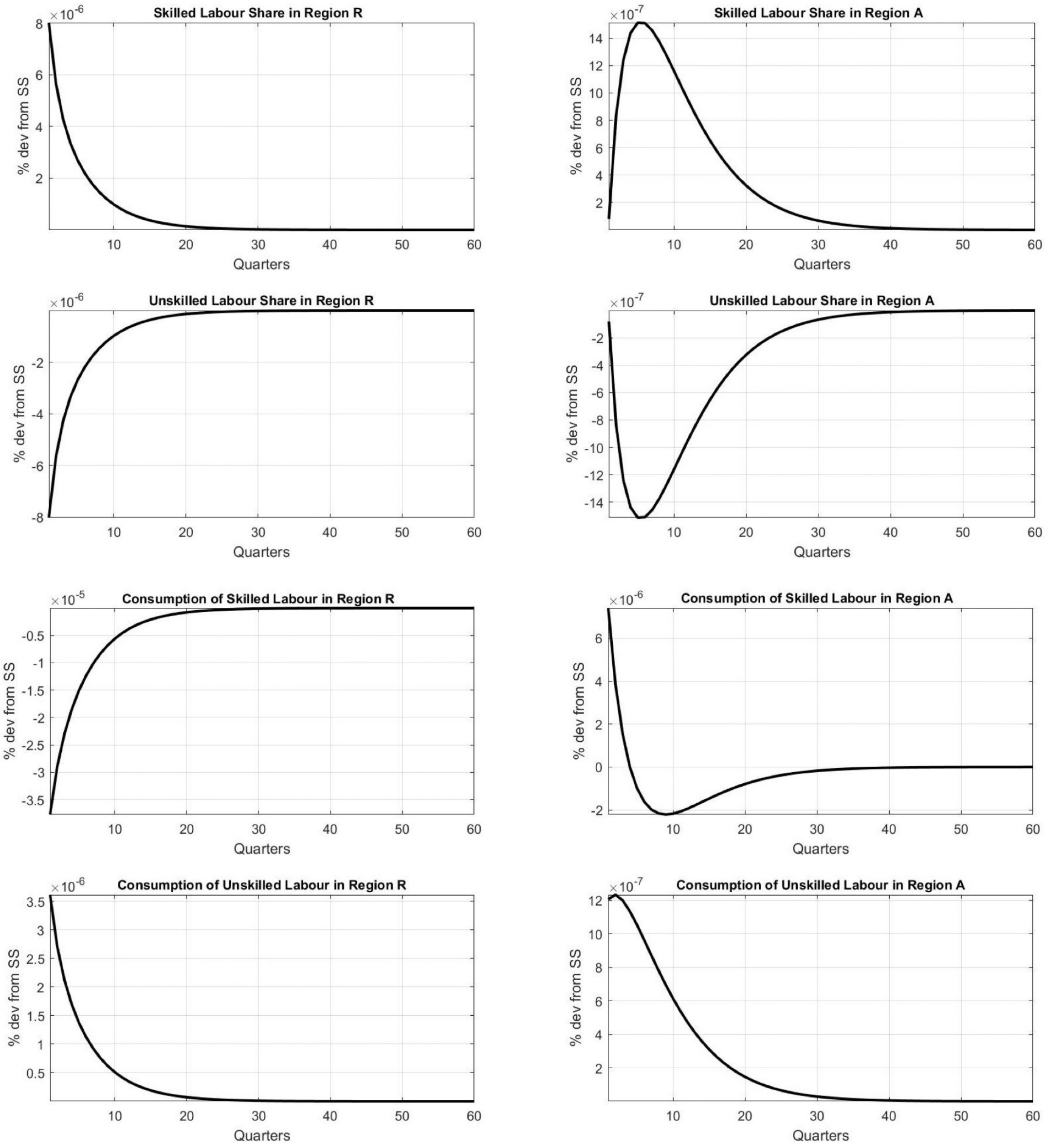
Source: Author’s calculation

Figure 2.10: Impulse response to a one standard deviation of monetary policy shock (A.3)



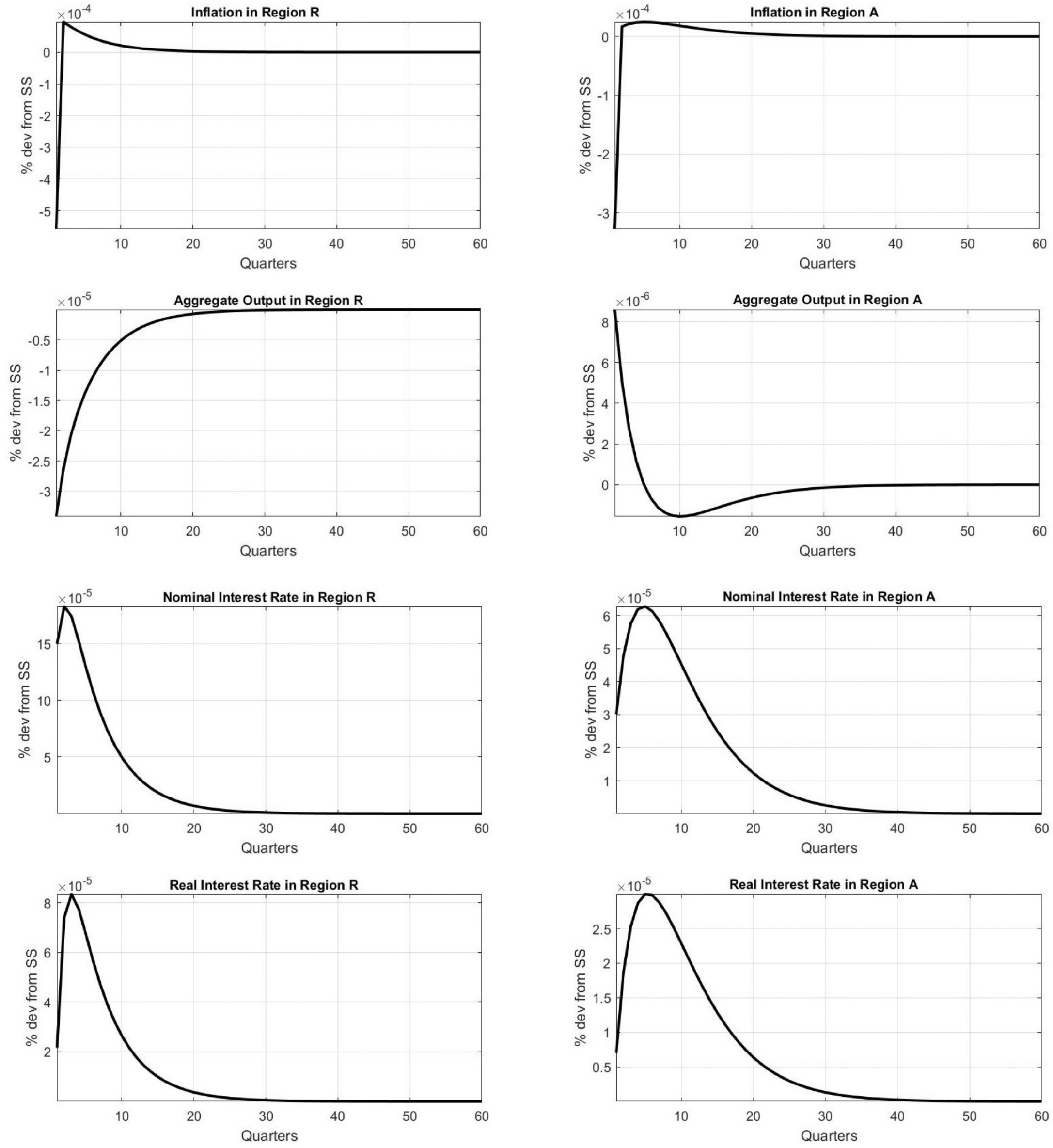
Source: Author's calculation

FIGURE 2.11: Impulse response to a one standard deviation of preference shock (B.1)



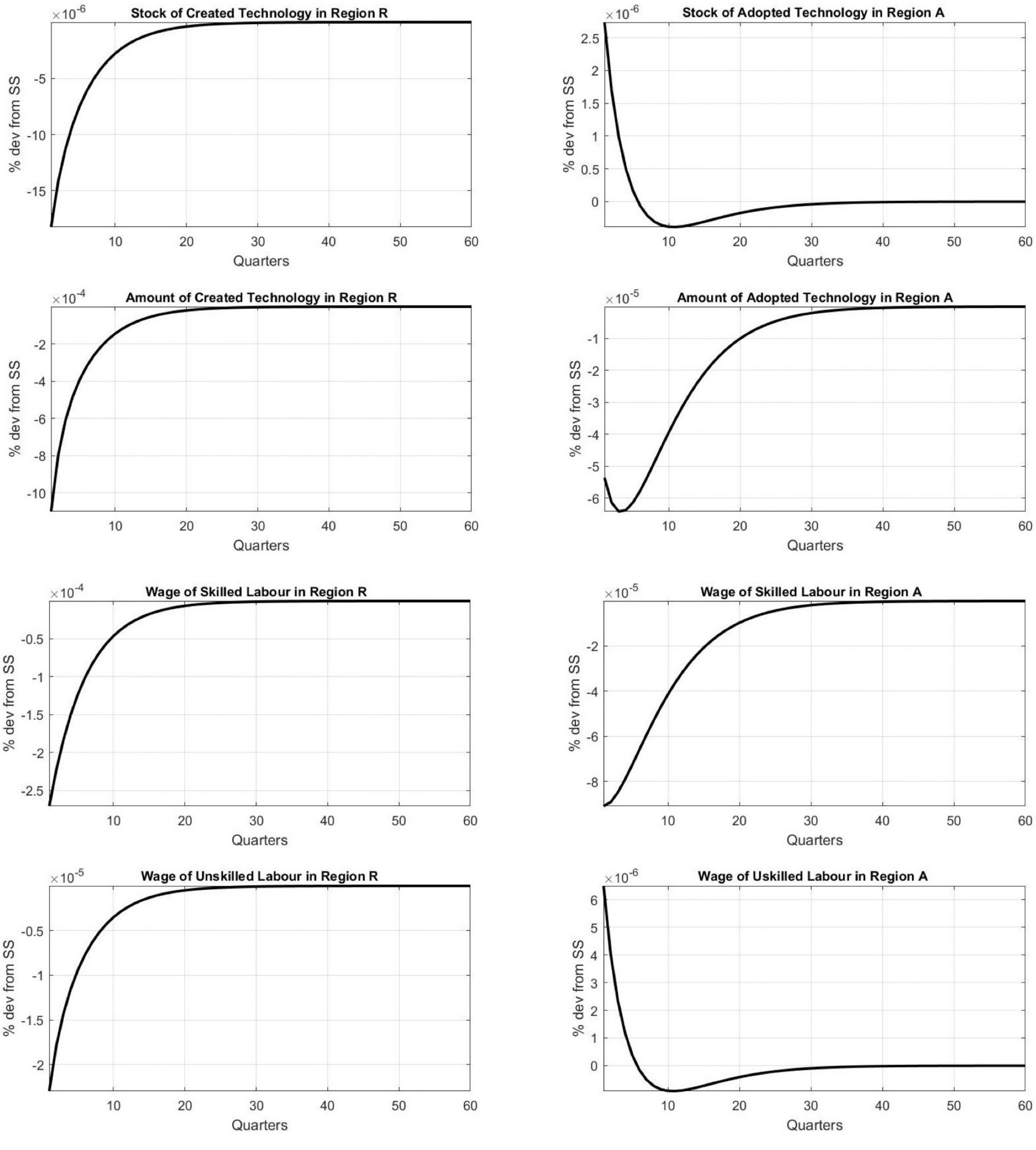
Source: Author's calculation

Figure 2.12: Impulse response to a one standard deviation of preference shock (B.2)



Source: Author's calculation

Figure 2.13: Impulse response to a one standard deviation of preference shock (B.3)



Source: Author's calculation

Chapter 3

Productivity Growth and Convergence Across Countries

The previous two chapters mainly explored the relationship between productivity improvements and technological advancements in firms. These two chapters introduced a model that considers the effects of a dynamic policy change. Using the framework of endogenous growth models, RBC and NK models, we analysed two regions - a closed economy where growth is driven by technology creation and adoption. The quantitative results showed that both created and adopted technologies, as well as skilled labour involved in research and development (R&D), are significant factors. A positive monetary policy shock can hinder an overheated economy and decrease the severity of inflation, but it can also have a negative impact on the stock of endogenous technology besides monetary policy.

Even though the previous studies were mainly based on a theoretical framework, Chapter 3 provides practical evidence through an empirical study using country-industry data of developed and developing economies. Our study found that R&D and technology transfer are crucial drivers of economic growth and productivity. Countries that invest in R&D and facilitate technology transfer have higher productivity growth rates. International trade can also significantly increase productivity rates by providing access to new resources, markets, and technologies. Human capital, which refers to a country's workforce's knowledge, skills, abilities, and experience, also plays a role in boosting productivity, although to a lesser extent than international trade. Policymakers and business leaders should prioritise R&D, technology transfer, and international trade to promote innovation and drive economic growth.

3.1 Introduction

The role of technological innovation in driving economic growth is widely acknowledged as a critical factor in the development of any country. The adoption of technology is seen as a key driver of economic transformation, and therefore, it is essential to create policies that facilitate its usage. To achieve this, it is crucial to measure the extent of technology usage and understand the factors that both motivate and hinder innovation and technology adoption. While firms are primarily responsible for keeping up with technological advances (as in Perilla Jimenez, 2019 and Nelson, 2008), they are also the primary adopters of technology for producing goods and services. Upgrading technology is, therefore, of utmost importance in fostering productivity gains, which serve as the engine of economic growth and prosperity.

Moreover, technological advancement has the potential to create new industries, products, and services, which can lead to job creation, increased innovation, and higher living standards. It also plays a vital role in improving the efficiency and effectiveness of operations, reducing costs, and enhancing the quality of products and services. Therefore, it is crucial for policymakers to recognize the importance of technology in driving economic growth and prosperity and to create an environment that encourages innovation and technology adoption. By doing so, they can ensure that their nation remains competitive, productive, and prosperous in the global marketplace.

For countries with limited natural resources, the path to becoming a developed economy requires progress in agriculture, manufacturing, or services production technology (Hayami and Godo, 2005; Benhabib et al., 2014; and König et al., 2016). However, investing in research and development (R&D) is crucial for progress. R&D is then an essential catalyst for technological change and productivity growth, as it fosters innovation and adoption within and beyond the country (Romer, 1994; Jones and Williams, 2000; Nelson, 2008; König et al., 2016; and de Ridder, 2017). The recent empirical literature has dedicated significant attention to R&D, with various analyses conducted to comprehend its impact on productivity growth.

