FISCAL POLICY AND OPTIMAL TAX IN A SMALL-OPEN ECONOMY

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Abstract

The thesis studies the effect of fiscal policy on a small-open economy by estimating the DSGE Model calibrated for Thailand. The considered fiscal policies are composed of an increase in government spending and a decrease in tax rates, namely, a sales tax, a payroll tax, and a capital income tax. The model foundation is adopted from The Bank of Thailand Structural Model which is introduced by Tanboon (2008). This thesis extends the model and introduces a rich fiscal block for analysis of the effect of fiscal policy. The important findings are that the impact of fiscal policy on a small-open economy is smaller than the one on a closed economy. An increase in government expenditures has a positive impact on the domestic firms' output, whereas exporting firms respond by lowering their production. The impact multiplier of government spending on the national output is 0.25 and the impact multipliers of sales tax, payroll tax, and capital tax are 0.08, 0.37 and 0.09, respectively.

The second paper studies the optimal capital income tax and optimal labour income tax in a small-open economy with an imperfectly competitive market and habit formation preferences. This paper uses numerical estimates and analytical investigation. The numerical approach

solves the Ramsey problem, by parameterizing to Thailand data. The numerical finding indicates that the optimal capital income tax appeared to be negative. The analytical investigation simplifies the models in order to explain factors that influence the numerical results. The analytical results highlight that i) the optimal capital income tax in a small-open economy with a perfectly competitive market is not different with optimal capital income tax in a closed economy and equals to zero, ii) the optimal capital income tax in small open-economy with an imperfectly competitive market is negative and negatively related to price markup, iii) the deep habit preferences create a volatile and countercyclical markup, hence, the capital income tax is not smooth over the horizon. It should be increased during an economic boom period and lower in recessions.

The third paper examines the impact of the government spending on health on the economic growth by analyzing the improvement in national health condition. The research questions are i) what is the effect of the government spending on health on the improvement in national health indicators, such as life expectancy, infant mortality, and under-five mortality, ii) does an improvement in human capital on health leads to an economic growth. Three panel estimations are implemented: fixed-effect model, random-effect model, and the mean group estimator. The main findings show that the government spending on health has a significantly positive effect on the health status. An increase in life expectancy has a positive effect on output in developing countries but does not have a significant effect on output in developed countries. In addition, non-medical determinants of health, such as tobacco consumption and alcohol consumption have a significant effect on economic growth of OECD countries.

Declaration

I, Youthapoom Charusreni, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis. The work in this thesis is based on research carried out at the Department of Economics and Finance, Durham Business School Department, Durham University, England. No part of this thesis has been submitted elsewhere for any other degree or qualification

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Part 1

INTRODUCTION

Fiscal policy is an important governmental tool for stabilizing and maintaining economic growth, especially during a economic crisis. During the global financial crisis in 2008, many countries introduced remarkable fiscal expansions in order to stimulate their economies. The fiscal stimulus packages' sizes are relatively large and unprecedented. For example, G20 countries launched $2 trillion (1.4 percent of global GDP) stimulus packages and China spent roughly 12.7 percent of its GDP for fiscal expansion policies (ILO 2011). Many smaller countries also launched fiscal expansion policies. For example, Thailand introduced a fiscal stimulus package worth of $10 billion to stimulate aggregate demand and raise employment. The effectiveness of fiscal expansion policy is extensively examined in the macroeconomic literature. The impacts of fiscal policy on closed economies have been examined in studies such as Fernández-Villaverde (2010), Eggertsson (2011) and Zubairy (2014). However, the estimation of a fiscal multiplier in closed economy models may be sufficiently different from the estimation of one in a small-open economy, because trading in the goods and services sector can be important, and trade can potentially impact the exchange rate's adjustment and interest rate's response to fiscal policies. Therefore, it is worthwhile to study the effectiveness of fiscal policy on an open economy.

This thesis is composed of three papers presented as Part II, Part III and Part IV correspondingly. The first paper studies the effect of fiscal policy on a small-open economy by estimating the DSGE Model, which is calibrated for Thailand. The first part's research questions are: i) "What are the effects of expansionary fiscal policy shocks, such as an increase in government spending or a decrease in sales tax, payroll tax, and capital tax shocks, on macroeconomic variables in a small-open economy?", ii) "How large is the fiscal multiplier in a small-open economy?", and iii) "What is the long-term effect of the fiscal policy?" In order to answer these questions, a medium-scale DSGE model for a small-open economy is constructed and calibrated to Thailand's parameters. Thailand is a small-open economy in South East Asia with large amounts of trade. In 2014, trade openness, measured as a sum of exports and imports, was 147 percent of GDP. Thailand's economy relies highly on the international trade of goods and services. The model's foundation is adopted from The Bank of Thailand's Structural Model (DSGE model), which is introduced by Tanboon (2008) and is used mostly for monetary policy analysis. The DSGE model includes a number of micro-founded frictions, such as habit-adjusted consumption, sticky wages, sticky prices and investment adjustment costs. This thesis extends the DSGE model and introduces a rich fiscal block for analyzing the effect of fiscal policy. The model simulates the impulse responses to an increase in government spending and a decrease in tax rates, namely the effects of the reduction in sales tax rates, payroll tax rates and a capital income tax rates on various macroeconomic variables, such as the output of domestic firms, the output of export firms, the households' consumption and the labour supply. Two measures of the fiscal multiplier are used: one measures the size of the immediate response to fiscal expansion, while another measures the long-term effect and is computed as the net present value of the effect over the net "N" periods. This allows the analyst to compute and compare the short- and long-term effects of the different types of fiscal expansions.

The most important finding is that an increase in government expenditures has a significantly positive impact on the domestic firms' output, whereas exporting firms respond by lowering their production. This is because the government consumes only domestically produced goods. An increase in demand for the domestic sector generates higher prices for inputs, such as wage and capital rent, which leads to higher costs for the export sector. Thus, the total effect of an increase in government spending is smaller in a small-open economy as compared to a closed economy model. Moreover, the reduction of the tax rate has a fairly positive stimulative effect on domestic output. However, depending on the tax base, it can have a positive or negative effect on exporting firms. For example, a reduction in the payroll tax rate stimulates an export firm's output, while, in contrast, a reduction of the capital tax rate worsens an export firm's output. This can probably be explained by the difference in the market structure of the domestic and exporting firms. It is assumed that the export sector is perfectly competitive, while the domestic firms price their goods with a positive mark-up.