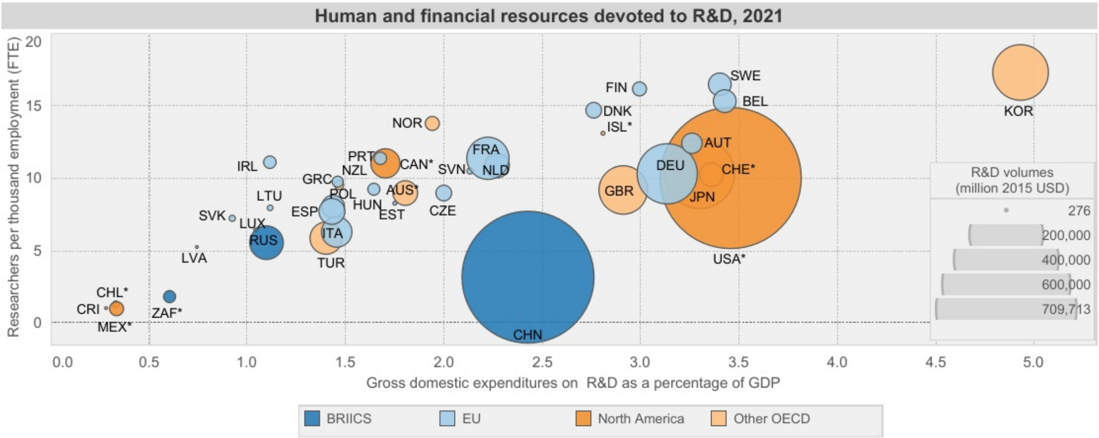
One popular approach is econometric studies, which aim to explore the relationship between productivity and R&D, along with other relevant variables. Various studies, e.g. Frantzen (2000) and Griffith (2000), have explored the significant role of R&D in driving technological advancements and enhancing productivity across different countries. Those literature have provided valuable insights into the benefits of investing in R&D for long-term economic growth and development. By investing in R&D, countries can create innovative products and services, which can lead to increased competitiveness and economic growth (Aghion and Howitt, 1998; Zachariadis, 2003; Aghion and Howitt, 2008; and Alder et al., 2022).

Additionally, developing new technologies through R&D can foster the creation of new industries and job opportunities and enhance the efficiency of existing ones. The findings of these studies highlight the critical importance of investing in R&D for countries to remain competitive in the global economy. By encouraging an innovative culture and promoting the adoption of new technologies, countries can improve their economic competitiveness, generate new employment opportunities, and enhance the quality of life for their citizens.

Extensive research has been conducted on income disparities across countries, focusing on identifying contributing factors, e.g. Coe et al. (1995) and Griffith et al. (2003). One of the key factors that has been found to influence income disparities is the endogenous factor, specifically the total factor productivity (TFP) or technical factor. Economic literature has discussed and utilized this factor widely. Several studies conducted by Harrigan (1997), Parente and Prescott (2002), Cameron et al. (2005), and Comin and Hobijn (2010) have provided evidence that supports the existence of income disparities between countries. Moreover, Evans (1997) has demonstrated that countries sharing a common technology have exhibited similar growth patterns over the postwar period.

Furthermore, it is commonly argued that the convergence of income levels can be attributed to R&D efforts that promote technological advancements and productivity within each country, regardless of varying levels of R&D intensity. Studies by Howitt (2000), Acemoğlu and Zilibotti (2001), and Jones (2016) support this notion. These studies have helped researchers understand how R&D can be instrumental in reducing income disparities between countries.

Figure 3.1: Human and financial resources devoted to R&D



Source: OECD, Main Science and Technology Indicators Database, http://oe.cd/msti , September 2023.

Furthermore, there has been a recent increase in the proportion of workers engaged in technology production through R&D. The Research and Development Statistics (RDS) is a comprehensive database that provides detailed and current information on R&D investments across all OECD countries and selected non-member economies. This resource includes data on the financial and human capital resources devoted to R&D. The latest release in 2021 features historical data on human capital and financial resources allocated to R&D, offering an in-depth look at how various countries have invested in R&D over time, represented by Figure 3.1. We can see the trend that links to the growth of R&D expenditure and researchers for each group of countries where the high potential country of each group tends to have a higher intensity of R&D and human resources.

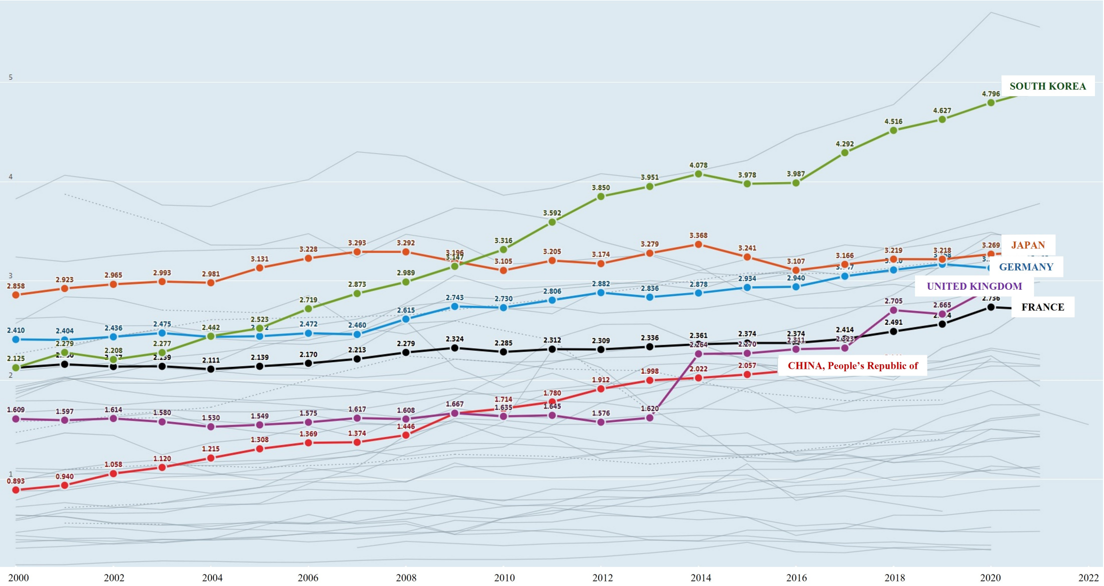
Persistent differences in income can be attributed in part to factors such as the expanding technology frontier, capital accumulation, and factor productivity, as detailed in studies by Barro and Sala-i-Martin (1997), Jones (2016), Berlingieri et al. (2020) and Cervellati et al. (2023). The diffusion of technology across countries can also be interpreted in terms of differences in TFP and income. However, the adoption of new technologies from leading countries can result in significant lags and reduced intensity of adoption, highlighting the critical importance of both the level and intensity of technology use in driving economic growth.

Figure 3.2 represents the per centage of a country's Gross Domestic Product (GDP) spent on R&D. This ratio is widely used to determine the intensity of technology usage within a country or region. The graph compares the R&D intensity in the Organization for Economic Cooperation and Development (OECD) area from 2001 to 2021, which shows a consistent increase in R&D and its intensity in recent years. Several emerging economies are playing a key role in driving technological advancements within the OECD area. However, the Republic of Korea stands out by making substantial investments and spearheading progress with the highest reported R&D intensity, which accounts for 4.9 per cent of its GDP.

This indicates that the Republic of Korea is making significant investments in developing new technologies and improving existing ones. Many empirical studies have shown that R&D can significantly impact economic growth. To estimate and test the effect of R&D on growth, researchers often use TFP growth as a proxy variable. For instance, Jones (1995) used the number of scientists and engineers in advanced economies like Germany, France, Japan, and the United States to measure TFP growth and R&D. In doing so, Jones was able to test the validity of endogenous R&D, which is an important concept in understanding the relationship between R&D and economic growth.

Technological advancements are a vital driving force behind economic growth and development. The process of creating new technology relies heavily on R&D, which can

Figure 3.2: Gross domestic spending on R&D, total percentage of GDP 2000-2022



Source: OECD (2023), doi: 10.1787/d8b068b4-en (Accessed on 6 June 2023).

involve innovating locally or adopting technology from other countries. However, several factors can impact the output of R&D. Bartelsman and Wolf (2014) found that despite less than 13 per cent of workers in the manufacturing industry being employed by firms that performed R&D, about 70 per cent of the measured R&D from 1981-2001 was carried out by these workers. This suggests that only a slight fraction of the population has the necessary skills to produce and innovate new technology.

Various studies have highlighted the significance of skilled individuals in creating new technology. Acemoğlu and Zilibotti (2001) and Hendricks and Schoellman (2023) have emphasized that the number of skilled individuals in a population is a determining factor in creating new technology. This emphasizes the need for governments and firms to invest in developing and encouraging talent in science, technology, engineering, and mathematics (STEM) fields.

Measuring the output of R&D or the stock of technology in the manufacturing industry can be challenging. Patents are often used as a proxy in various literature as they produce a constant growth rate (as in Griliches and Lichtenberg, 1984; and Kortum, 1997) and can be viewed as a proportional improvement in productivity. Patents are a proper way to track technological progress as they offer insights into the volume and direction of R&D investments. However, it is essential to note that patents can be thought of as a proportional improvement in productivity.

The world is experiencing a remarkable increase in the speed of technology adoption, resulting in a decrease in the time gap between the creation and application of new technologies. This period, known as the speed of adoption, has a significant impact on the growth of countries across the world. By reducing the adoption lag, we can help narrow the growth gap between countries at the forefront of technology adoption and those that are lagging behind. Previous research conducted by Nelson and Phelps (1966) and Acemoğlu et al. (2006) established that the speed of adoption is a critical factor in determining a country's growth.

Comin and Hobijn (2010) conducted a comprehensive study on the Cross-country Historical Adoption of Technology (CHAT) database, which revealed that the time it takes for technology to be adopted has significantly decreased over time. For example, there was an average of 4.3 years reduction in the adoption period of a technology invented a decade later. The dataset provides information on the international adoption of 15 technologies between 1820 and 2003 across 166 countries. This study illustrates that the pace of technology adoption is a crucial component in determining a country's growth, as it can reduce the growth gap between countries and provide opportunities for countries that lag behind to catch up with the rest of the world. Hence, the rate of technology adoption is one of fundamental factor determining growth.

The role of R&D in innovation and imitation has been extensively discussed in theoretical literature, with scholars suggesting that R&D can play both of these roles. However, there is limited empirical research that examines the statistical significance and quantitative importance of cross-country R&D interactions. Some studies conducted at the firm level suggest that firms with high R&D investments benefit from spillovers, as found by Jaffe (1986) in the United States Additionally, innovative firms tend to benefit the most from the innovations of others, as Geroski et al. (1993) found in the United Kingdom While these findings are insightful, further research is necessary to obtain a complete understanding of how R&D affects industry productivity growth and social rates of return in various countries. This extension study on this topic could benefit in the creation of more favourable policies that endorse innovation and technological advancement, while considering the distinctive features of various regions and industries.

This empirical chapter will explore the importance of R&D in driving productivity growth across industries in fourteen countries from 1990 to 2019. The results of this study highlight that countries that are technologically less advanced than others at the productivity frontier can catch up at a faster pace if they increase their investments in the R&D sector. We use a panel of industries from different countries to emphasize the role of technology transfer and absorptive capacity in driving productivity growth for economies that are lagging behind in technology. This implies that the ability of an economy to absorb new technologies and innovations plays a crucial role in driving productivity growth. In addition, The study will provide insights into the importance of

R&D investment in driving productivity growth, technology transfer, and absorptive capacity in the context of lagging economies and highlight the need for countries to invest in R&D to enhance their technological capabilities and achieve sustained productivity growth.

The analysis of this chapter takes into account various factors while examining the rate of TFP growth. These factors include the impact of R&D, international trade, and human capital. In order to determine the extent of technology transfer, the distance from the technological frontier is calculated directly. The country that is situated at the frontier of technology or productivity growth is defined as the one with the highest level of technology. However, this leads to the question of whether countries that are further from the technological frontier have more significant potential for productivity growth. This potential can be achieved through the adoption of technology by more advanced countries.

Chapter 3 will first begin with the theoretical framework of R&D and TFP growth in Section 3.2. After that, Section 3.3 will describe the data and variable measurements used in this study. Next, Section 3.4 will present the empirical analysis and interpretation of the findings from fourteen different advanced and emerging countries between 1990 and 2019. The study has revealed that technology transfer and innovation significantly reduce technology disparities between countries. At the same time, higher levels of adoption are strongly associated with increased productivity in emerging economies, ultimately benefiting advanced economies as well. Finally, Section 3.5 will conclude the chapter.

3.2 Theoretical Framework

This section will provide a comprehensive and detailed overview of the theoretical framework that explains the relationship between R&D and TFP growth. The framework is based on existing literature from Griffith et al. (2004). The relationship between R&D and TFP growth is of great interest to researchers, policymakers, and businesses. R&D activities are seen as a crucial driver of innovation, which, in turn, leads to increased productivity and economic growth. However, the exact nature of the relationship between R&D and TFP growth is complex and needs to be more adequately understood.

Griffith et al. (2004) proposed a theoretical framework to shed light on this relationship. Their framework suggests that R&D activities contribute to TFP growth by generating new knowledge, which is then used to improve production processes and develop new products and services. This leads to increased efficiency, competitiveness, and economic growth through higher productivity. To support their framework, they reviewed a significant body of literature on R&D and TFP growth. Their analysis covered theoretical and empirical studies, highlighting the importance of R&D investment for long-term economic growth. Overall, this literature offers a useful theoretical framework to understand the R&D and TFP growth relationship. By taking into account the various factors that influence this relationship, researchers, policymakers, and businesses can develop more effective strategies to promote innovation, productivity, and economic growth.

To better understand this framework, this study considers a world that consists of two distinct types of countries, $i \in \{I, F\}$, - frontier countries (denoted as F) and non-frontier countries (denoted as I). Frontier countries are characterized by their high technological advancement and innovation level, while non-frontier countries are lagging in these areas. Each country, whether frontier or non-frontier, is capable of producing a fixed number of manufacturing goods, which are represented by $j = 1, \dots, J$. The value added in each industry j at time t is defined as $Y_{ij,t}$, produced using a combination of labour input, represented by $N_{ij,t}$, and physical capital stock, represented by $K_{ij,t}$ as in Equation 3.1. This production process is carried out using a standard neoclassical production technology.

$$Y_{ij,t} = A_{ij,t}\mathbb{F}_{j,t}(N_{ij,t}, K_{ij,t}) \quad . \tag{3.1}$$

where $A_{ij,t}$ is an index that measures technical efficiency, also known as TFP, which is allowed to vary across countries i, sectors j and time t, and $\mathbb{F}(\cdot,\cdot)$ is the production function with homogeneous degree one and indicate a diminishing marginal return to the accumulation of each factor either labour input $N_{ij,t}$ or physical capital stock $K_{ij,t}$.

It is essential to note that this framework is built upon the concept of R&D, which is the process of discovering new knowledge that can be used to develop new or improved products, processes, or services. We will explore how R&D activities impact TFP growth in both frontier and non-frontier countries and how these activities can drive economic growth in the long run.

This study is based on the literature on productivity growth and R&D and assumes that the TFP denoted as $A_{ij,t}$, is a function of two main factors: the stock of R&D knowledge ($S_{ij,t}$) and the residual of influences ($D_{ij,t}$). Moreover, a vector of control variables, including human capital and international trade, is also considered. To determine the rate of TFP growth, take logarithms and differentiate them with respect to time. This helps us to identify the rate of growth of the stock of R&D knowledge that affects the rate of TFP growth.

Specifically, the equation for the growth rate of TFP in discrete time is

$$\Delta \ln A_{ij,t} = \gamma \Delta \ln S_{ij,t} + \delta \Delta \ln D_{ij,t} + u_{ij,t} \quad , \tag{3.2}$$

where $\Delta \ln A_{ij,t}$ is the change in the natural logarithm of TFP and $\gamma = (dY/dS)(S/Y)$ represents the elasticity of value added in response to changes in the R&D knowledge stock. Moreover, $\Delta \ln S_{ij,t}$ stands for the change in the natural logarithm of the stock of R&D knowledge and $\delta = (dY/dD)(D/Y)$ is the elasticity of output with respect to the residual set of influences. The term $\Delta \ln D_{ij,t}$ represents the change in the natural logarithm of the residual of influences, and $u_{ij,t}$[1] is a stochastic error with a zero expected value and constant variance for all observations, where $E(u_{ij,t}) = 0$ and $E(u_{ij,t}^2) = \sigma^2$.