This study finds that the impact multiplier of government spending on the national output is 0.25, and the impact multipliers of sales tax, payroll tax, and capital tax are 0.08, 0.37 and 0.09, respectively. The long-term impact of government spending is smaller than the long-term impact of the tax cut. Just after one year, the effect of reductions in any of the tax rates surpasses the effect of an increase in government expenditures. Lastly, lowering the payroll tax can be the most effective means in the long-term.

The next paper studies the optimal taxes, namely the optimal capital income tax and optimal labour income tax, in a small-open economy with an imperfectly competitive market and habit preferences. Early studies of optimal taxation consider a perfectly competitive market and suggest that the optimal capital income tax on it is appeared to be zero (Chamley 1981, Judd 1985, Chamley 1986, Lucas 1990, and Chari et al. 1991). However, Judd (1997) shows that, if an economy is imperfectly competitive, the optimal capital income tax is negative and a capital income subsidy should be used to offset monopolistic distortions. Consequently, when the price markup is constant over time, the optimal level of capital income subsidies does not change either. This result is called tax smoothing. The intention of this chapter is to check whether a tax smoothing policy is optimal in an economy with a time-varying markup. For this purpose, a model with a deep habit formation Ravn, Schmitt-Grohé & Uribe (2006) is investigated. Households with deep habits tend to smooth aggregate consumption over the time and gradually adjust their consumption to exogenous disturbances (Dynan 2000). This type of preference obviously changes the household's behaviour and makes the demand for particular goods more persistent and less responsive to price changes. Facing more persistent demand, firms reduce prices to increase the market share when the business environment is favorable. This results in a countercyclical markup; in fact, the price markup is negatively related to the output growth. When markup declines, the optimal capital income tax rate should increase. Therefore, the second paper also suggests that the capital income tax should be higher during an economic boom and lower during a recession in an economy with a countercyclical price markup. Moreover, when a price mark-up is volatile, tax smoothing is sub-optimal.

The second paper starts with numerical calculation of the optimal tax rate in a DSGE model. The numerical approach solves the Ramsey problem in order to calculate the optimal capital income and labour income tax rates. The procedure consists of maximizing the households' utility subject to the households' behaviour and firms' profit maximization constraints. The model is parameterized to Thailand's data.

Since the considered model has various frictions and includes monopolistic distortions, the optimal capital income tax appears to be negative, which is consistent with Judd (1997) 's results. However, it is necessary to understand the effect of each model's distortions on the final result. Therefore, a number of simplified models are considered, and analytical results are derived in order to explain factors that influence the optimal tax's simulation results. The simplifications include a zero investment adjustment cost and flexible wages and prices. The focusing factors are trade openness, an imperfectly competitive market and habit preferences. Three models are incorporated in the analytical result section, which are the closed economy model with an imperfectly competitive market, the closed economy model with an imperfectly competitive market and deep habit preferences, and the simple small-open economy model. The most interesting result comes from the model with deep habits, where the optimal capital tax is negatively related to a counter-cyclical price mark-up.

According to Ravn et al. (2006), deep habits preferences create a negative correlation between the price mark-up and economic growth. The price markup is lower in an economic boom, because firms have incentives to buy habits when aggregate demand is high. Therefore, firms reduce their prices below the level that maximizes the current profit in order to gain more market shares and generate higher profits in the future.

The second paper of this thesis contributes to the literature in the following way. First, this thesis extends the Judd (1997) results for the optimal capital income tax and calculates optimal tax rates in a small-open economy with an imperfectly competitive market and habit persistence, as in Tanboon (2008) 's model. The result indicates that governments should subsidize capital income taxes to offset gaps between the price and the marginal cost. Therefore, the capital income tax and the mark-up are negatively related. The finding is similar to the result of closed economy with an imperfectly competitive market studies of Guo, Lansing et al. (1995), Judd (1997) and Judd (2002). The labour income tax is set to maintain the implementability of the government budget.

Moreover, the analytical investigation highlights three important findings. First, the optimal capital income tax in a small-open economy with a perfectly competitive market is not different from the optimal capital income tax in closed economy, and it equals to zero as in Chamley (1981), Judd (1985), Chamley (1986), Lucas (1990) and Chari, Christiano & Kehoe (1991). Second, the optimal capital income tax in small-open economy with an imperfectly competitive market is negative and negatively related to price mark-up. This analytical result ensures the finding regarding optimal capital income tax in numerical calculation. Third, deep habit preferences create a volatile and counter-cyclical mark-up. Hence, capital income tax is not smooth and volatile over the horizon as a response to the price mark-up's adjustment. The optimal capital income tax rate should be increased during an economic boom period and lowered during recessions.

The third chapter examines the impact of the government spending on health on economic growth by analyzing improvement in the national health condition. As a measure of national health, three indicators are considered: life expectancy at birth, infant mortality and under-five mortality rates. Global life expectancy at birth significantly has risen by approximately 16 years in the past five decades. The improvement of public health care is one of the main factors that contribute to this increase in global life expectancy. A rise in global life expectancy creates several economic advantages. Healthier workers with better physical and mental conditions are more productive and efficient. Healthy people with longer life expectancies also tend to train more and have higher abilities than whom have shorter life expectancies, as in Becker (1993), Barro & Lee (1994) and Oster, Shoulson & Dorsey (2013). Moreover, a longer life expectancy can lead to an increase in saving, because the population tries to save more for consumption after retirement. An increase in saving leads to higher amounts of physical capital and investment, which consequently induces more economic activity and output (Well 2007). The improvement in national health leads to an increase in human capital in the form of health, which contributes to economic growth. The paper intends to look at two research questions. The first one investigates the effect of the government's spending on health on the improvement of national health indicators, such as life expectancy, infant mortality and under-five mortality. The global panel data, which is the most up-to-date and observed over 200 countries (including developed countries and developing countries) is used for the study. The health model is estimated by using the fixed-effects model, the random effect model, and the two-stage least-squares approach, which is applied for dealing with the reverse causality problem. In addition, this study introduces private health spending to the model, which has not been considered in the literature on health due to a lack of data (Gupta, Verhoeven & Tiongson 2002).

The second research question considers the importance of human capital for productivity and economic growth. The hypothesis of this model is that an increase in human capital in the form of health, such as a longer life expectancy, can contribute to economic growth. Three panel estimations are implemented:

the fixed-effect model, the random-effect model, and the mean group estimator, which is used to deal with a cross-sectional dependence problem. The models are estimated with three data-sets: global data, developed countries' data, and developing countries' data. Moreover, non-medical determinants of health, such as tobacco consumption, alcohol consumption, sugar supply, and total fat supply, are used as proxies for health indicators in developed countries. According to Larson & Mercer (2004), life expectancy and mortality rate may not be appropriate health indicators for developed countries, since they reflect neither the quality of life nor the lifestyles of populations in developed countries. The data of non-medical determinants of health are obtained from the OECD's country statistics.

The third paper discusses a number of interesting results. First, government spending on health has a significantly positive effect on health status by improving life expectancy at birth, infant mortality and the under-five mortality rate. For example, an increase in government spending on health by the amount equal to one percentage of GDP leads to approximately a half year increase in life expectancy and a reduction in infant mortality rate and under-five mortality rate by 11.1 and 1.3-1.6, respectively. These results are consistent with Gupta et al. (2002) and Baldacci, Guin-Siu & Mello (2003) studies, which find a negative relation between government spending on health and mortality rates. This is in contrast to the early findings of Filmer & Pritchett (1999) , who concludes that government spending on health is not a powerful determinant of the mortality rate. Interestingly, private spending on health has a significant positive effect on life expectancy, but it does not have the significant effect on mortality rates. This gives rise to the implication of government budget allocation on health. Private spending on health can effectively substitute government spending on health for improving longevity.

The second result is that an increase in life expectancy has a positive effect on output in developing countries. The model predicts that a one-year increase in life expectancy can raise output by one percent. The finding is consistent with studies by Barro et al. (1996), Bloom & Williamson (1998), Bloom & Canning (2000), and Bloom, Canning & Sevilla (2004). Their findings suggest that a one-year increase in the life expectancy can generate a 4 to 6% increase in national output. However, an increase in life expectancy does not have a significant effect in developed countries. Since most developed countries have significantly longer life expectancies and lower mortality rates than developing countries, more resources are required to improve health in a developed country than in a developing country.

The third result is that tobacco and alcohol consumption have a significantly (at 10% level) positive effect on economic growth in OECD countries. This may be surprising, but tobacco and alcohol consumption may have two offsetting effects on economic growth. On the one hand, tobacco and alcohol consumption certainly lower human capital, because they shorten the consumer's life expectancy (Olshansky, Passaro, Hershow, Layden, Carnes, Brody, Hayflick, Butler, Allison & Ludwig 2005, Valkonen & Van Poppel 1997, Bloom et al. 2004). On the other hand, the positive effect of higher tobacco and alcohol consumption on economic growth arises from the higher demand, which may increase economic activities, create jobs related to manufacturing (in the farming, industrial production, wholesale, transportation and retail sectors, for example) and generate additional tax revenue. In addition, a higher tax revenue can be used to support the fiscal health of OECD countries.

Part 2

Fiscal Policy in Small-Open Economy : An Estimated DSGE Model for Thailand

2.1 INTRODUCTION

During the Global Financial crisis, numerous fiscal stimulus policy and bailout plans were introduced to tackle the economic contraction and high unemployment in several countries. Fiscal policy, such as increase in government spending or decrease in tax rates, is an important government tool that can stabilize and stimulate economies. According to Kollmann, Roeger et al. (2012), the United States's expansionary fiscal policy in 2009 and 2010 was comprised of a rise in government spending and the lowering of tax rates, measures with impacts calculated at 1.98 and 1.77 percent of the country's annual GDP respectively. Similarly, the European Union's policies in 2009 and 2010, which are akin to those utilized by the United States, are calculated to have impacts of 0.83 and 0.73 percent of annual GDP respectively. Although the fiscal policy is believed to be a useful treatment for the economic crisis, more research needs to be done to investigate the effectiveness of fiscal policy and the factors upon which its efficiency depends.

The most significant article to approach this field studies fiscal multipliers in a small-open economy, applying a similar type of analysis as the form employed in closed economy models (Zubairy, 2014). Since the trading of goods and services is not modelled within its closed economy framework, the article's findings may be inaccurate for determining the impact of fiscal policy expansion on an open economy country. The behavior of fiscal multipliers can be significantly different in small-open economies as compared to closed economies. According to Ilzetzki, Mendoza & Végh (2013), the effectiveness of fiscal policy shocks on countries relies on several trade-specific factors, such as a degree of openness of trade, an exchange rate regime, a government liability and public debt. International trade and the openness of financial markets impact the exchange rate's adjustment and interest rate's response to fiscal policies, which can potentially affect the output of exporting firms. That is why studying fiscal policies in a small-open economy should be done in order to close the gap in the existing body of literature.

This paper seeks to provide a more detailed investigation regarding the effects of fiscal policy shocks, including government spending shocks and various tax rate shocks, such as decreases in sales taxes, payroll taxes and capital taxes, on macroeconomic variables in Thailand's small-open economy. Countries with small-open economies trade their goods and services in the global market. Because of its small size, small-open economy countries are price-takers, whilst their policies are not large enough to alter global prices. This paper models Thailand, small-open country in Southeast Asia, which has a large degree of openness, calculated to be 147 percent of GDP in 2014[1]. The characteristics of Thailand's economy will be investigated and employed for a parameterization of the Dynamic Stochastic General Equilibrium (DSGE) model designed by Thailand's central bank (Tanboon 2008). The analysis in this paper will mainly focus on the investigation and explanation of the effect of fiscal policy on macroeconomic variables, including national output, private consumption, private investment, inflation, exchange rates and interest rates. This investigation is performed by employing a micro-founded medium-scale DSGE model, which employs a number of valuable features, such as habit-adjusted consumption, capital accumulation, investment adjustment costs, and wage adjustment costs. The model is extended by introducing a rich fiscal block focusing on government

[1] The data of gross domestic product is obtained from Office of the National Economic and Social Development Board (http://www.nesdb.go.th)

spending as financed by taxes on sales, labour and capital income. Fiscal stabilization policies are modelled in the form of dynamic fiscal rule.