This study also assumes that the rate of depreciation of the stock of R&D knowledge, τ, is low, then the rate of TFP growth can be rewritten as the ratio of R&D expenditure to value-added,

$$\Delta \ln A_{ij,t} = \eta \left(\frac{R_i}{Y_i}\right)_{j,t-1} + \delta \ln D_{ij,t-1} + u_{ij,t} \quad , \tag{3.3}$$

where $\eta \equiv (dY/dS)$ is the rate of return of R&D knowledge stock or marginal product of R&D and variable $R_{ij,t-1}$ is the real R&D expenditure which is a crucial element of the stock of R&D knowledge, $S_{ij,t}$.[2] A term of $(R_i/Y_i)_{j,t-1}$ can be defined as R&D expenditure as a ratio or percentage of GDP or as R&D intensity. This percentage is used to indicate an economy's degree of investment in generating new technology.

In order to account for factors that are not directly observed but still affect the rate of TFP growth, such as specific characteristics of a country or industry that encourage investment in R&D, this study includes a country-industry specific fixed effect (ω_{ij}) in

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[1] The errors corresponding to different observations have zero correlation, and $E(u_{ij,t} \cdot u_{kj,t}) = 0$ for $i \neq k$. We also assume that any control variables are not correlated with the error term, then $E(\Delta \ln S_{ij,t} \cdot u_{ij,t}) = 0$ and $E(\Delta \ln D_{ij,t} \cdot u_{ij,t}) = 0$.

[2] Note that $\dot{S}_{ij,t} = R_{ij,t} - \tau S_{ij,t}$, where τ is the rate of depreciation of the stock of R&D knowledge

the error term ($u_{ij,t}$). This helps to control for any unobserved heterogeneity that may be correlated with the explanatory variables. Using this econometric specification as outlined in Equation 3.4, we can then use the Equation for TFP growth in industry j for a given country i as presented in Equation 3.3.

$$u_{ij,t} = \omega_{ij} + \epsilon_{ij,t} \quad , \tag{3.4}$$

where $\epsilon_{ij,t}$ represents a serially uncorrelated error.

This model aims to clarify how R&D impacts the growth of TFP. The endogenous technology or innovation and growth model is the theoretical basis for this model. It posits that new ideas can be used at zero marginal cost in the R&D sector. Moreover, patent protection enables each innovator to benefit from their discoveries. The model highlights that R&D activity has a direct effect on the rate of TFP growth. This is because R&D produces innovations, which in turn affect TFP growth. Specifically, innovations increase the expected flow of profits from acquiring patents for new technologies, thus providing an economic incentive to engage in R&D. The model stresses that R&D is a key driver of TFP growth, which has significant implications for economic development and growth.

Furthermore, the model emphasizes that the expected flow of profits from the acquisition of patents to new technology is necessary to determine the level of R&D investment. It also highlights that the presence of patent protection, which enables innovators to appropriate the returns from their discovery, is a necessary condition for the R&D activity to generate innovations. Hence, the model underscores the importance of R&D activity in promoting technological progress and innovation, which are crucial economic growth and development determinants.

Equation 3.3 represents the relationship between R&D activity and TFP growth. However, to further enhance the model's scope and applicability, this study also considers the possibility of technology transfer from frontier to non-frontier countries within the same industries, as suggested by the convergence literature, e.g. Caselli and Coleman (2006), Bartelsman et al. (2008), Bai et al. (2024) and Lamperti et al. (2023). This implies that countries that are behind the frontier can experience productivity growth by adopting and incorporating the technologies developed by the frontier countries.

In addition to the possibility of technology transfer, the speed of international diffusion of technology depends on several factors, including industry-specific characteristics and relative levels of TFP with the frontier. Therefore, to accurately capture the effects of technology transfer on TFP growth, the term technology transfer from the frontier to the non-frontier, $\ln{(A_F/A_i)}_{j,t-1}$, should be included in Equation 3.5. This will enable us to understand better the role of technology transfer in promoting sustainable economic growth and development across countries and industries.

$$\Delta \ln A_{ij,t} = \eta_1 \left(\frac{R_i}{Y_i}\right)_{j,t-1} + \theta_1 \ln \left(\frac{A_F}{A_i}\right)_{j,t-1} + \delta \ln D_{ij,t-1} + \omega_{ij} + \epsilon_{ij,t} \quad , \tag{3.5}$$

When examining countries that are not technology leaders, it is important to consider the positive distance between their current level of technological development and the technological frontier. This distance can be reduced through the transfer of technology, which has been shown to impact productivity growth positively. This is supported by the estimated value of θ_1, which is a statistical measure used to quantify the relationship between technology transfer and productivity growth. It is also important to consider the dynamic adjustment of TFP over time. That is why the lagged dependent variable is used. This variable captures the effect of past levels of TFP on current levels. It helps to ensure that the study analysis considers the complete picture of TFP growth in these countries.

In some academic papers (as in Nelson and Winter, 1977; Grossman and Helpman, 1990; Jones and Williams, 2000; and Benhabib et al., 2014), it has been argued that the process of R&D can assist individuals or organizations in imitating or adopting existing technologies. Adopting a particular technology depends on the adopter's technical knowledge and skills in the respective industry or country. This concept is commonly referred to as absorptive capacity and is represented by Equation 3.6. The term absorptive capacity, $(R_i/Y_i)_{j,t-1} * \ln (A_F/A_i)_{j,t-1}$, captures the interaction between the intensity of R&D and the gap in TFP. This highlights the role of R&D in the transfer of technology. The TFP gap refers to the difference between the productivity of a particular country or industry and the productivity of the leading country or industry in that particular sector. Therefore, the greater the TFP gap, the further the country or industry is from the technology frontier.

In turn, this creates more potential for technology transfer through R&D. The use of R&D in technology transfer is a crucial factor in the development of competitive industries. It enables the transfer of knowledge and technology from the leading industries to the industries that are behind in terms of productivity. The implementation of new technologies is crucial for economic growth, as it can result in a significant increase in productivity and efficiency. Therefore, it is important to understand the role of R&D in technology transfer, particularly for countries and industries that need to catch up in terms of productivity.

$$\begin{aligned}\Delta \ln A_{ij,t} = \eta_1 \left(\frac{R_i}{Y_i}\right)_{j,t-1} + \theta_1 \ln \left(\frac{A_F}{A_i}\right)_{j,t-1} + \theta_2 \left(\frac{R_i}{Y_i}\right)_{j,t-1} \ln \left(\frac{A_F}{A_i}\right)_{j,t-1} \\ + \theta_2 \left(\frac{R_i}{Y_i}\right)_{j,t-1} \ln \left(\frac{A_F}{A_i}\right)_{j,t-1} + \delta \ln D_{ij,t-1} + \omega_{ij} + \epsilon_{ij,t} \quad ,\end{aligned} \tag{3.6}$$

where the interaction term shows an absorptive capacity that captures the role of R&D in technology transfer which in turn suggests a positive value for θ_2.[3]

When analysing a country's technological advancements, it is crucial to consider the expression for TFP growth, denoted by $\Delta \ln A_{ij,t}$. This expression can be switched from Equation 3.6 to Equation 3.3. In the case where country i is the frontier country, it is easy to note that Equation 3.6 simplifies to Equation 3.3 because $\ln(A_F/A_i)_{j,t-1} = 0$ when $i = F$ and η is equivalent to η_1. By combining Equation 3.6 with this simplification, we can determine how far a non-frontier country is from becoming a technological leader. This model allows for an endogenous switch between country i for being either frontier or non-frontier countries, resulting in consistent TFP growth across all industries and countries. Thus, this approach is helpful in assessing a country's technological advancement level and can help identify areas where further investment and development are needed to achieve a more efficient and productive economy.

Therefore, the econometric specification of TFP growth in industry j for a nonfrontier country can be derived as Equation 3.6. Similarly, the econometric specification of TFP growth in industry j for a frontier country is

$$\Delta \ln A_{Fj,t} = \eta \left(\frac{R_F}{Y_i}\right)_{j,t-1} + \delta \ln D_{Fj,t-1} + \omega_{Fj} + \epsilon_{Fj,t} \quad . \tag{3.7}$$

This study merges the equations of frontier and non-frontier economies through cross-equation constraints on the R&D intensity variable. Equations 3.6 and 3.7 are estimated using the within-group estimator, while frontier observations are excluded when cross-equations prove invalid for dependable results. The objective is to provide insight into the influence of R&D intensity on economic growth in both economy types. According to the model, a country's identity plays a minor role in determining its potential for technology transfer. Instead, what matters the most is the distance between a country and the technological frontier. This implies that countries with productivity levels higher than others but lower than the frontier still have the potential for technology transfer.

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[3] In this additional specification, the parameter $\Theta \equiv \theta_1 + \theta_2(R_{ij,t-1}/Y_{ij,t-1})$ denotes as the speed of technology transfer, and $\eta \equiv \eta_1 + \theta_2(R_{ij,t-1}/Y_{ij,t-1})$.

The study further confirms that the correlation between distance from the technological frontier and the potential for technology transfer remains valid even when using alternative measures of spillover potential. For instance, the frontier is defined using the average of the two highest TFP levels instead of relying on the country with the highest relative TFP. The gap of TFP measurement used in the study reveals proximity to the cutting edge of technology by demonstrating different results when using TFP distance to the geometric mean TFP in the industry. This means that the gap of TFP measurement can provide insights into a country's proximity to the leading edge of technology, which can be useful in determining its potential for technology transfer.

This research study utilises time series analysis techniques to estimate the correlation between TFP in frontier and nonfrontier countries. The study outlines the convergence literature, such as a study by Nelson (2008) and Bartelsman et al. (2008), to provide further insights into how standard measures of cross-country correlation between growth rates and initial levels of relative TFP may be impacted. The standard deviation of relative TFP, a measure of a country's industry productivity compared to others in the same sector, may be influenced by the correlation between initial and steady-state distributions. This correlation can cause the standard deviation to increase, indicating more significant productivity level variability, to decline, indicating more distinguished uniformity, or remain consistent over time, indicating a consistent level of variation. It is important to note that the sample period examined in this study is characterised by cross-country variation across most industries. However, this is not a necessary model implication but rather a data feature. The findings of this study provide insight into the elaborate relationship between TFP across various countries and industries and could have significant implications for policymakers and researchers.

3.3 Data Description

This study uses a wide range of reputable and dependable data sources with a high reputation among the academic and research communities. These sources include renowned institutions such as OECD Statistics, the World Bank, and the Penn World Table. The data from these sources cover critical factors like value-added, labour, capital stock, and R&D expenditure. Furthermore, the study enhances its accuracy and validity by incorporating business expenditures from the OECD ANBERD dataset and bilateral trade data from the indicator for structural analysis (iSTAN) to represent R&D expenditures.

For a thorough and comprehensive analysis, this study was first conducted across fourteen countries, divided into two groups: seven advanced countries and seven high-potential developing countries as in Table 3.1. The data analysed spans three decades, from 1990 to 2019, and involved a total of 420 observations.[4]

TABLE 3.1: Country list

Advanced Countries	High-Potential Country
Canada	Brazil
Germany	the People's Republic of China
France	India
United Kingdom	the Republic of Korea
Italy	Singapore
Japan	Türkiye
United States	South Africa

This study aims to explore the linkage between TFP growth, the TFP gap to the frontier, and potential factors that can impact innovation and technology transfer. To determine the TFP growth rate and TFP gap level, this study will the superlative-index-number approach in Caves et al. (1982). This approach is flexible in specifying the production technology and has been proven effective. In addition, this study will also draw upon Harrigan (1997) and Griffith et al. (2004) to ensure accuracy in the measurement of TFP for differences across countries on varied factors. This will provide a reliable basis for investigating the correlation between TFP growth, the TFP gap to the frontier, and other controlling factors.

Various studies have been conducted to calculate TFP growth in different contexts. Some of these studies have used firm-level data to estimate firms' productivity. Two-step methods are commonly used in economics to estimate production functions that define the relationship between inputs and outputs in a production process. These methods are particularly useful when it is difficult or impossible to observe all the factors directly contributing to productivity. Two well-known examples of two-step methods are the ones developed by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

These methods work by using investment and intermediate inputs as proxies for unobserved productivity. The first step involves estimating a set of equations that relate investment and intermediate inputs to output. This provides estimates of the productivity of each firm. The second step then involves using these estimates to construct a

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[4] Within the empirical analysis, there is Section 3.4.2, which details an extension study. This extension study incorporates a country-industry variation and includes a selection of countries that are listed in Table 3.1. The extension study features a total of 825 observations, which provide a detailed and comprehensive analysis of the various industries and countries involved.

production function describing the relationship between the inputs and output. By using investment and intermediate inputs as proxies for unobserved productivity, two-step methods allow researchers to estimate productivity even when some of the inputs are unobservable or difficult to measure. These methods have been used to estimate production functions in a variety of different industries, including manufacturing, agriculture, and services.

However, Ackerberg et al. (2015) have highlighted a crucial issue related to identifying coefficients on variable inputs. They argue that if a variable input is selected as a function of unobserved productivity, then it becomes challenging to determine the coefficient on that variable input. To overcome this limitation, Wooldridge (2009) suggests using a generalized method of moment estimation. This method relies on instrumental variables to identify the parameters of a model, which can help in obtaining consistent and efficient estimators of the coefficients of interest. By using this approach, researchers can account for the endogeneity of variables and obtain more reliable estimates of the relationships between different inputs and outputs.

The methodologies established by Olley and Pakes (1996) and Ackerberg et al. (2015) have been widely utilized to measure TFP growth using firm-level data. Compared to industry-level studies, these approaches offer a more detailed and comprehensive analysis of productivity and efficiency at the firm level. They allow for the measurement of not only the inputs and outputs but also the underlying technology used by the firm. However, the application of these approaches may be limited by data availability and comparability issues at the industry level. As a result, this study has opted for an alternative approach, namely, the value-added TFP index, to assess productivity growth in firms followed from Griffith et al. (2004).

This study will measure TFP growth using a superlative index number approach derived from the translog production function, which is widely recognised as one of the most accurate in calculating TFP growth, as follows:

$$\Delta \ln A_{ij,t} \equiv \Delta gTFP_{ij,t} = \Delta \ln Y_{ij,t} - \tilde{\mu}_{ij,t} \Delta \ln N_{ij,t} - (1 - \tilde{\mu}_{ij,t}) \Delta \ln K_{ij,t} \quad , \tag{3.8}$$

where $Y_{ij,t}$ is the real value added, $N_{ij,t}$ is the number of workers employed, $K_{ij,t}$ is the real capital stock, and $\tilde{\mu}_{ij,t} = \frac{1}{2}(\mu_{ij,t} + \mu_{ij,t-1})$ is the average of the share of labour where $\mu_{ij,t}$ is the share of labour in value-added.

In this study, the level of TFP in each country relative to the frontier is measured using a superlative index number derived from the translog production function, as defined by Equation 3.9. To evaluate the level of TFP in each country, a common reference point is necessary. For this purpose, the geometric mean (G.M.) of all other countries is used as a reference point. The process of determining the level of TFP in each country relative to the geometric mean of all other countries is carried out for each industry year. For instance, the value-added in the machinery and equipment industry of a country in 1990 is measured relative to the geometric mean of the machinery and equipment industry of all other countries in 1990.