The contributions of this study are valuable, as the resulting outcomes can be capitalized not only for academic works but also as guidelines for the practical implementation of fiscal measures in Thailand. This study's findings will then assist policy planners and governments in understanding the mechanisms and impacts of fiscal policy innovations on macroeconomic variables in small-open economies. The explicit examination of the effectiveness of fiscal policy can be useful for annual government budget planning, introducing new stimulus policies when a country faces an economic downturn and in stabilizing an economy for long-term growth. Moreover, the results illustrate a comparative effect among various types of fiscal policy measures. An appropriate policy, based on an increase in government revenue with the fewest side effects, can then be selected and delivered over the proper period. Imposing an effective fiscal policy during economic recessions can successfully mitigate economic problems and smoothly restart economic engines. Furthermore, the current study will enhance the academic development of the DSGE model in small-open economy countries, such as Thailand and other developing states in Asia, which are still developing fiscal policy analyses.

This article is divided into seven sections. In Section 2.2, economic theories on fiscal policy mechanism and previous academic literature examining the role and impacts of distorting fiscal policies are thoroughly reviewed. Various fiscal policy models are compared for their advantages and disadvantages. This section also shows different views of the New Keynesian economics school and the New Classical macroeconomics school on the theoretical impacts of distorting fiscal policies. Section 2.3 explains the main structure of DSGE model. The economic agent's behaviors in the households sector, the business sector, the bank sector, the government sector and the central bank sector are all defined. Moreover, this section explains the calibration of the model based on the various empirical data from diverse sources, and parameters are calibrated for Thailand's economic data.

Section 2.4 shows the dynamic effects of fiscal policy shocks on macroeconomic variables in small-open economy countries by employing the DSGE model. Impulse responses, such as a response to an increase in government expenditure, a reduction of various tax rates, namely, sales tax, payroll tax, and capital tax, are investigated in this section. In addition, the fiscal multipliers generated by different fiscal shocks are computed. Two multiplier calculation approaches are used to provided a clear understanding of the impact of fiscal policy distortions on an economy. Finally, Section 2.5 concludes the study.

2.2 LITERATURE REVIEW

In this section, economic theories and various concepts related to fiscal policy implications will be thoroughly explained. Understanding the principle of fiscal policy's role would be a great value for exploring the remaining chapters. Moreover, the related academic research from recent journals is summarized. The advantages and disadvantages of each methodology from seminal papers will be compared.

2.2.1 Fiscal Multipliers

The literature on fiscal multipliers is divided into two groups, namely the New Keynesian economics school and the New Classical macroeconomics school. The first group argues for the positive ability of expansionary fiscal policy to aggregate output, whereas the second group considers that a fiscal multiplier's benefit is equal to zero. The main anchor of the second group is the Ricardian equivalence proposition, which employs a rational expectation of households.

The theory of fiscal policy implementation has been studied by both the New Keynesian economics school and the New Classical macroeconomics school for almost a century. During the 1930s, John Maynard Keynes (1883-1946) initially introduced the theory of economic stabilizing through fiscal policy implementations. During an economic downturn, most households may lower their consumption since they are aware of the future's uncertainty. Therefore, private consumption cannot generate enough aggregate demand. Consequently, production firms lower demand for labour and an unemployment rate continually rises. Keynes states that implementing a fiscal policy in this period can increase economic activity, employment, and aggregate demand (Keynes 1936). Keynes's proposition has been an essential foundation of fiscal policy analysis for many well-known researchers. The effect of fiscal policy is transmitted to the economy through aggregate demand and aggregate supply adjustment (Mankiw 2009).

Fiscal policy expansion can affect various macroeconomic variables, such as, private consumption, private investment, import of goods and service, employment and inflation. A higher private consumption can cause a second round effect, an expansion of aggregate demand. This additional aggregate demand stimulates an "animal spirit" within companies and an anticipated optimism (Mankiw 2009). Firms, who expect a positive expansionary effect from fiscal policies, try to produce more output to meet a surplus demand in the future by increasing investments in production, employing more labour and reserving more raw materials. Therefore, the second round effect not only creates a larger output but also raises employment, thereby ensuring the benefits of fiscal policies on economic growth.

Despite a number of advantages of an expansion fiscal policy from the Keynesian perspective's view, there is an argument from some New Classical school economists that fiscal expansion cannot effectively increase aggregate demand or stimulate an economy (Hur 2007). This group, also known as the non-activists, believes that government should neither intervene nor support the economy. This argument is primarily based on three main assumptions. Firstly, wages and prices are fully adjustable to clear labour and product markets; thus, the economy always reaches its equilibrium at full employment. Therefore, fiscal expansion cannot increase production and the aggregate supply curve in this case is a vertical line instead of a downward sloping line (Almeida 2012). Secondly, households are assumed to be forward-looking agents with infinite planning horizons, and the Ricardian equivalence proposition may hold. Their current consumption decisions depend on the present and future government budget plan. If the government would like to increase government expenditure today for stimulating aggregate demand, it can issue bonds for financing the government deficit. The forward-looking households will consider that, in the future, they will be more taxed for repaying a government debt; thus, they will not change their consumption today and begin to save more for the future. The result of an expansionary fiscal policy can be eventually similar to the result of an increase in tax today, and neither of these fiscal policies would affect the real variables. This hypothesis was introduced in the early nineteenth century by David Ricardo (Ricardo, Gonner et al. 1891) and elaborately examined by Barro (1974). Barro's study is the central pillar of the New Classical macroeconomics, which is built on the rational expectation assumption. Lastly, crowding out effects can mitigate the effectiveness of expansionary fiscal policy because of the increase in interest rate. When governments choose to rise fiscal spending, they borrow money from the financial market, causing an increase in the interest rate. In addition, an increase in government expenditures or a decrease in taxation can lead to a rise in public debt and a higher debt-to-GDP ratio. Since risk premiums have positive relations with the debt-to-GDP ratio, the interest rate within the financial market will increase. Ultimately, the higher interest rate crowds out the effect of expansionary fiscal policies and worsens both private investment and private consumption (Hur 2007).

However, the Ricardian equivalence proposition require strong assumptions, including, for example, that taxes are not discretionary, that households have infinite planning horizons and form rational expectations, that the economy is a closed economy and has no financial friction and that both prices and wages are adjusted perfectly. These conditions are crucial for the Ricardian equivalence proposition. If one condition is missed, the Ricardian equivalence proposition cannot hold. For instance, if the government increases spending to improve the infrastructure, it will improve technologies and increase productivity. In this example, the Ricardian equivalence proposition is violated and the fiscal multiplier may not be equal to zero. The present paper includes four assumptions that are inconsistent with the Ricardian equivalence: 1) the model considers distortionary taxation, 2) borrowing interest rate depends on the government debt to GDP ratio, 3) prices and wages are sticky, because price adjustment is costly for firms as in Rotemberg (1982) (For further discussion on firms price setting behavior see Romer (2006)), and 4) the model considers an open economy where a fiscal expansion affects the change of the terms of trade and the exporting sector.

2.2.2 Openness and Fiscal Multipliers

The study of the open economy environment is one of the essential parts of this paper. Although the effect of fiscal policy has been widely investigated in the last decade, some recent and advanced papers have considered the closed economy environment, for example the study of Fernández-Villaverde (2010), Eggertsson (2011), and Zubairy (2014). It is interesting how those models will perform in a small-open economy framework. An effect of fiscal policy in an open economy, which has a free trade of goods and services, may significantly differ from one in a closed economy. The open economy assumption violates the Ricardian equivalence proposition, because fiscal explanation leads to the exchange rate adjustment. Gärtner (2009) believes that the presence of the foreign exchange market affects the fiscal multiplier. The most well-known model that can clearly explain the mechanism of foreign exchange market is called The Mundell–Fleming model, which includes a balance of payment components (Fleming 1962, Mundell 1963). Fiscal policy shock can influence the equilibrium in foreign exchange market which may lead to an appreciation or a depreciation of exchange rate. Gärtner (2009) illustrates that the impact of expansionary fiscal policy on the economy relies on how the foreign exchange market is managed. Under the flexible exchange rate regime, the effect of fiscal policy expansion on the overall output is lower due to the exchange rate's adjustment.

The fiscal policy expansion leads to an excess demand. As a result, the exchange rate appreciates, consequently damaging the economy's exporting sector. Exchange rate appreciation reduces the positive effect of fiscal policy expansion by decreasing exports; thus, an expansionary fiscal policy has smaller effects on an economy with a flexible exchange rate regime. In contrast, under fixed exchange rates, the exporting sector suffers less. As a result, the output is higher at the new equilibrium and the fiscal policy expansion has a more significant effect to outputs under fixed exchange rates.

2.2.3 Costs of Borrowing and Fiscal Multipliers

Since the Ricardian equivalence proposition's assumption is demanding, it is easily violated. One important assumption that should be addressed is the absence of financial friction. Financial friction leads to a higher cost of borrowing and lending. This thesis considers a developing economy that relies on foreign loans for its private investments. In this case, financial friction arises from a higher interest rate risk premium when the foreign debt-to-GDP ratio increases. That ratio depends on the exchange rate, which in turn depends on fiscal policy. A country with high foreign debt may experience a high risk premium and a correspondingly high cost of borrowing that reduces productive investments. Moreover, as foreign debt consists of both private and public debt, an increase in fiscal expansion may result in larger foreign debt. After the global financial crisis in 2008, a number of countries encountered a high level of foreign debt and consequent increases in the cost of private borrowing. As higher debt increases the cost of borrowing, the Ricardian equivalence proposition does not hold. Therefore, the effectiveness of fiscal policy should be re-evaluated under a new paradigm, which the present paper contributes towards by including the effect of financial friction in its model.

2.2.4 Fiscal multiplier in DSGE models

According to Hur (2007), examinations of the effectiveness of fiscal policy can be done through the general equilibrium approach, which is a well-known analytical technique employed to study the response of national output to fiscal policy shocks. Among general equilibrium models, the DSGE model gained additional popularity in the 2000s. Kydland & Prescott (1982) introduces the real business cycle (RBC) model by modifying the equilibrium growth model, which may be considered as an early stage of DSGE model development. In 1997, Rotemberg & Woodford (1997) adapts the RBC model by examining monopolistically competitive firms and price stickiness. Their influential model is recognized as the New Keynesian DSGE model. The DSGE model achieves its reputation because of its adequate assessment of monetary policy, although it may also be applied to determine the effect of fiscal policy. The important advantage of the DGSE model is that it is invulnerable to Lucas's critique, since it employs rational expectation. This is because Lucas's critique is raised in conventional macro-econometric models. The DSGE model is extensively used in economic research and employed by well-known policy making organizations (Eggertsson 2011). The DSGE framework is used for studying the effects of fiscal policies on output in Forni, Monteforte & Sessa (2009), Furceri & Mourougane (2010), and Eggertsson (2011). Zubairy (2014) also used the DSGE to compute the fiscal multipliers associated with government expenditures and tax reduction.

Several DSGE model studies in the literature report that fiscal policy shocks, such as an increase in government spending shock, and a reduction of tax rate shock, have positive effects on national outputs. These studies have been examined by Zubairy (2014), who used the DSGE model with full fiscal policy elements and several channels of government expenditure innovation, and Fernández-Villaverde (2010) , who examined the impact of fiscal policy by using the DSGE model with financial friction by setting an asymmetric information between borrower and lender. In addition, the DSGE model has been appropriated to explore fiscal policy impacts on the Eurozone economy by Ratto, Roeger & in't Veld (2009), who studied the effects of fiscal and monetary policies by using a DSGE model for an open economy with Bayesian estimation techniques. Forni et al. (2009) evaluated the effect of fiscal policy in the Euro area by using a DSGE model featuring a fraction of non-Ricardian agents. Moreover, the effect of fiscal policy distortion on various GDP components is also described in several studies, such as Forni et al. (2009), Furceri & Mourougane (2010), and Bhattarai & Trzeciakiewicz (2012).