This approach enables the estimation of the level of TFP in each country relative to the geometric mean of all countries, which serves as a reference point for all countries. Overall, this method provides a comprehensive and detailed approach to evaluating the level of TFP in each country relative to the frontier and in comparison to other countries. Calculating the level of TFP in each country relative to the geometric mean as a reference point for all countries, or the MTFP (mean TFP), is as follows:

$$MTFP_{ij,t} = \ln\left(\frac{Y_{ij,t}}{\bar{Y}_{j,t}}\right) - \tilde{\rho}_{ij,t}\ln\left(\frac{N_{ij,t}}{\bar{N}_{j,t}}\right) - (1-\tilde{\rho}_{ij,t})\ln\left(\frac{K_{ij,t}}{\bar{K}_{j,t}}\right) \quad . \tag{3.9}$$

The variables for the geometric means are denoted with the bar symbol. Specifically, $\bar{Y}_{j,t}$ represents the geometric mean of value-added, $\bar{N}_{j,t}$ represents the geometric mean of the number of workers employed, and $\bar{K}_{j,t}$ represents the geometric mean of the real capital stock in industry j at time t. The parameter $\tilde{\rho}_{ij,t}$ is calculated as follows: first, finding the labour share in the country i for industry j at time t, represented by $\mu_{ij,t}$. Next, taking the geometric mean of the labour share for industry j at time t, represented by $\bar{\mu}_{j,t}$. Finally, take the average of $\mu_{j,t}$ and $\bar{\mu}_{ij,t}$ and divide it by two. This gives us $\tilde{\rho}_{ij,t} = \frac{1}{2}(\mu_{ij,t} + \bar{\mu}_{j,t})$.

The frontier is the country with the highest TFP levels in each industry j relative to the geometric mean at time t. We calculate the TFP gap or the distance from the frontier by subtracting the MTFP of a non-frontier country from the MTFP of the frontier. This provides us with a superlative-index-number measure of the TFP gap[5] as follows.

$$\ln\left(\frac{A_F}{A_i}\right)_{j,t} \equiv TFPGAP_{ij,t} = MTFP_{Fj,t} - MTFP_{ij,t} \quad . \tag{3.10}$$

Before delving into the analysis of the results, the study provides an overview of simple descriptive statistics, which can be found in Tables 3.2. The TFP measurement has been adjusted in various ways as suggested by the literature, and the preferred method is the one that corrects for hours worked. Table 3.2 presents the mean annual growth rates of TFP, highlighting the considerable heterogeneity in TFP growth rates across countries. These findings certify further investigation and emphasize the need to identify the drivers of this heterogeneity. The analysis of these results will help illustrate the factors contributing to differences in TFP growth rates across countries.

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[5] A country's TFP distance or TFP gap from the frontier equivalences to $\ln(A_F/A_i)_{j,t}$.

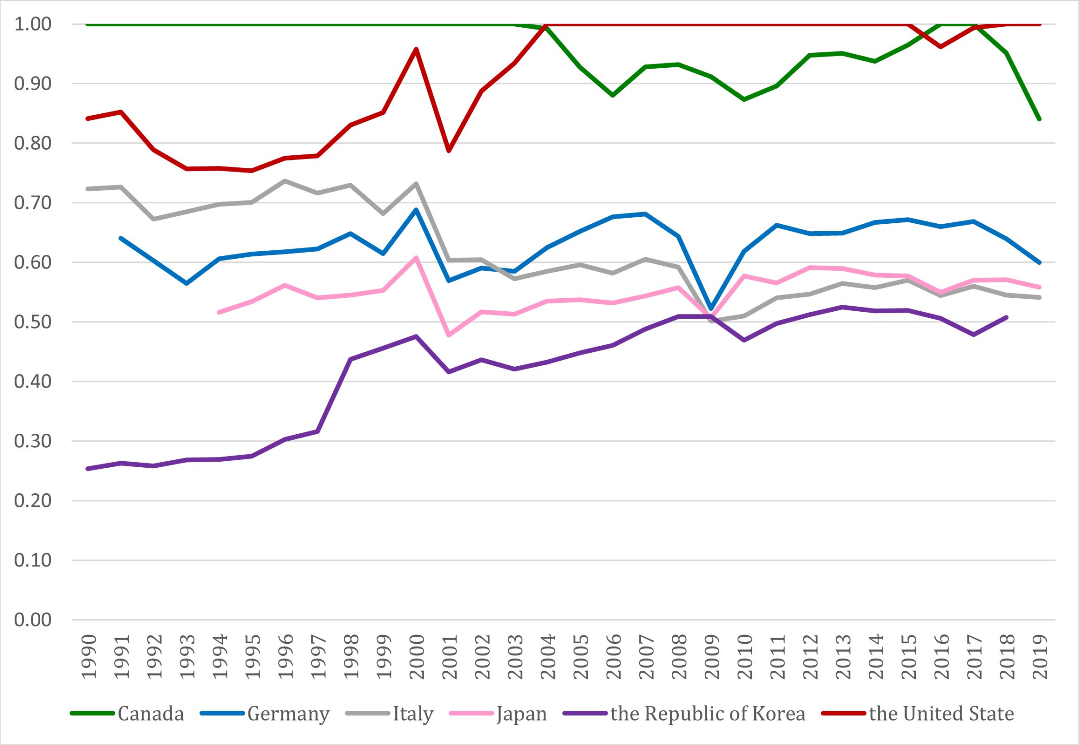
Table 3.2: Mean annual growth rate of TFP as percentage between 1990-2019

Industry		CAN	DEU	ITA	JPN	KOR	USA
MAN	Obs	29	28	29	25	28	29
	Mean	0.0797	0.1325	0.0354	0.0934	0.0347	0.0213
	S.D.	0.0559	0.0669	0.0424	0.0531	0.0653	0.0379

Source: Author's calculation

In order to demonstrate this approach, Figure 3.3 shows the relative TFP for an aggregate manufacturing sector using this method. The graph illustrates the exponential value of the negative of the TFP gap, which corresponds to the TFP levels of each country as a proportion of the relative TFP in the frontier. This figure contains six countries: Canada, Germany, Italy, Japan, the Republic of Korea, and the United States. Relative TFP is a measure that compares a country's TFP to the technological frontier, representing the highest level of productivity achievable with current technology. It assigns a score of 1 to the frontier and less than 1 to nonfrontier countries, reflecting their relative distance from the frontier. The larger the deviation from 1, the greater the distance from the frontier for country i.

Figure 3.3: Relative TFP of sample countries on the aggregate manufacturing between 1990 and 2019.

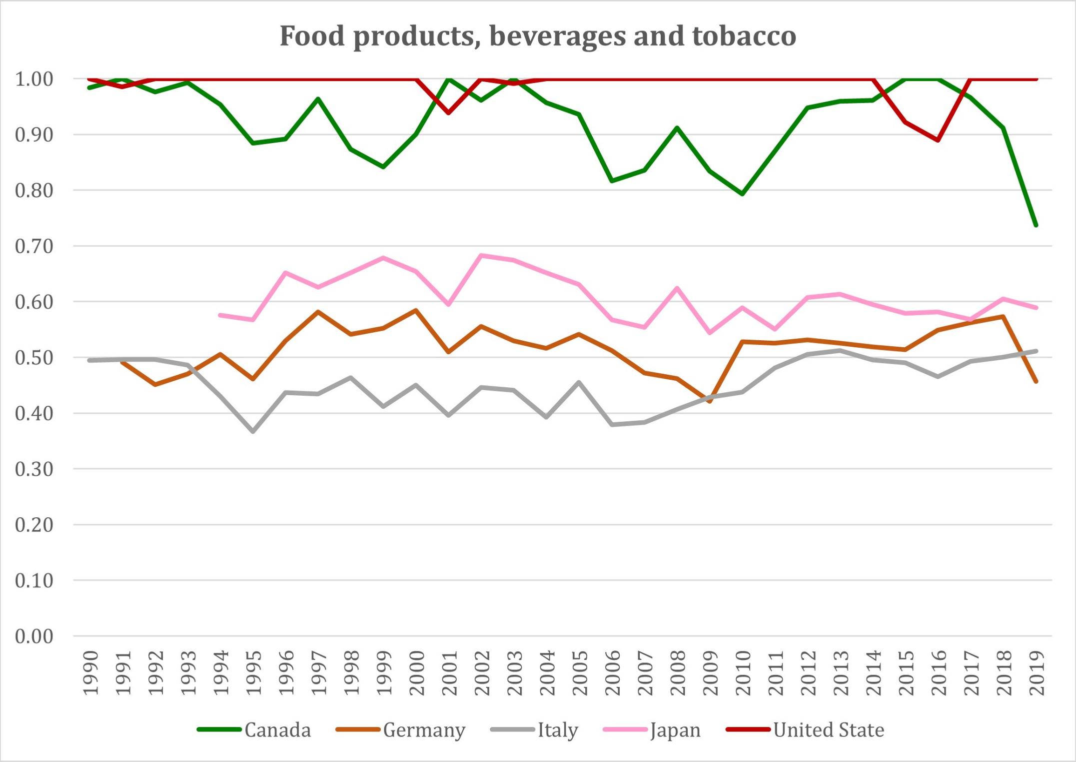


Source: Author's calculation

Throughout the study period, the United States was considered the leading country in terms of technological advancement, except for 2016, when Canada surpassed it.

However, many countries have managed to narrow the gap with the United States in the overall manufacturing industries. Specifically, the Republic of Korea, which was initially one of the furthest countries from the United States in 1990, has made significant progress and closed almost half of the TFP gap by 2018. While some other countries like Italy and Germany have not shown significant improvements in their relative positions to the United States. At the same time, Canada was a strong competitor to the United States throughout the considered sample periods.

FIGURE 3.4: Relative TFP of sample countries on the food products, beverages, and tobacco industries between 1990 and 2019.



Source: Author's calculation

It is important to note that the relative TFP differs by industry, and the identity of the frontier and the country with the next highest and other lower levels of relative TFP remains relatively stable over time in some industries. For example, during the study period, which spans from 1990 to 2019, the United States remained the technological frontier country in the food products, beverages, and tobacco industries, while other countries continued to maintain their positions relative to the frontier country, depicted by Figure 3.4. However, there are instances of a loss of technological leadership as one economy overtakes another in specific industries, such as Canada losing its position as the leader from the 2000s to the United States in the machinery and equipment industry.[6]

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[6] For more detailed figures information, kindly refer to Appendix 3.7.4.

The study presents Table 3.3, which provides a detailed analysis of the sample mean and standard deviation of relative TFP for each various countries in 1999, 2009, and 2019. The values have been calculated using Equation 3.10. Relative TFP measures the productivity of a country relative to a frontier country. A country is considered a frontier country if it has the highest productivity level in a particular industry. To determine a country's productivity level, the study has interpreted the exponent of each country relative TFP, where this number equals to 1 for the frontier country and less than 1 for non-frontier countries. The closer this number is to 1, the higher the level of TFP in the country i relative to the frontier. On the other hand, the further away the number is from 1, or the smaller the number, the lower the level of TFP in country i relative to the frontier.

Table 3.3: Relative TFP in 1999, 2009 and 2019 (hours adjustment)

Industry		1990	1994	1998	2002	2006	2010	2014	2019
MAN	Frontier	KOR	JPN	USA	USA	SGP	JPN	KOR	SGP
	Mean	0.5963	0.7310	0.5235	0.5987	0.6949	0.7144	0.7954	0.7816
	S.D.	0.7190	0.8245	0.6811	0.6921	0.6123	0.5834	0.7039	0.8441

Note: Frontier is the highest TFP country; Mean is the mean and S.D. is the standard deviation of the relative TFP across countries.

As previously discussed, the econometric estimation in this study does not primarily focus on the identity of a frontier country. Instead, this study uses the measure of distance from the technology frontier to capture the potential for technology transfer. In the analysis of aggregate manufacturing industry data from 1990 to 2019, this study has observed that there have been significant changes in the average levels of relative TFP across countries. This indicates that there has been a convergence in levels of relative TFP within the manufacturing industries of the fourteen countries in the sample. In other words, the productivity levels of these countries have been steadily advancing towards the technological frontier over time, which is a positive indicator of their economic growth and development. This convergence in TFP levels within the manufacturing industries of these countries is a promising sign that they are moving towards a more equal foundation with more technologically advanced countries. Such advancements could lead to more economic development and opportunities for the citizens of these countries.

3.4 Empirical Results

3.4.1 The determinants of productivity growth of aggregate manufacturing industries across countries

This study is focused on understanding the growth of total factor productivity (TFP) in the manufacturing sector over time. The research is based on panel data on aggregate manufacturing and employs a rigorous analysis that controls for heterogeneity and fixed effects. The study is conducted across fourteen countries[7], including Canada, Germany, France, the United Kingdom, Italy, Japan, the United States, Brazil, the People's Republic of China, India, the Republic of Korea, Singapore, Türkiye, and South Africa, and spans three decades from 1990 to 2019.

The research aims to evaluate the impact of various factors on TFP growth. Specifically, the study starts by examining the impact of technology transfer on productivity growth in the manufacturing sector without taking into account the effect of R&D as seen in column (1) of Table 3.4. The analysis provides valuable insights into the individual effects of each variable on TFP growth and contributes to the understanding of manufacturing productivity growth over time.

TABLE 3.4: Impact of R&D in TFP growth: aggregate manufacturing

$\Delta TFP_{i,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{i,t-1}$	θ_1	1.3548** (0.4626)	1.7210** (0.5210)	1.8456 (1.1887)	0.2638*** (0.0186)
$(R/Y)_{i,t-1}$	η_1		0.3877 (0.3472)	0.4065 (0.3444)	0.0567** (0.0177)
$(TFPGAP \times R/Y)_{i,t-1}$	θ_2			-0.0488 (0.4143)	-0.0592** (0.0195)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 420 observations from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and countries; robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

The variable $TFPGAP_{i,t-1}$ is a crucial factor in facilitating technology transfer, which is essential for increasing productivity growth rates in countries that are lagging behind in aggregate manufacturing datasets. To better understand the link between R&D expenditure and productivity growth, this analysis includes the lagged level of R&D intensity, $(R/Y)_{i,t-1}$, in the econometric analysis. This term of $(R/Y)_{i,t-1}$ refers to the ratio of R&D expenditure to real value-added and is a crucial factor in promoting innovation. When R&D intensity is combined with a term of a lagged TFP gap, $TFPGAP_{i,t-1}$, it captures the effect on the rate of technological transfer.

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[7] See full description in Table 3.1

However, despite showing positive and negative signs, the R&D intensity and its interaction terms in columns (2) and (3) are no longer significant in this analysis. This suggests that other factors may be at play in determining the impact of R&D expenditure on productivity growth in these countries. Despite this, incorporating the lagged TFP gap and R&D intensity variables in the analysis offers valuable insights into how technology transfer can promote productivity growth. This emphasizes the significance of sustained investment in research and development in these countries.

In column (4) of the measurement of TFP growth, adjustments are made to consider the differences in the number of hours worked across various countries. The statistical analysis reveals that both R&D intensity and interaction terms significantly impact the TFP measurement. In other words, countries that invest 1 per cent more in research and development tend to have 5.67 per cent higher TFP levels than those that do not. Moreover, the interaction between R&D intensity and TFP gap level has an impact on the measurement of TFP. However, the estimated coefficient on the interaction R&D intensity term is negative at 5.92 per cent. This suggests that as the TFP gap level increases, the potential for technologies to be transferred through research and development decreases. In other words, when there is a large gap between the TFP levels of two countries, transferring technologies through research and development becomes more challenging. As a result, there are fewer opportunities for new inventions to be created and implemented in other areas, leading to lower productivity growth rates.