Some studies find a rise in inflation after an increase in government expenditures. Among them are a DSGE fiscal model with endogenous government bond yields by Furceri & Mourougane (2010), a new Keynesian DSGE model in the UK by Bhattarai & Trzeciakiewicz (2012) and a DSGE model in the Eurozone by Forni et al. (2009). The other studies reported declining inflation after a reduction of various tax rate shock (Forni et al. (2009), Bhattarai & Trzeciakiewicz (2012) and Zubairy (2014)).

Furthermore, several studies have investigated a crowding in and crowding out of fiscal policy shocks to private consumption and private investment. Ratto et al. (2009), Forni et al. (2009) and Bhattarai & Trzeciakiewicz (2012) find a crowding out effect of private consumption of Ricardian households, which is a decrease in private consumption in response to an increase in government expenditures. The reason behind a crowding out effect from private consumption is that Ricardian households anticipate a rise in taxation for financing a massive increase in government spending during the current period. Thus, they begin to consume less and save more when the shock is introduced. Similarly, Zubairy (2014), Ratto et al. (2009) and Bhattarai & Trzeciakiewicz (2012) find a crowding out effect from an increase in government expenditure on private investment since the cost of investment increases following the rise in interest rates after a rise in public debt. The tax reduction shock's crowding out effect is also shown in some research. Unlike an increase in the government expenditure shock, decreases in tax rate differently affect private consumption. The tax rate shock's impact depends on the type of taxes. Forni et al. (2009) and Bhattarai &

Trzeciakiewicz (2012) find a crowding in effect from private consumption as a response to a decrease in sales taxes. Once a sales tax rate drops, the price of consumption goods decreases. Consequently, household consumption increases. In contrast, a decrease in the capital tax leads to the crowding out of private consumption for non-Ricardian households. Forni et al. (2009) and Bhattarai & Trzeciakiewicz (2012) explain that the decrease in the capital tax makes capital more attractive. Firms re-allocate the factor of production from labour to capital, thus decreasing the demand for labour. The decrease in labour demand lowers income from wages and labour. Therefore, consumption by non-Ricardian households declines according to lower incomes.

2.2.4.1 Empirical evidence

In order to test theories, an empirical investigation is generally used to estimate a reduced-form equation. Empirical studies are employed to examine the effect of fiscal policy on GDP and other macroeconomic variables. A well-known reduced-form equation is called the Structural Vector Autoregressive (SVAR). The SVAR procedure has several distinctive features for analyzing shocks. Isolating a change in the exogenous variable is one of the significant advantages of employing the SVAR method. Bouakez, Chihi & Normandin (2010) suggest that inspecting an effect of fiscal policy requires a clear identification and an additional assumption. When the fiscal shock hits the economy, it is useful to isolate the adjustment of exogenous variables, which are not theoretically related to fiscal shocks. This objective can be clearly achieved by using the SVAR approach. In addition, various desirable relationships between exogenous variables and endogenous variables can impose a restriction when examining a fiscal policy's effects. Furthermore, the SVAR approach can also properly explore policy transmission mechanisms (Gottschalk 2001).

A number of empirical research on the impact of fiscal policy suggests that a fiscal multiplier is non-zero. Most studies on SVAR approaches reveal a positive effect of fiscal policy on output, such as, Perotti (2005), Caldara & Kamps (2008) and Mountford & Uhlig (2009). Several macroeconomic variables significantly respond to fiscal shock, for example, Caldara & Kamps (2008) and Mountford & Uhlig (2009) suggest a notable increase private consumption after the implementation of expansionary fiscal policy. However, when the expectation formation is considered, the impact of fiscal policy on private consumption is remarkably negative as illustrate in an SVAR study by Tenhofen & Wolff (2007). The economy's size is another factor that influences the impact of fiscal policy. Perotti (2005) has employed the VAR for investigating the effect of fiscal policy to 5 OECD countries[2], e.g., Australia, Canada, Germany, the United Kingdom and the Unites States. He suggests that the government spending multiplier for the Unites States is the largest among the 5 countries. Additionally, it is unclear whether a tax cut policy or an increase in government expenditure policy is more effective. Later, a VAR model featuring an anticipation of Mountford & Uhlig (2009) found that a tax cut policy has the largest impact on increases in GDP.

In order to measure the degree of fiscal policy impacts, a number of studies have calculated the fiscal multiplier of each shock on national output and macroeconomic variables, such as private consumption, private investment, and employment. Zubairy (2014) finds that an impact fiscal multiplier of an increase in government expenditure (1.07) is considerably higher than an impact fiscal multiplier of a reduction of taxation (0.13 and 0.34 for labour tax shock and capital tax shock, respectively). She also reports that the present value of the government spending multiplier decays over time, which obviously contrasts with a present value tax multiplier that accumulates along the horizontal axis. These adjustments of the present value multiplier are in line with the findings of Furceri & Mourougane (2010).

The fiscal multiplier's size is depended on various economic characteristics of

[2]OECD is the Organization for Economic Co-operation and Development which has the objective to improve the economic and social welfare of people around the world. The members consist of 35 countries, including many of the world's most advanced countries and also emerging countries.

the country and structural parameters. Ilzetzki et al. (2013) find that exchange rate regimes, the degree of trade openness, a level of government debt and the stage of economic development influence the size of the fiscal multiplier of each country. In a large open economy country or a flexible exchange rate regimes country, they suggest that fiscal policy shock does not cause a significant increase in national output. In addition, Furceri & Mourougane (2010) exploit a DSGE model to calculate the effect of various kind of fiscal shocks on national output of European countries. They find that price persistence and the share of liquidity constrained by households could significantly change a fiscal multiplier.