Table 3.5: Impact of R&D, human capital, and trade in TFP growth: aggregate manufacturing

$\Delta TFP_{i,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{i,t-1}$	θ_1	0.3307*** (0.0757)	0.4464** (0.1528)	0.4806** (0.1498)	0.7925*** (0.1755)
$(R/Y)_{i,t-1}$	η_1	0.0721** (0.0246)	0.0857** (0.0241)	0.0761** (0.0271)	0.0791** (0.0228)
$(TFPGAP \times R/Y)_{i,t-1}$	θ_2	-0.0779** (0.0268)	-0.1028* (0.0480)	-0.0969* (0.0476)	-0.0947* (0.0406)
$H_{i,t-1}$	η_2	0.0541** (0.0207)	0.1559 (0.1230)	0.1427 (0.1131)	0.1568 (0.1093)
$(TFPGAP \times H)_{i,t-1}$	θ_3		-0.1903 (0.2153)	-0.2075 (0.2046)	-0.2192 (0.1891)
$IMP_{i,t-1}$	η_3			0.0036** (0.0014)	0.0051** (0.0016)
$(TFPGAP \times IMP)_{i,t-1}$	θ_4				-0.0045* (0.0019)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes	Yes	Yes	Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 420 observations from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and countries; robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

This study extends upon a prior investigation by including human capital and trade roles. The extended model, of the Equation 3.6, including impact of R&D, human capital, and trade in TFP growth is shown as the Equation 3.11. It reproduces the previous findings using the TFP gap measurement to account for working-hour differences. The analysis shows a significant positive value for a lagged human capital variable, $H_{i,t-1}$, in column (5) of Table 3.5, which suggests the importance of human capital in the growth of technology and innovation. Furthermore, the research expands on the previous analysis by including a level and interaction human capital term in column (6).

$$\begin{aligned}\Delta \ln A_{ij,t} =& \theta_1 \ln\left(\frac{A_F}{A_i}\right)_{j,t-1} + \eta_1 \left(\frac{R_i}{Y_i}\right)_{j,t-1} + \theta_2 \left(\frac{R_i}{Y_i}\right)_{j,t-1} \ln\left(\frac{A_F}{A_i}\right)_{j,t-1} \\ &+ \eta_2 H_{ij,t-1} + \theta_3 H_{ij,t-1} \ln\left(\frac{A_F}{A_i}\right)_{j,t-1} \\ &+ \eta_3 IMP_{ij,t-1} + \theta_4 IMP_{ij,t-1} \ln\left(\frac{A_F}{A_i}\right)_{j,t-1} + u_{ij,t} \quad ,\end{aligned} \tag{3.11}$$

Although the two variables are not statistically significant, they indicate the potential role of human capital in developing technology and innovation. Surprisingly, the coefficient on the interaction human capital term is negative, which suggests that human capital might have a negative impact on the TFP growth rate through technology transfer and the distance of TFP to the frontier. Therefore, the study's results suggest that human capital plays a crucial role in technology and innovation growth, but its impact on the TFP growth rate needs further investigation.

In addition, international trade can lead to knowledge spillovers, which can impact productivity growth through various channels. One channel is an increase in product market competition, which can stimulate innovation and improve productivity. This study then used the World Development database to measure imports from the frontier. The findings suggest that the lagged import level term, $IMP_{i,t-1}$, positively impacts productivity growth as seen in column (7) of Table 3.5, which means that increased imports from the frontier can enhance productivity growth rates.

This finding is consistent with the idea of knowledge spillovers, as increased imports from the frontier can bring new ideas and technologies to follower countries. However, the study also found that the effects of R&D and technology transfer remain unchanged. This implies that while international trade can be a source of knowledge spillovers, it may not replace the role of R&D and technology transfer in promoting productivity growth.

When an import interaction term, $(TFPGAP \times IMP)_{i,t-1}$, is introduced, it was found that productivity growth rates are negatively affected, as seen in column (8). This implies that increased trade with the frontier may negatively impact productivity growth rates for follower countries by affecting the speed of technology transfer. Specifically, the negative impact of the import interaction term suggests that increased imports from the frontier may lead to faster obsolescence of existing technologies in follower countries, which can hinder productivity growth.

The findings indicate that the connection between international trade, R&D activities, and productivity growth is complicated and influenced by typical circumstances. The study reveals that the relationship between these factors can vary significantly depending on the context and is less precise than previously believed. While international trade can be a source of knowledge spillovers, it may not replace the need for R&D and technology transfer.

In column (8) of our analysis, we have found a potential link between the TFP gap and imports within the dataset. The estimated coefficient for the TFP gap has jumped from 0.4806 to 0.7925. Various literature indicates that technological convergence across countries can increase through technology diffusion via imports, such as Coe and Helpman (1995) and Somale (2021). However, the endowment of a country is also a crucial factor in determining its potential for adopting technology from a frontier country. If a country has low-quality learning and low-productive producers, they will benefit more from imports rather than improving their learning and producing quality. Consequently, the distance from the frontier tends to be larger and diverge when countries increase their import level.

Moreover, the impact of international trade on TFP growth may depends on several factors, such as the level of product market competition and the speed of technology transfer. When countries that are followers of technological advancements increase their trade with technologically advanced countries or frontier countries, it can have a negative impact on their productivity growth rates. This happens because the rapid transfer of technology from the frontier countries can sometimes result in the follower countries experiencing difficulties adapting to the new technological advancements and integrating them into their existing systems. As a result, they may be unable to fully utilise the benefits of the new technologies with their domestic endowment, leading to a slower rate of productivity growth.

After thoroughly analysing these empirical results and comparing them with the study performed by Griffith et al. (2004), the findings revealed that the coefficients on technology transfer, R&D, human capital, and international trade terms were positively signed and statistically significant. This implies that these variables significantly influence the growth and development of the economy under consideration. However, this study also observed that the interaction terms of technology transfer, $TFPGAP_{i,t-1}$, with R&D intensity and human capital were weakly statistically significant and showed different directions. This suggests that the relationship between these variables could be more complex and require further investigation to understand their economic impact.

In addition, the interaction effect of international trade showed a negative coefficient, which aligns with the findings of previous studies. This emphasises that international trade has a significant impact on the economy of any country. However, the effects can be positive or negative, depending on the resources and capabilities of the country. A country with abundant resources and advanced capabilities can benefit immensely from international trade. On the other hand, if a country lacks resources and has limited capabilities, it may face negative consequences from international trade. Therefore, policymakers must carefully consider a country's strengths and weaknesses before engaging in international trade to ensure maximum benefits and minimise potential adverse effects.

Hence, the findings of this study demonstrate that technology transfer, R&D, human capital, and international trade are critical determinants of economic growth and development. However, their interaction effects need to be studied further to understand their impact on the economy comprehensively.

3.4.2 The determinants of productivity growth of a sample countries in OECD area

This study was designed to explore the significance of R&D and its influence on a country's economic growth. There is an extension study on various industries within a select group of OECD countries, which included Canada, France, Germany, Italy, Japan, the Republic of Korea, Türkiye, the United Kingdom, and the United States. This extension study thoroughly analysed eight different industries as in Table 3.6, conducting testing on diverse country and industry samples to ensure the dependability and precision of our findings.

Table 3.6: Selected Industries

No	Industry
1	Manufacturing
2	Food products, beverages and tobacco
3	Textiles, wearing apparel, leather and related products
4	Wood and paper products, and printing
5	Chemical, rubber, plastics, fuel products and other non-metallic mineral products
6	Basic metals and fabricated metal products, except machinery and equipment
7	Machinery and equipment
8	Furniture, repair and installation of machinery and equipment, and other manufacturing

After addressing gaps in the data, there are 825 observations from the countries and industries mentioned earlier. This data is collected over three decades, from 1990 to 2019, which allowed us to gain valuable insights into how R&D spending impacts economic growth and innovation in these countries and industries. The objective of this extension study is still focused on analysing the relationship between research and development and productivity growth while considering the impact of international trade and human capital. The aim is to assess the accuracy of the results by studying how each variable affects innovation and technology transfer.

The study starts by examining simple descriptive statistics by industry before commencing the extension analysis. In Table 3.7, the study presents the mean annual growth rates of TFP by industry, highlighting significant variations in TFP growth rates across countries and manufacturing industries. These findings suggest that further investigation is necessary to identify the drivers of this heterogeneity. Analysing these results will help illustrate the factors contributing to differences in TFP growth rates across countries and industries.

TABLE 3.7: Mean annual growth rate of TFP as percentage between 1990-2019

Industry	CAN	DEU	ITA	JAP	USA
MAN	0.0079	0.0132	0.0035	0.0093	0.0213
FBT	-0.0118	-0.0027	-0.0047	-0.0077	-0.0025
TWL	0.0097	0.0181	0.0079		0.0239
WPP	0.0136	0.0183	0.0122		0.0081
CHR	0.0045	0.0199	0.0070		-0.0033
MFM	0.0090	0.0134	0.0068	-0.0019	0.0092
MAE	0.0157	0.0194	0.0057	0.0376	0.0692
FUR		0.0099	-0.0021		0.0166
Total	0.0068	0.0141	0.0037	0.0093	0.0173

MAN: Aggregate manufacturing; FBT: Food products, beverages and tobacco; TWL: Textiles, wearing apparel, leather and related products; WPP: Wood and paper products, and printing; CHR: Chemical, rubber, plastics, fuel products and other non-metallic mineral products; MFM: Basic metals and fabricated metal products, except machinery and equipment; MAE: Machinery and equipment; FUR: Furniture, repair and installation of machinery and equipment, and other manufacturing.

Table 3.8 provides a summary statistics of the countries with the highest relative TFP levels. The table offers a broad overview of the sample mean and standard deviation of relative TFP for each industry across different countries in 1999, 2009, and 2019. The values were obtained using Equation 3.10 as well as the previous analysis in Section 3.4.1, with relative TFP performing as a measure of the productivity of a country's industry compared to a frontier country. The table findings reveal significant variations in relative TFP levels across different industries. Some industries, such as food products, beverages and tobacco and wood and paper products, have consistently maintained their position as leaders in TFP levels, while others have experienced a shift in technological leadership. The study further indicates that the identity of the frontier economy is less significant than the distance measurement from the technological frontier country, which captures the potential for technology transfer.

To determine the productivity level of a country, the study interprets the exponent of each country-industry relative TFP. This number equals 1 for the frontier country and less than 1 for non-frontier countries. The closer this number is to 1, the higher the level of TFP in country i relative to the frontier. Conversely, the further away from 1, or the smaller the number, the lower the level of TFP in country i relative to the frontier. Based on the study's findings, it has been concluded that all manufacturing industries, except for the machinery and equipment industry, displayed higher average levels of relative TFP in 2009 as compared to 1999. Furthermore, the standard deviation of relative TFP was observed to be greater in 2009 than in 1999 for all industries except for the machinery and equipment industry. These results indicate a convergence in the relative TFP levels among the manufacturing industries during the sample period.

Table 3.8: Relative TFP in 1999, 2009 and 2019 (hours adjustment)

Industry		1999	2009	2019	Industry		1999	2009	2019
MAN	Frontier	CAN	USA	USA	CHR	Frontier	USA	USA	CAN
	Mean	0.4015	0.4646	0.3763		Mean	0.4268	0.4479	0.2472
	S.D.	0.2867	0.3257	0.2740		S.D.	0.4270	0.4654	0.3722
FBT	Frontier	USA	USA	USA	MFM	Frontier	USA	USA	USA
	Mean	0.4593	0.5455	0.5250		Mean	0.2608	0.3202	0.1876
	S.D.	0.3773	0.4403	0.3777		S.D.	0.2362	0.3130	0.2256
TWL	Frontier	ITA	USA	USA	MAE	Frontier	CAN	USA	USA
	Mean	0.1183	0.2861	0.1731		Mean	0.5344	0.3098	0.2602
	S.D.	0.1259	0.2007	0.1569		S.D.	0.4656	0.2877	0.3257
WPP	Frontier	USA	USA	USA	FUR	Frontier	USA	USA	USA
	Mean	0.2655	0.4262	0.2515		Mean	0.2928	0.5296	0.3760
	S.D.	0.2387	0.3776	0.2969		S.D.	0.2577	0.4603	0.5317

MAN: Aggregate manufacturing; FBT: Food products, beverages and tobacco; TWL: Textiles, wearing apparel, leather and related products; WPP: Wood and paper products, and printing; CHR: Chemical, rubber, plastics, fuel products and other non-metallic mineral products; MFM: Basic metals and fabricated metal products, except machinery and equipment; MAE: Machinery and equipment; FUR: Furniture, repair and installation of machinery and equipment, and other manufacturing. Note: Frontier is the highest TFP country; Mean is the mean and S.D. is the standard deviation of the relative TFP across countries.

Additionally, we found that there was a movement for the manufacturing industries to compare similar levels of TFP during the sample period. This suggests that the productivity gap between the best and worst-performing industries decreased. However, it is worth mentioning that this inclination varied among industries, with some showing more significant convergence than others. A second dataset was used to extend the study, which differed from the first dataset in terms of variable size and level of variation due to the difference in limited access for both datasets. This distinction was attributed to the fact that each industry's technology leader country changed over time.

It should be noted that relative TFP is a valuable measure that considers an entity's productivity in comparison to its peers within the same manufacturing industry. Calculating relative TFP involves utilising the geometric mean, a reliable point of reference for economic variables in panel data at an aggregate level. As such, it is crucial to approach the interpretation of Tables 3.7 and 3.8 with care, taking into account both the level of relative TFP and its magnitude. It is worth mentioning that relative TFP is a measure that takes into account the productivity of an entity relative to its peers in the same manufacturing industry. The calculation of relative TFP requires the use of the geometric mean, which is a fixed point reference for economic variables in panel data at this aggregate level. It is, therefore, important to notice when interpreting the level of relative TFP as presented in Tables 3.7 and 3.8.

The results of the extended study have been partially shown in Table 3.9. In order to adjust for differences in working hours, two additional columns, (2) and (3), have been included, which replicate the results from column (1) using the relative TFP measure. The coefficient value of the R&D remains the same and is not statistically significant for any critical value. However, the findings suggest that technology transfer terms ($TFPGAP_{ij,t-1}$) and absorptive capacity or an interaction terms of technology transfer and R&D intensity, $(TFPGAP \times R/Y)_{ij,t-1}$, play crucial roles. The former has a positive estimated coefficient value, indicating that technology transfer positively impacts TFP growth. On the other hand, the latter or a term of absorptive capacity, exhibits a negative coefficient value, suggesting that absorptive capacity has a negative impact on the TFP growth. Overall, the study concludes that technology transfer and absorptive capacity are significant factors that impact the growth of TFP.

TABLE 3.9: Impact of R&D, human capital, and trade in TFP growth: all industries

$\Delta TFP_{ij,t}$		(1)	(2)	(3)
$TFPGAP_{ij,t-1}$	θ_1	0.1787*** (0.0408)	0.1527*** (0.0368)	0.1797*** (0.0390)
$(R/Y)_{ij,t-1}$	η_1	-0.0677 (0.1809)	-0.0818 (0.1833)	-0.0171 (0.1224)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	-0.5061*** (0.0865)	-0.5198*** (0.0812)	-0.3041*** (0.0934)
$H_{ij,t-1}$	η_2	0.0592*** (0.0176)	0.0676*** (0.0194)	-0.0380 (0.0401)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.1259** (0.0516)	-0.1043** (0.0490)	-0.1079** (0.0425)
$IMP_{ij,t-1}$	η_3	-0.2556* (0.1480)	-0.2946* (0.1613)	-0.1656 (0.0117)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4	0.6255*** (0.1713)	0.6818*** (0.1639)	0.2856* (0.015)
Controls		Yes	Yes	Yes
Hours adjustment			Yes	Yes
Time FE				Yes
Country-Industry FE		Yes	Yes	Yes

Sample countries 825 observations of Canada, France, Germany, Italy, Japan, the Republic of Korea, United Kingdom, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Those two terms describe different aspects of the relationship between productivity growth and technology transfer. The first part suggests that countries that are further behind the frontier in the OECD group experience higher rates of productivity growth within each industry. This means that countries that are less advanced in terms of technology and productivity experience higher growth rates when compared to those at the frontier of technological advancement. This is likely due to the fact that there is more room for growth and improvement in these countries, and they have the opportunity to adopt and adapt the latest technologies and practices.

Additionally, the second part highlights the importance of technology transfer through R&D in promoting productivity growth. It suggests that the further a nonfrontier country lies behind the frontier or the larger gap of TFP, the lower the potential for technologies to be transferred through R&D and the lower the rates of productivity growth. This highlights the importance of technology transfer through R&D and the potential limitations that countries may face if they are not able to access and absorb new technologies effectively.