Despite extensive uses of the DSGE models and the SVAR models, there are numerous contradictions in the previous studies' findings. Ilzetzki et al. (2013) investigate the discretionary fiscal policy multipliers of 44 counties by using the SVAR approach. Their findings reveal that the impact of an increase in government consumption is fairly small in the short-term and significantly large in the medium-long term. Nevertheless, their findings contrast with the result from DSGE model by Furceri & Mourougane (2010) in various aspects. Furceri & Mourougane (2010) suggests strong positive impacts from fiscal policy in the short-term, especially from an increase in government investment and consumption. An impact multiplier of government investment for one year on output is revealed to be around 0.6, while a long-run multiplier in 10 years is slightly smaller at 0.2.

The next section presents a model calibrated for the Thailand economy in order to investigate fiscal multipliers.

2.3 THE MODEL

The present model shares a number of features with The Bank of Thailand's DSGE model introduced by Tanboon (2008). The Bank of Thailand's DSGE model has been used to investigate the Thailand economic factors related to microeconomics foundations. This model incorporates a habit-adjusted consumption, a households' capital accumulation, and an investment and wage adjustment cost. Nominal rigidities, such as wage and price, are included in model features. Moreover, for examining the various fiscal policy shocks, a rich fiscal policy block is developed from Eggertsson (2011) and Zubairy (2014). Various tax policies are added to the households' constraint equation for studying the behavior and reaction of households to taxation shocks. Government equations contain the fiscal stabilizer function which controls the tax rate with respect to output for preventing an undesirably explosive government debt. The present DSGE model is used for investigating the dynamic respond of endogenous variables to uncertainties. Micro-level structures determine the relationship among economics variables. Five vital sectors, namely, households, firms, banks, government, and the central bank, simultaneously interact and optimize their behaviors subject to constraints. In the households sector, household agents maximize their expected utility by adjusting consumption and leisure with respect to budget constraints. Firms maximize their expected profits by setting prices subject to production functions and the demand for output. In the financial sector, the bank receives a deposit from households and lends it to firms subject to the cost of hiring labour. The government, in the role of fiscal authority, maintains a fiscal rule by setting government expenditures according to the total production. Lastly, the central bank, in the role of monetary authority, manages a monetary rule by adjusting an interest rate subject to the expected inflation and target interest rate. The detail of each sector is illustrated as follows.

2.3.1 Households Sector

There are numerous identical infinitely lived households who populate the economy. The preference of all households is regularly similar over their lifetime and infinite consumption series. Households are homogeneous with respect to consumption and labour service. The continuum of expected lifetime households utility can be assumed as follows:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\chi) \log \tilde{C}_t - \varphi^L \frac{L^{1+\eta}}{1+\eta} \right] \tag{1}$$

Habit-adjusted consumption is defined by:

$$\tilde{C}_t = \frac{C_t - \chi h_t}{1-\chi} \tag{2}$$

Households make the decision for consumption and labour service supply. The utility that households obtain from consumption is represented in a logarithm function. Habit-adjusted consumption $\tilde{C}_t$ is used in an expected lifetime household's utility equation, instead of using a current period consumption, C_t . The advantage of applying habit-adjusted consumption is illustrated by Fuhrer (2000). He finds that employing a habit formation for consumers in the monetary model substantially enhances the response of macroeconomic variables to policy shocks. Habit formation specification transmits an intention to households for smoothing an adjustment of consumption. In addition to the utility that households obtain from consumption, they sacrifice their leisure by supplying labour to firms. The second term of continuum represents a disutility that households sacrifice. The disutility equation is expressed in an exponential function, which depends on a number of labour supply, L_t. The continuum of expected lifetime household's utility is composed of four important parameters. Firstly, β is a discount factor which represents a percentage rate required to compute the present value of the household's utility in the next period. Normally, β is greater than zero and smaller than 1, $\beta \in (0, 1)$.

From habit-adjusted consumption equation, $\tilde{C}_t$ represents consumption in the current period that is adjusted by a degree of habit, h_t, and a consumption habit persistence factor, χ. It is employed to describe a change of consumption over two periods with respect to households' habits. When households consume more in the current period, it will lower the marginal utility of consumption of this period but raise the marginal utility of consumption for the next period. Naturally, the more the households consume today, the more starving they face in the future (Ravn et al. 2006). h_t reveals the size of households' habits.

$$h_t = (1 + \alpha)C_{t-1} \tag{3}$$

h_t is the function of the previous period consumption, C_{t-1}, and productivity growth rate, α . The higher the last period's consumption is, the greater the degree of households' habits. Under simple model, steady-state of zero growth rate, α is set equal to 0, therefore, $h_t = C_{t-1}$and $\tilde{C}_t = \frac{C_t - \chi C_{t-1}}{1-\chi}$. Now, households only gain more utility when their current consumption is greater than χ proportion of the last period's consumption. Moreover, habit-adjusted consumption in steady-state of zero growth rate, $\tilde{C}_t^S$, equals to current period consumption ,C_t^S , or $\tilde{C}_t^S = C_t^S$. Hence, the households' utility will only depend on current period consumption.

The households' utility function is subject to households' budgeting constraints, which is assumed as:

$$(1+\tau_t^s)P_t^D C_t + P_t^D I_t + D_t \leq (1 + R_{t-1}) D_{t-1} + (1-\tau_t^w)W_t L_t + \left[1 - (1-\delta)\tau_t^k\right] R_t^K K_t + \sum_{j=D,X} \Phi_t^j \tag{4}$$

At time t, households allocate their income into three parts, namely, consumption, investment, and deposit. These allocations should be smaller or equal to total households budget, which is composed of a deposit from previous period plus interest, return from supplying labour, return from capital, and a profit of firms operation. P_t^D is a price of goods that households consume and invest. Consumption goods and investment goods are assumed to have the same price level. I_t is a current period investment. D_t is an amount of money that households deposit to a bank. R_t is an interest rate for the deposit which is similar to the policy interest rate. W_t is a nominal wage rate. It is a price of labour supply which is returned to households who provide their labour. R_t^K is a nominal price of capital or a return that capital's owner receives. Φ_t^D and Φ_t^X is a profit of domestic firms and export firms that households who are a firms' owner receive from goods production. Three types of taxation are collected from households budget constraint. τ_t^s denotes the sales tax that is collected from households consumption in the current period. τ_t^w is a payroll tax which is imposed on wage payment. Lastly, τ_t^k is the capital taxed which is taxed from a persistent capital.