These findings suggest that the transfer of technology and knowledge is essential to promote productivity growth. However, the ability to adopt these new technologies is essential in determining the extent to which productivity growth can be achieved. Therefore, countries must focus on building their absorptive capacity to ensure that they can effectively adopt and adapt new technologies and practices in order to achieve sustainable productivity growth.

In addition, the estimated coefficient on the level of human capital in column (3) is negative and not statistically significant. The interaction with technology transfer, $TFPGAP_{ij,t-1}$, is also negative and significant at a significance level of 0.05. This suggests that higher levels of education may lead to negative externalities, such as lower innovation rates and slower technology transfer. It is worth noting that the data used in this study primarily focused on industries where higher skill levels were not crucial. Thus, investing in human capital may not necessarily result in increased productivity in such industries. For example, machines can perform tasks more efficiently than humans in industries such as wood, paper, and printing. Hence, firms may choose to substitute workers with machines to boost productivity. This study offers valuable insights into the connection between human capital and productivity. It indicates that while education and skill development are essential, they may not always lead to better outcomes.

Furthermore, international trade alone does not seem to impact productivity growth rates significantly. The findings show that the interaction of trade and technology transfer has a positive and statistically significant effect at a significance level of 0.01. This suggests that there are potential benefits to accelerating technology transfer through trade and the frontier, as it can lead to increased productivity growth rates. Thus, it is essential to incorporate technological advancements into international trade policies to promote economic growth and development. The evolution of a country's technology is dependent on its initial stock of technology and the arrival of new ideas, which are randomly and exogenously distributed to potential firms. The quality of these new ideas is influenced by domestic components and random insights drawn from the productivity distribution among all producing firms. Therefore, international trade can play a significant role in creating and diffusing technology and ideas, ultimately linking to productivity. This highlights the importance of considering technology transfer as an essential element of international trade policies.

The results of the second dataset of OECD countries, as shown in Table 3.9, suggest that technology transfer, absorptive capacity, and R&D have influenced the TFP growth. This finding is consistent with the results of the first dataset of fourteen developed and developing countries, as shown in Tables 3.4 and 3.5. However, there is a difference in the estimated coefficient signs and results for the human capital variables between the two datasets. Despite the fact that these two datasets use different groups of sample countries, with one having a group of advanced and emerging economies and the other having a group of OECD countries, the analysis of both datasets highlights the importance of technology transfer, absorptive capacity, and international trade in promoting productivity growth.

TABLE 3.10: Impact of R&D, human capital, and trade in TFP growth:
food products, beverages and tobacco

$\Delta TFP_{ij,t}$		(1)	(2)	(3)
$TFPGAP_{ij,t-1}$	θ_1	0.2717* (0.1074)	0.2184 (0.1064)	0.3567** (0.1277)
$(R/Y)_{ij,t-1}$	η_1	-0.0144** (0.0039)	-0.0113* (0.0041)	-0.0244* (0.0091)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0332 (0.0384)	0.0379 (0.0386)	0.1162* (0.0434)
$H_{ij,t-1}$	η_2	0.0463 (0.0317)	0.0468 (0.0278)	0.2005** (0.0466)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.1187 (0.0616)	-0.0537 (0.0529)	0.0443 (0.0855)
$IMP_{ij,t-1}$	η_3	0.0086 (0.0129)	0.0043 (0.0136)	0.0213 (0.0318)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4	-0.0017 (0.0294)	0.0100 (0.0315)	0.0002 (0.0287)
Controls		Yes	Yes	Yes
Hours adjustment			Yes	Yes
Time FE				Yes
Country FE		Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, Japan, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

It is important to highlight that the dissimilarities in the characteristics and magnitude of the data utilized in the two datasets may have impacted the conclusions drawn from the analysis. Consequently, the findings suggest that while the dissemination of technology, the skill for assimilating information, and worldwide trade all play a crucial role in improving productivity, the impact of human capital on TFP expansion may vary depending on both the specific industry and the broader contextual factors.

This study highlights the importance of technology transfer, absorptive capacity, and international trade in boosting productivity growth, as evidenced by the two datasets examined. However, further research is necessary to understand the impact of these factors on TFP growth across various industries and contexts. The study also features a detailed analysis of each industry in Table 3.6.[8] For example, Table 3.10 provides econometric analysis for food products, beverages, and tobacco, followed by Equation 3.11. Interestingly, the results suggest a negative correlation between R&D intensity and TFP growth in this industry, which is similar to the all industries datasets but statistically significant. The analysis also underscores the importance of technology transfer, R&D intensity, absorptive capacity, and human capital in this industry. However, unlike all industry data, international trade does not appear to play a significant role in this industry's dataset.

3.4.3 Diagnostic tests

Diagnostic tests are commonly used to determine whether a regression model has been properly specified by testing for a non-zero mean of the error term associated with the included regressors. This is particularly important in the analysis of panel data. In this study, the first test conducted was for time fixed effects. Entities have individual characteristics that may or may not influence the TFP growth rate. Therefore, it is important to ensure that the predictors are not influenced by these fixed characteristics.

Table 3.11: Time-fixed effect diagnostic test

· testparm i.year		
(1)	1993.year = 0	
(2)	1994.year = 0	
(3)	1995.year = 0	
.	.	
.	.	
.	.	
(25)	2017.year = 0	
(26)	2018.year = 0	
(27)	2019.year = 0	
	F(27, 29)	= 47.63
	Prob > F	= 47.63

Source: Author's calculation

When testing for entity fixed effects, it is assumed that there is a correlation between the error term and predictor variables, but an entity's fixed effects cannot be correlated with another entity's. To determine if time-fixed effects are required, this study tested the null hypothesis that the coefficients for the years are jointly equal to zero. Based on

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[8] See Appendix 3.7.4 that contains additional econometric analysis for each industry.

the tests presented in Table 3.11, this study has determined that time-fixed effects are essential since the null hypothesis is rejected.

Furthermore, this particular study has also conducted a comprehensive examination to determine whether random effects are required. The results of the statistical tests show that it has been determined that there is no significant difference in the variances across various entities. This finding leads to the conclusion that the presence of random effects is not necessary. In other words, the data does not suggest any significant variation between the entities, so there is no requirement to account for random effects in the analysis.

Table 3.12: B-P or LM test

Correlation matrix of residuals: [OMITTED]
Breusch-Pagan LM test of independence: chi2(435) = 995.884, Pr = 0.0000
Based on 23 complete observations over panel units

Source: Author's calculation

The study conducted an analysis of the correlation between panels, applying the approach of Baltagi (2008, p.412). This approach considers cross-sectional dependence a common issue in macro panels with long time series. The method used to test the hypothesis of independence, known as the B-P or LM test, assumes that residuals across entities are not correlated. The results of the study are presented in Table 3.12, which shows that the null hypothesis was rejected, indicating that the panel is indeed cross-sectionally dependent. Therefore, the study concludes that cross-sectional dependence should be taken into account for heteroskedasticity across countries and industries.

Table 3.13: Pesaran CD test

Pesaran's test of cross sectional independence = -2.975, Pr = 0.0029
Average absolute value of the off-diagonal elements = 0.222

Source: Author's calculation

To further investigate the correlation of residuals across entities, the study employed the Pesaran (2015) cross-sectional dependence (CD) test.[9] The null hypothesis presumes that the residuals are not correlated. The results in Table 3.13 show that the null hypothesis is rejected and indicating that the residuals are correlated. The correlation of residuals across entities can occur due to various reasons, such as omitted variables or measurement errors. The study's conclusion that the panel is correlated highlights the need to account for this correlation in the analysis to ensure accurate and unbiased estimates.

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[9] The Pesaran CD test is a statistical method used to check if errors in a panel data model are weakly cross-sectionally dependent. The test on the null hypothesis depends on the expansion rates of N and T. For large N panels, a null hypothesis of weak dependence is more suitable than independence. The CD test is valid for a range of alpha values, and it works for all N and T combinations, regardless of whether the panel includes lagged values of the dependent variables.

Table 3.14: Testing for heteroskedasticity

Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model
H0: sigma(i)2 = sigma2 for all i
$chi2(30) = 236.89$
$Prob > chi2 = 0.0000$

Source: Author's calculation

In addition to analysing the data, the study also tested heteroskedasticity. This refers to the assumption that the variance of the residuals, which are the differences between the actual values and the predicted values, is constant across all entities. The null hypothesis of the test was that the variance of the error term was homoskedastic or constant. However, the test result, as indicated in Table 3.14, rejected the null hypothesis, suggesting the presence of heteroskedasticity. This means that the variance of the residuals is not constant across all entities and implies that certain factors may affect the variance of the residuals. Identifying and considering these factors when interpreting the results is important to ensure reliable and accurate results. Therefore, this study analysis includes heteroskedasticity and cross-sectional dependence while calculating the standard errors in the estimation results in the previous section. This means that the potential impact of varying levels of variability and correlation across observations has been appropriately addressed in the statistical analysis.

3.5 Conclusions

The study has shed light on the crucial role of research and development (R&D) and technology transfer in driving economic growth across fourteen countries and a sample group of OECD countries. It has provided practical evidence that changes in R&D directly and indirectly impact manufacturing industries' overall productivity growth rates. The findings suggest that R&D is a necessary driver of productivity growth as it nurtures innovation and facilitates technology transfer, particularly in countries that need to catch up on technological advancements.

The study has further shown that innovation and technology transfer have a profound effect on productivity growth rates, as measured by $TFPGAP_{ij,t-1}$. However, the absorptive capacity of the aggregate manufacturing dataset curbs productivity growth rates for non-frontier countries. This implies that the ability of a country to absorb and implement new technology can limit its productivity growth rate. While the study primarily focused on the manufacturing industry, the implications of absorptive capacity on productivity growth rates may vary for other industries. Future studies may explore this area in greater depth to better understand the impact of R&D and technology transfer on different industries and countries.

According to this study, international trade and human capital are two important factors that significantly increase productivity rates. The study found that when a country engages in international trade, it can directly influence its overall productivity levels. International trade can deliver access to new markets, technologies, and resources, which can help firms improve the quality of domestic goods and services. It is beneficial for a country to import goods from advanced countries with better technologies, as this can create and distribute innovative ideas. The sharing of knowledge and expertise between countries can result in developing new products and processes that enhance productivity. Moreover, importing from advanced countries can help determine the sources from which producers derive their insights, leading to market expansion and increased competition.

While human capital also plays a role in boosting productivity, its effect is less significant than that of international trade. Human capital is a term used to describe the intangible assets that a country's workforce possesses. These assets include the knowledge, skills, abilities, and experience of the people who assemble the workforce. A country's human capital is an important factor in its economic growth and development, contributing to its productivity, innovation, and competitiveness. It is important to note that these findings were based on an analysis of the aggregate manufacturing dataset, which includes various industries and workforces.

These findings highlight the need to focus on technological transfer, innovation, and international trade as key drivers of economic growth. Countries can promote innovation and drive economic growth by prioritizing R&D and facilitating technology transfer. This, in turn, can help ensure a prosperous future for all. Therefore, policymakers and business leaders must invest in technology transfer and innovation to boost international trade and eventually drive economic growth.

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3.7 Appendix

3.7.1 Data sources and Computation

The dataset this study is working with consists of two distinct sets of data. The first set covers a period from 1990 to 2019 and includes data from fourteen countries, including Canada, Germany, France, the United Kingdom, Italy, Japan, the United States, Brazil, the People's Republic of China, India, the Republic of Korea, Singapore, Türkiye, and South Africa, These countries are split evenly between seven advanced economies and seven developing economies. The second set of data is particularly interesting as it covers the same period as the first set, but it includes information from nine OECD countries. These countries are Canada, France, Germany, Italy, Japan, the Republic of Korea, Türkiye, the United Kingdom, and the United States. This information could be beneficial in analysing trends and patterns across different countries and industries. The study aimed to ensure the outcomes' accuracy and reliability by thoroughly testing samples from different countries and industries. This particular approach towards testing alternative samples helped to gain precise and reliable results. After clearing any missing values, the first dataset contains 420 observations, while the second set has 825 observations across various countries and industries. This study has used various data sources to compile this information as follows.

OECD Statistics: Data on real value added, real capital stock, employment, and real gross output.

OECD Analytical Business Enterprise Research and Development (ANBERD): Data on business enterprise expenditure on research and development includes all sources of funding (industry, business, domestic, and overseas).

Penn World Table (PWT 10.0): Data on human capital, annual hours worked, number of population, capital stock, TFP levels, real gross output, and share of labour.

Structural Analysis (STAN) Database: Data on value added, capital stock, employment, hours worked, and their deflators.

Indicators for Structural Analysis (iSTAN) Database: Data on labour share of value added, hours worked share, and average hours worked.

STAN Bilateral Trade Database by Industry and End-use category (BTDIxE): Data on the value of each country's bilateral imports from all other countries.

World Bank Databases: Data on real value added, real capital stock, employment, average annual hours worked, and number of persons engaged.

3.7.2 List of Countries and Industries

The list of countries abbreviation is as following table:

Abbreviation	Country	Abbreviation	Country
CAN	Canada	BRA	Brazil
DEU	Germany	CHN	the People's Republic of China
FRA	France	IND	India
GBR	United Kingdom	KOR	the Republic of Korea
ITA	Italy	SGP	Singapore
JAP	Japan	TUR	Türkiye
USA	United States	ZAF	South Africa

TABLE 3.15: Country abbreviations

The list of industries abbreviation is as following table:

No	Abbreviation	Industry
1	MAN	Manufacturing
2	FBT	Food products, beverages and tobacco
3	TWL	Textiles, wearing apparel, leather and related products
4	WPP	Wood and paper products, and printing
5	CHR	Chemical, rubber, plastics, fuel products and other non-metallic mineral products
6	MFM	Basic metals and fabricated metal products, except machinery and equipment
7	MAE	Machinery and equipment
8	FUR	Furniture, repair and installation of machinery and equipment, and other manufacturing

TABLE 3.16: Industry abbreviations

3.7.3 Variable and parameters descriptions

The model consists of 26 variables and parameters described in the following table.

No	Symbolic object	Description
1	$A_{ij,t}$	An index that measures technical efficiency or Total Factor Productivity (TFP) for each country i, industry j at time t
2	$K_{ij,t}$	Physical capital stock for each country i, industry j at time t
3	$N_{ij,t}$	Labour input for each country i, industry j at time t
4	$Y_{ij,t}$	The value added for each country i, industry j at time t
5	$R_{ij,t}$	The real R&D expenditure for each country i, industry j at time t
6	$S_{ij,t}$	The stock of R&D knowledge for each country i, industry j at time t
7	$u_{ij,t}$	The error term for each country i, industry j at time t
8	$\Delta A_{ij,t}$	The growth rate of TFP for each country i, industry j at time t
9	$\bar{K}_{ij,t}$	The geometric mean of the real capital stock for each country i, industry j at time t
10	$\bar{N}_{ij,t}$	The geometric mean of the number of workers employed for each country i, industry j at time t
11	$\bar{Y}_{ij,t}$	The geometric mean of value-added for each country i, industry j at time t
12	$MTFP_{ij,t}$	The level of TFP in each country i relative to the geometric mean in each industry j at time t
13	$TFPGAP_{ij,t}$	The TFP gap or the distance from the frontier of a non-frontier country
14	γ	The elasticity of value added with respect to the R&D knowledge stock
15	δ	The elasticity of value added with respect to the residual set of influences
16	η_1	The rate of return of R&D knowledge stock or marginal product of R&D or the rate of R&D intensity
17	η_2	The rate of return of human capital
18	η_3	The rate of return of international trade
19	θ_1	The rate of technology transfer
20	θ_2	A coefficient of the interaction term between the TFP gap and R&D or the potential for technology transfer from frontier to non-frontier country via R&D channel
21	θ_3	A coefficient of the interaction term between the TFP gap and human capital
22	θ_4	A coefficient of the interaction term between the TFP gap and international trade
23	τ	The rate of depreciation of the stock of R&D knowledge
24	$\mu_{ij,t}$	The share of labour in value-added for each country i, industry j at time t
25	$\tilde{\mu}_{ij,t}$	The average of the share of labour for each country i, industry j at time t
26	$\tilde{\rho}_{ij,t}$	The average of the share of labour and its geometric mean for each country i, industry j at time t

Table 3.17: Variable and parameters description

3.7.4 Additional results

This study utilizes panel data on the total manufacturing industries over time to investigate the marginal effects of each variable on rates of TFP growth. It takes into account unobserved heterogeneity in the sources of productivity growth and controls for fixed effects. This study has extended to include all industry data over time, 1990-2019, and analyses the impact of technology transfer on productivity growth, as shown in the following tables.

The dataset includes seven industries: food products, beverages, and tobacco; textiles, wearing apparel, leather, and related products; wood and paper products, including printing; chemical, rubber, plastics, fuel products, and other non-metallic mineral products; basic metals and fabricated metal products, except machinery and equipment; machinery and equipment; and furniture, other manufacturing, repair, and installation of machinery and equipment.

The data used in these additional results come from several sources. The main and major one is the Structural Analysis (STAN) database, which provides information at an annual-industry level for most variables, such as value-added, capital stock, and bilateral trade datasets.

Table 3.18: Impact of R&D in TFP growth: all industries

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.0686** (0.0272)	0.1317*** (0.0237)	0.1407*** (0.0260)	0.1302*** (0.0250)
$(R/Y)_{ij,t-1}$	η_1		-0.1709*** (0.0349)	0.0486 (0.1227)	0.0484 (0.1125)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			-0.1092* (0.0657)	-0.1036* (0.0667)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country-Industry FE		Yes	Yes	Yes	Yes

Sample countries 825 observations of Canada, France, Germany, Italy, Japan, the Republic of Korea, United Kingdom, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.19: Impact of R&D, human capital, and trade in TFP growth: all industries

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.2071*** (0.0362)	0.1787*** (0.0408)	0.1527*** (0.0368)	0.1797*** (0.0390)
$(R/Y)_{ij,t-1}$	η_1	-0.0024 (0.1084)	-0.0677 (0.1809)	-0.0818 (0.1833)	-0.0171 (0.1224)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	-0.1777** (0.0665)	-0.5061*** (0.0865)	-0.5198*** (0.0812)	-0.3041*** (0.0934)
$H_{ij,t-1}$	η_2	-0.0360 (0.0409)	0.0592*** (0.0176)	0.0676*** (0.0194)	-0.0380 (0.0401)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.1084** (0.0450)	-0.1259** (0.0516)	-0.1043** (0.0490)	-0.1079** (0.0425)
$IMP_{ij,t-1}$	η_3		-0.2556* (0.1480)	-0.2946* (0.1613)	-0.1656 (0.0117)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.6255*** (0.1713)	0.6818*** (0.1639)	0.2856* (0.015)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country-Industry FE		Yes	Yes	Yes	Yes

Sample countries 825 observations of Canada, France, Germany, Italy, Japan, the Republic of Korea, United Kingdom, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Additional to the impact of technology transfer on productivity growth for each industry, there are the empirical results of those impact for each industry as follow.

Food products, beverages and tobacco

There are 150 observations of four countries including Canada, Germany, Italy, Japan, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the food products, beverages and tobacco products as follows.

Table 3.20: Impact of R&D in TFP growth: food products, beverages and tobacco

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.4033*** (0.0399)	0.4096*** (0.0461)	0.3471*** (0.0412)	0.3995*** (0.0.0459)
$(R/Y)_{ij,t-1}$	η_1		-0.0137 (0.0190)	-0.0185 (0.0123)	-0.0077 (0.0.0104)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			0.0886 (0.0498)	0.0570 (0.0476)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, Japan, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.21: Impact of R&D, human capital, and trade in TFP growth: food products, beverages and tobacco

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.3807** (0.1018)	0.2717* (0.1074)	0.2184 (0.1064)	0.3567** (0.1277)
$(R/Y)_{ij,t-1}$	η_1	-0.0118 (0.0192)	-0.0144** (0.0039)	-0.0113* (0.0041)	-0.0244* (0.0091)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0728 (0.0729)	0.0332 (0.0384)	0.0379 (0.0386)	0.1162* (0.0434)
$H_{ij,t-1}$	η_2	0.1033 (0.0948)	0.0463 (0.0317)	0.0468 (0.0278)	0.2005** (0.0466)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	0.0348 (0.1017)	-0.1187 (0.0616)	-0.0537 (0.0529)	0.0443 (0.0855)
$IMP_{ij,t-1}$	η_3		0.0086 (0.0129)	0.0043 (0.0136)	0.0213 (0.0318)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		-0.0017 (0.0294)	0.0100 (0.0315)	0.0002 (0.0287)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, Japan, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Textiles, wearing apparel, leather and related products

There are 120 observations of four countries including Canada, Germany, Italy, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the textiles, wearing apparel, leather and related products as follows.

Table 3.22: Impact of R&D in TFP growth: textiles, wearing apparel, leather and related products

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.1451 (0.0661)	0.1456 (0.0705)	0.0621 (0.0994)	0.0580 (0.0789)
$(R/Y)_{ij,t-1}$	η_1		-0.0076 (0.0054)	-0.0109* (0.0040)	-0.0107** (0.0029)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			0.0612 (0.0333)	0.0490* (0.0204)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.23: Impact of R&D, human capital, and trade in TFP growth:
textiles, wearing apparel, leather and related products

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.1399 (0.3254)	-0.0238 (0.3170)	-0.0995 (0.2659)	0.1561 (0.3737)
$(R/Y)_{ij,t-1}$	η_1	-0.0069 (0.0099)	-0.0178 (0.0094)	-0.0245* (0.0088)	-0.0017 (0.0229)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0337 (0.0391)	0.0834 (0.0605)	0.0979* (0.0354)	0.0159 (0.0814)
$H_{ij,t-1}$	η_2	-0.0099 (0.2427)	0.0273 (0.1399)	0.0147 (0.1571)	-0.0370 (0.2474)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.1008 (0.3684)	-0.2211 (0.4723)	-0.1886 (0.4914)	-0.1574 (0.4741)
$IMP_{ij,t-1}$	η_3		-0.0028 (0.0119)	-0.0007 (0.0084)	-0.0127 (0.0295)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.0264 (0.0130)	0.0344 (0.0233)	0.0055 (0.0321)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Wood and paper products, and printing

There are 120 observations of four countries including Canada, Germany, Italy, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the wood and paper products, and printing industries as follow.

Table 3.24: Impact of R&D in TFP growth:
wood and paper products, and printing

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.1976** (0.0523)	0.1941* (0.0525)	0.1839*** (0.0239)	0.1267*** (0.0203)
$(R/Y)_{ij,t-1}$	η_1		0.0272 (0.0181)	0.0253 (0.0228)	0.0189 (0.0196)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			0.0115 (0.0948)	0.0332 (0.0785)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.25: Impact of R&D, human capital, and trade in TFP growth:
wood and paper products, and printing

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.0567 (0.2007)	0.0192 (0.1955)	0.0658 (0.1850)	0.0875 (0.1955)
$(R/Y)_{ij,t-1}$	η_1	0.0064 (0.0155)	0.0385** (0.0066)	0.0313*** (0.0048)	0.0184 (0.0262)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0678 (0.0642)	-0.0174 (0.0879)	-0.0118 (0.0754)	0.0155 (0.1018)
$H_{ij,t-1}$	η_2	-0.1822 (0.2702)	0.0538 (0.0476)	0.0636 (0.0349)	-0.1421 (0.2521)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	0.1241 (0.2491)	0.0312 (0.2729)	-0.0408 (0.2641)	-0.2093 (0.2307)
$IMP_{ij,t-1}$	η_3		-0.0064 (0.0047)	-0.0038 (0.0058)	-0.0157 (0.0225)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.0242 (0.0215)	0.0187 (0.0146)	0.0312 (0.0174)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Chemical, rubber, plastics, fuel products and other non-metallic mineral products

There are 120 observations of four countries including Canada, Germany, Italy, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the chemical, rubber, plastics, fuel products and other non-metallic mineral products as follows.

Table 3.26: Impact of R&D in TFP growth:
chemical, rubber, plastics, fuel products and other non-metallic mineral products

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.1481 (0.0829)	0.2097 (0.1054)	0.2462 (0.1795)	0.2467 (0.1823)
$(R/Y)_{ij,t-1}$	η_1		-0.0086 (0.0043)	-0.0076 (0.0039)	-0.0069 (0.0040)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			-0.0048 (0.0131)	-0.0053 (0.0122)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.27: Impact of R&D, human capital, and trade in TFP growth: chemical, rubber, plastics, fuel products and other non-metallic mineral products

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.4975** (0.1154)	-0.2738 (0.5054)	-0.2971 (0.4614)	0.1397 (0.2623)
$(R/Y)_{ij,t-1}$	η_1	-0.0031 (0.0057)	-0.0115 (0.0052)	-0.0117 (0.0052)	-0.0042 (0.0048)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	-0.0196 (0.0136)	0.0132 (0.0212)	0.0140 (0.0187)	-0.0205 (0.0099)
$H_{ij,t-1}$	η_2	-0.1983 (0.1447)	0.0037 (0.0634)	0.0214 (0.0663)	-0.1480 (0.1444)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.2282 (0.1093)	-0.0580 (0.1893)	0.0459 (0.2034)	-0.1753 (0.1723)
$IMP_{ij,t-1}$	η_3		0.0001 (0.0042)	0.0003 (0.0044)	0.0060 (0.0039)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.0169 (0.0110)	0.0183 (0.0095)	0.0160 (0.0089)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 120 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Basic metals and fabricated metal products

There are 150 observations of five countries including Canada, Germany, Italy, Japan, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the basic metals and fabricated metal products, except machinery and equipment, as follows.

Table 3.28: Impact of R&D in TFP growth: basic metals and fabricated metal products

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.3384*** (0.0391)	0.3374*** (0.0405)	0.2367*** (0.0410)	0.2464*** (0.0460)
$(R/Y)_{ij,t-1}$	η_1		-0.0061 (0.0132)	-0.0206** (0.0070)	-0.0213** (0.0075)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			0.0742** (0.0212)	0.0621* (0.0252)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, Japan, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.29: Impact of R&D, human capital, and trade in TFP growth: basic metals and fabricated metal products

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.0.1773 (0.1761)	-0.1868 (0.1986)	-0.0356 (0.1660)	0.1636 (0.1678)
$(R/Y)_{ij,t-1}$	η_1	-0.0259** (0.0071)	-0.0155 (0.0207)	-0.0141 (0.0182)	-0.0232* (0.0085)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0835 (0.0492)	0.1629** (0.0534)	0.1332** (0.0440)	0.0901 (0.0524)
$H_{ij,t-1}$	η_2	0.0284 (0.0543)	-0.0576 (0.0322)	-0.0439** (0.0122)	0.0228 (0.0546)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	0.0769 (0.2221)	0.3387 (0.2173)	0.1954 (0.1279)	0.1051 (0.2163)
$IMP_{ij,t-1}$	η_3		-0.0130** (0.0046)	-0.0133** (0.0048)	-0.0066 (0.0057)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.0114 (0.0110)	0.0064 (0.0123)	0.0015 (0.0073)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Machinery and equipment

There are 150 observations of five countries including Canada, Germany, Italy, Japan, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the machinery and equipment industries, as follows.

Table 3.30: Impact of R&D in TFP growth: machinery and equipment

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.0256*** (0.0042)	0.1226* (0.0537)	0.1755** (0.0621)	0.1655** (0.0562)
$(R/Y)_{ij,t-1}$	η_1		-0.1641* (0.0685)	0.0310 (0.0753)	0.0144 (0.0751)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			-0.1657** (0.0541)	-0.1451** (0.0510)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, Japan, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.31: Impact of R&D, human capital, and trade in TFP growth: machinery and equipment

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.2732*** (0.0237)	0.3532** (0.1124)	0.2967* (0.1347)	0.3442*** (0.0649)
$(R/Y)_{ij,t-1}$	η_1	-0.0417 (0.0452)	0.0741 (0.2143)	0.0639 (0.2154)	-0.0524 (0.0314)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	-0956** (0.0274)	-0.1202 (0.1264)	-0.0986 (0.1262)	-0.0831** (0.0284)
$H_{ij,t-1}$	η_2	-0.0075 (0.0590)	0.0824** (0.0293)	0.0880* (0.0367)	-0.0463 (0.0776)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	-0.2724*** (0.0465)	-0.3204** (0.0888)	-0.2739** (0.0816)	-0.2574*** (0.0359)
$IMP_{ij,t-1}$	η_3		0.3074 (0.2188)	0.2832 (0.3010)	0.3741 (0.2430)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		-0.3179 (0.2878)	-0.2612 (0.3494)	-0.2845 (0.1931)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 150 observations of Canada, Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Furniture, repair and installation of machinery and equipment, and other manufacturing

There are 90 observations of three countries including Germany, Italy, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the furniture, other manufacturing, repair and installation of machinery and equipment industries as follows.

TABLE 3.32: Impact of R&D in TFP growth:
furniture, other manufacturing, repair and installation of machinery and equipment

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.1009 (0.0347)	0.1152(0.0538)	0.1202 (0.0524)	0.1107 (0.0531)
$(R/Y)_{ij,t-1}$	η_1		0.0022 (0.0037)	0.0021 (0.0041)	0.0021 (0.0042)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			-0.0025 (0.0174)	-0.0044 (0.0108)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 90 observations of Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

TABLE 3.33: Impact of R&D, human capital, and trade in TFP growth:
furniture, other manufacturing, repair and installation of machinery and equipment

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.1615** (0.0344)	-0.4102 (0.3201)	-0.4793* (0.2904)	0.0230 (0.5202)
$(R/Y)_{ij,t-1}$	η_1	0.0042 (0.0045)	-0.0055* (0.0032)	-0.0046* (0.0027)	0.0063 (0.0046)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	-0.0057 (0.0097)	0.0101 (0.0115)	-0.0052 (0.0038)	-0.0131 (0.0365)
$H_{ij,t-1}$	η_2	-0.0483 (0.1760)	-0.0090 (0.0375)	-0.0543 (0.0724)	-0.0624 (0.1221)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	0.0002 (0.0109)	0.1837 (0.1256)	0.1865 (0.1746)	0.0311 (0.1095)
$IMP_{ij,t-1}$	η_3		0.0222** (0.0087)	-0.0018 (0.0222)	-0.0132 (0.0159)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		0.1710 (0.1436)	0.2390* (0.1246)	0.0869 (0.3189)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 90 observations of Germany, Italy, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Aggregate Manufacturing

There are 180 observations of six countries including Canada, Germany, Italy, Japan, Republic of Korea, and United States from 1990-2019 to analyse the impact of technology transfer on productivity growth in the aggregate dataset of manufacturing as follows.

Table 3.34: Impact of R&D in TFP growth: aggregate manufacturing

$\Delta TFP_{ij,t}$		(1)	(2)	(3)	(4)
$TFPGAP_{ij,t-1}$	θ_1	0.1146*** (0.0249)	0.1641* (0.0718)	0.0962 (0.0692)	0.0851 (0.0668)
$(R/Y)_{ij,t-1}$	η_1		0.0611 (0.0511)	-0.0608 (0.0664)	-0.0756 (0.0647)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2			0.0143** (0.0049)	0.0154** (0.0052)
Controls			Yes	Yes	Yes
Hours adjustment					Yes
Time FE		Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 180 observations of Canada, Germany, Italy, Japan, Republic of Korea, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; * denotes significance at 0.10 level ($p < 0.10$), ** denotes significance at 0.05 level ($p < 0.05$), *** denotes significance at 0.01 level ($p < 0.01$).

Table 3.35: Impact of R&D, human capital, and trade in TFP growth: aggregate manufacturing

$\Delta TFP_{ij,t}$		(5)	(6)	(7)	(8)
$TFPGAP_{ij,t-1}$	θ_1	0.0301 (0.1375)	0.6945 (0.5594)	0.8077 (0.5808)	1.2389 (0.6617)
$(R/Y)_{ij,t-1}$	η_1	-0.0395 (0.0752)	0.0673 (0.0924)	0.0669 (0.0868)	-0.0696 (0.0702)
$(TFPGAP \times R/Y)_{ij,t-1}$	θ_2	0.0146* (0.0057)	0.0074 (0.0070)	0.0080 (0.0072)	0.0205*** (0.0050)
$H_{ij,t-1}$	η_2	-0.0390 (0.0863)	-0.0226 (0.0200)	-0.0219 (0.0233)	0.0433 (0.0889)
$(TFPGAP \times H)_{ij,t-1}$	θ_3	0.0787 (0.0917)	-0.0038 (0.0915)	-0.0302 (0.1027)	-0.1098 (0.1349)
$IMP_{ij,t-1}$	η_3		-0.0241 (0.0185)	-0.0251 (0.0231)	0.0860 (0.0484)
$(TFPGAP \times IMP)_{ij,t-1}$	θ_4		-0.0490 (0.0419)	-0.0564 (0.0445)	-0.0917 (0.0498)
Controls		Yes	Yes	Yes	Yes
Hours adjustment		Yes		Yes	Yes
Time FE		Yes			Yes
Country FE		Yes	Yes	Yes	Yes

Sample countries 180 observations of Canada, Germany, Italy, Japan, Republic of Korea, and United States from 1990-2019; sample is annual dataset; all regressions include full set of time dummies and full set of country-industry interactions (within-group estimators); robust standard errors are in parentheses; ΔTFP is the TFP growth; $TFPGAP$ is the relative level of TFP; R/Y is the R&D intensity; H is human capital; IMP is imports from high-income economies; * denotes significance at 0.10 level ($\rho < 0.10$), ** denotes significance at 0.05 level ($\rho < 0.05$), *** denotes significance at 0.01 level ($\rho < 0.01$).

3.7.5 Plots from raw data

The relative TFP for each manufacturing industry that graphs the exponent of the TFP gap's negative is as follows.

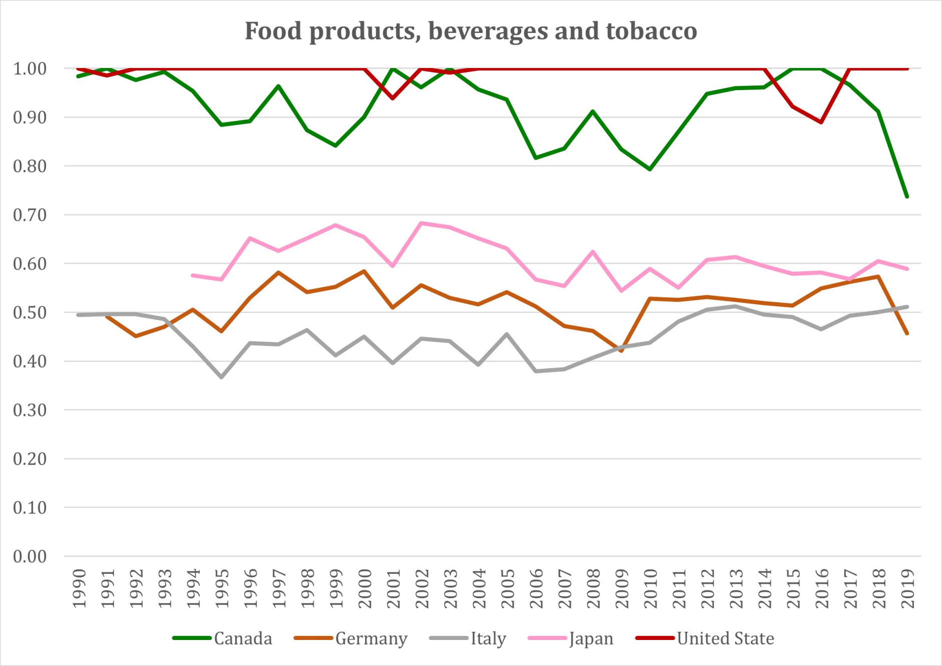

FIGURE 3.5: Relative TFP of sample countries on food products, beverages and tobacco industries between 1990 and 2019.

Source: Author's calculation

FIGURE 3.6: Relative TFP of sample countries on textiles, wearing apparel, leather and related products between 1990 and 2019.

Source: Author's calculation

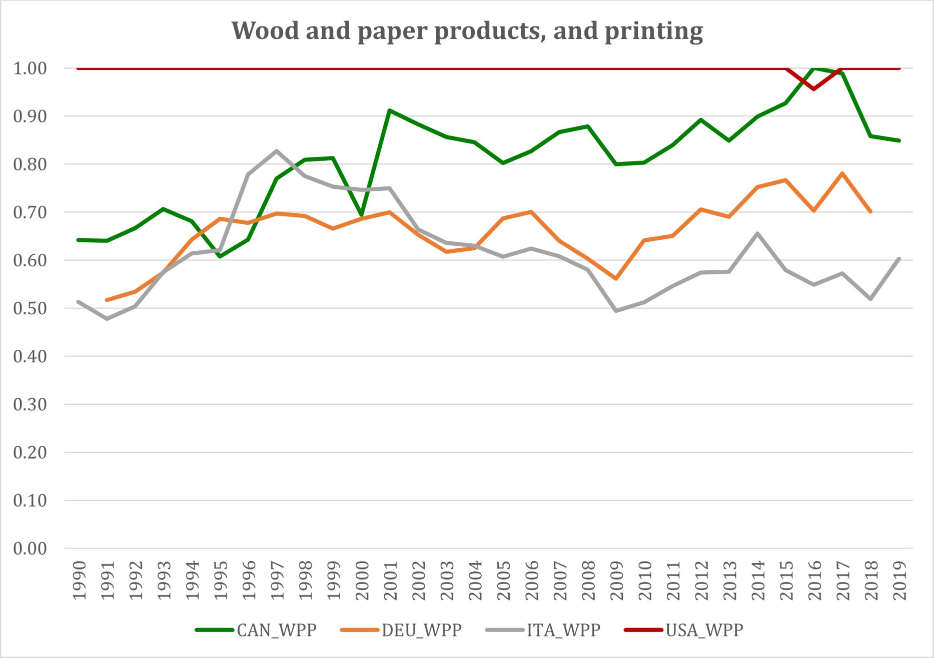

Figure 3.7: Relative TFP of sample countries on wood and paper products, and printing industries between 1990 and 2019.

Source: Author's calculation

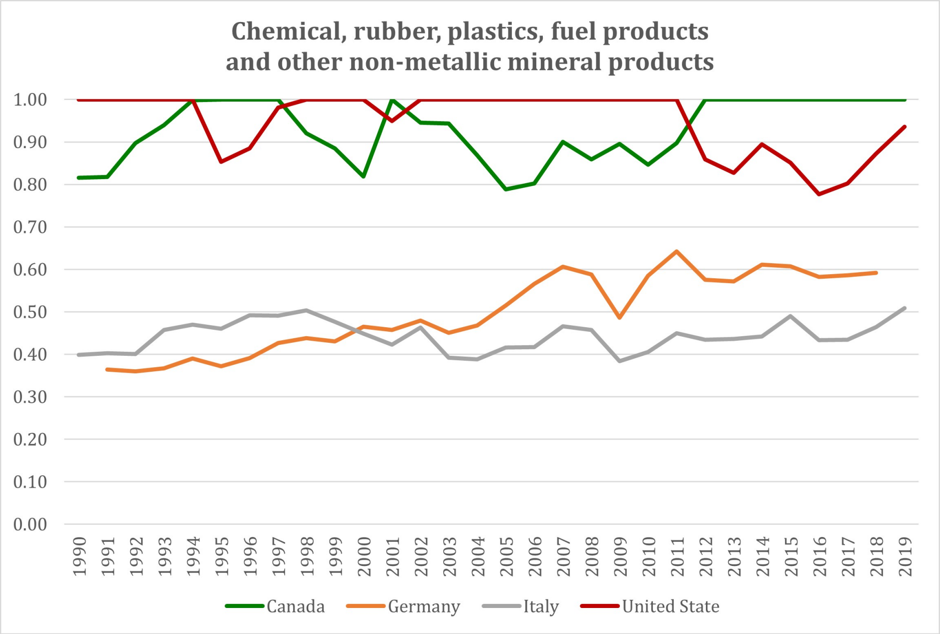

Figure 3.8: Relative TFP of sample countries on chemical, rubber, plastics, fuel products and other non-metallic mineral products industries between 1990 and 2019.

Source: Author's calculation

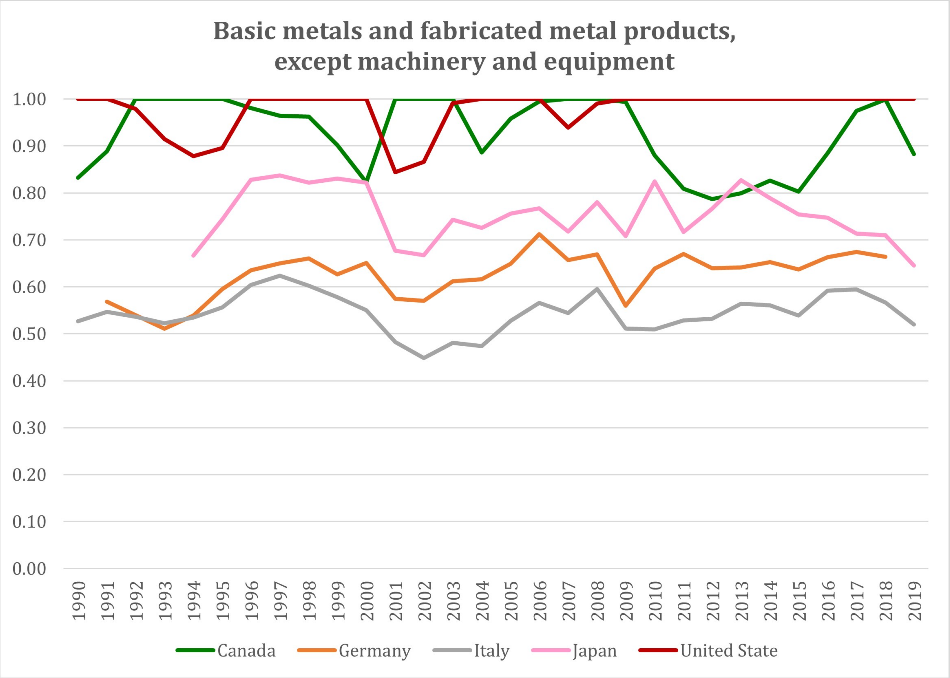

FIGURE 3.9: Relative TFP of sample countries on basic metals and fabricated metal products, except machinery and equipment industries between 1990 and 2019.

Source: Author's calculation

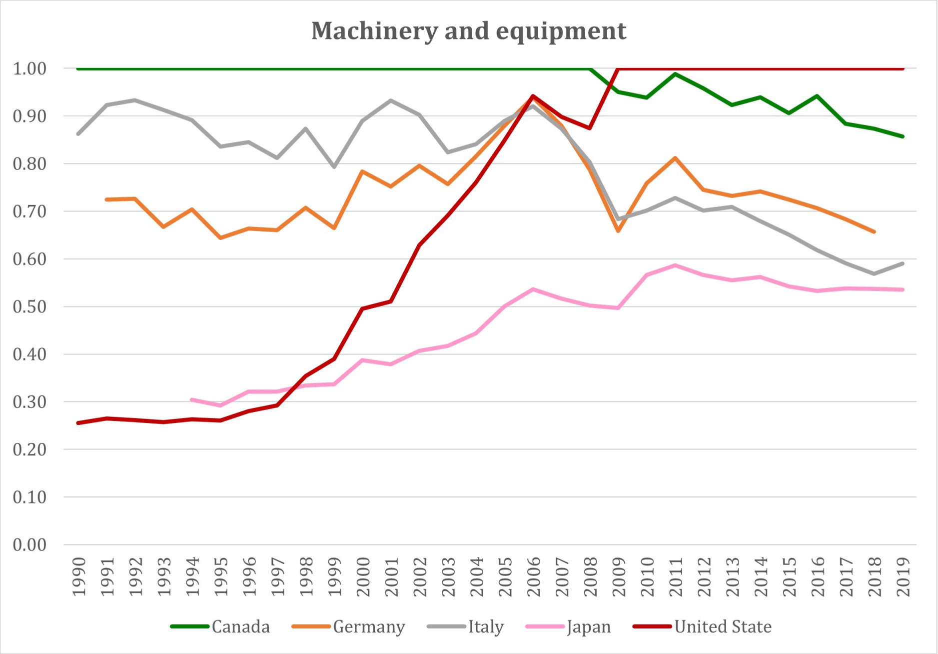

FIGURE 3.10: Relative TFP of sample countries on machinery and equipment industries between 1990 and 2019.

Source: Author's calculation

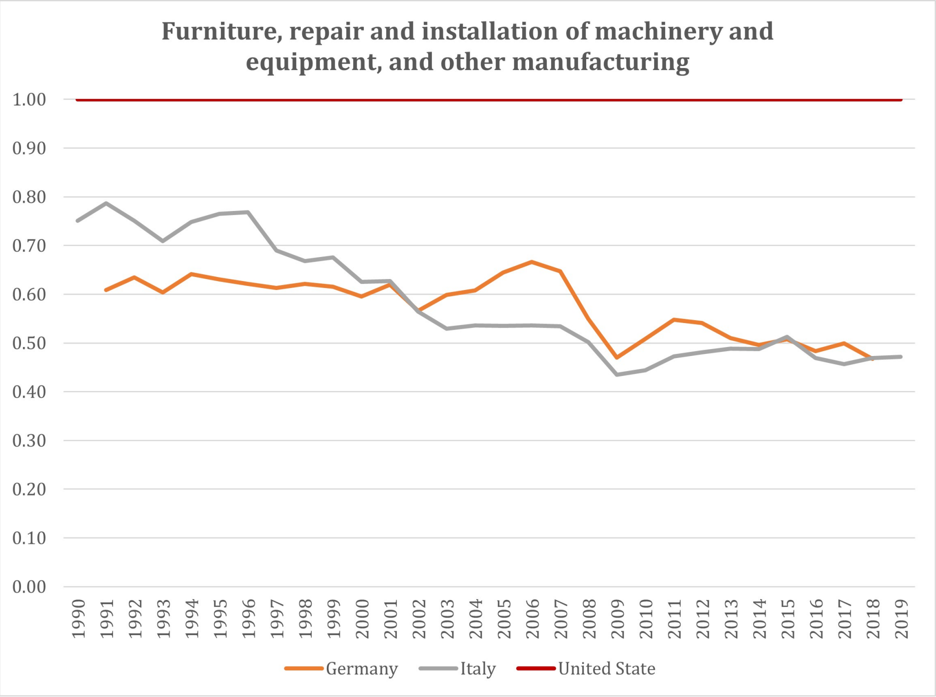

Figure 3.11: Relative TFP of sample countries on furniture, repair and installation of machinery and equipment, and other manufacturing industries between 1990 and 2019.

Source: Author's calculation