Capital accumulation constraint is assumed as:

$$K_{t+1} \leq (1-\delta)\, K_t + F(I_t, I_{t-1}) \tag{5}$$

Capital accumulation constraints which are composed of two parts, represents the capital of households in the next period, K_{t+1}. The first part is capital in the current period, K_t, which is decayed by the rate of depreciation, δ. The second part is an investment adjustment costs function, $F(I_t, I_{t-1})$, which can be assumed as follows:

$$F(I_t, I_{t-1}) = \left[1 - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - (1+\alpha)\right)^2\right] I_t \tag{6}$$

An investment adjustment costs function is an investment minus an adjustment cost. It is the knowledge that converts a current period's investment and a previous period's into an installed investment for the next period operation's (Christiano, Eichenbaum & Evans 2005). A second term represents an adjustment cost which is multiplied by an investment adjustment cost parameter, ξ^I. An adjustment cost is considered when a growth rate of investment is greater than the growth rate of the economy at balance growth path, or $\frac{I_t}{I_{t-1}} > \alpha$. An adjustment cost lowers the amount of investment that will be carried into the future. In contrast, when the investment adjustment cost parameter is absented, $\xi^I = 0$, investment adjustment costs function will be shortened to I_t.

Households maximize their utility subject to budget constraints and capital accumulation. Lagrangian formulation, which is constructed from households utility function, budget constraint, and capital accumulation, is employed for determining a households' intertemporal problem. The Lagrangian function is assumed as follows:

$$\begin{aligned}\mathcal{L} &= E_0\sum_{t=0}^{\infty}\beta^t\Bigg\{(1-\chi)\log\tilde{C}_t-\varphi^L\frac{L_t^{1+\eta}}{1+\eta}+\lambda_t\left[(1+R_{t-1})\,D_{t-1}+(1-\tau_t^w)W_tL_t+\left[1-(1-\delta)\,\tau_t^k\right]R_t^KK_t\right.\\ &\quad\left.+\sum_{j=D,X}\Phi_t^j-(1+\tau_t^s)(1-\chi)P_t^D\tilde{C}_t-(1+\tau_t^s)\chi P_t^Dh_t-P_t^DI_t-D_t\right]\\ &\quad+\lambda_tQ_t^K\left[(1-\delta)\,K_t+F(I_t,I_{t-1})-K_{t+1}\right]\Bigg\}\end{aligned} \tag{7}$$

Households' decisions consist of capital for investment, K_t, a labour supply for firms' production, L_t, a habit-adjusted consumption, $\tilde{C}_t$, investment, $I_{t,}$, and a saving deposit to a financial institution, D_t. λ_t shows an additional change in utility from a unit change in nominal income, namely a marginal utility of nominal income. Q_t^K represents a shadow price of capital. The first-order condition of each variable is applied for determining the households' decisions (the detailed exposition is described in Appendix A.1).

Consumption-decision is acquired from deriving the first-order condition by applying $\frac{\partial\mathcal{L}}{\partial\tilde{C}_t}=0$

$$\lambda_t=\frac{1}{(1+\tau_t^s)P_t^D\tilde{C}_t} \tag{8}$$

Capital decision is obtained from deriving the first-order condition by using $\frac{\partial\mathcal{L}}{\partial K_{t+1}}=0$

$$Q_t^K=\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\left[\left[1-(1-\delta)\,\tau_{t+1}^k\right]R_{t+1}^K+Q_{t+1}^K\,(1-\delta)\right] \tag{9}$$

Investment decision is received from deriving the first-order condition by applying $\frac{\partial\mathcal{L}}{\partial I_t}=0$

$$\frac{Q_t^K}{P_t^D} = \frac{1}{1 - \xi^I \frac{I_t}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} - (1+\alpha) \right) - \frac{\xi^I}{2} \left(\frac{I_t}{I_{t-1}} - (1+\alpha) \right)^2} \left[1 - \xi^I \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{Q_{t+1}^K}{P_t^D} \left(\frac{I_{t+1}}{I_t} \right)^2 \left(\frac{I_{t+1}}{I_t} - (1+\alpha) \right) \right] \tag{10}$$

$\frac{Q_t^K}{P_t^D}$ is called a Tobin's q, which is firstly introduced in 1968 by James Tobin and William Brainard. It can be used to describe the level of investment. Tobin's q is the proportion of a replacement cost for the newly production unit or a shadow price of capital, Q_t^K, and the market valuation of investment goods or a price of investment, P_t^D (Tobin 1969). When a cost of investment adjustment is absent, investment adjustment costs function, $F(I_t, I_{t-1})$, will be equal to I_t in the equilibrium. Thus, Tobin's q is equal to 1 or $Q_t^K = P_t^D$

If labour market were perfectly competitive and without friction, the Labour supply decision would be acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}}{\partial L_t} = 0$

$$(1 - \tau_t^w)\lambda_t W_t = \varphi^L L_t^\eta \tag{11}$$

In a competitive wage setting, households solely provide their differentiated labour to firms for production. Christiano et al. (2005) indicates that there is a labour aggregator who merge a differentiated labour supply into a group of labour (Tanboon 2008). The essential role of labour aggregator is negotiating labour supply, L_t , and optimal nominal wage, W_t , as a representative of a group of labour with firms. In a generalization of competitive wage setting, marginal labour cost and nominal wage are equated. Q_t^l denotes the solution of the effective market

$$(1 - \tau_t^w)\lambda_t Q_t^l = \varphi^L L_t^\eta \tag{12}$$

However, this model employs a monopolistic distortion in the wage setting and assume that the wage is set higher than the marginal cost of labour. If W_t^* is a flexible wage in a monopolistic market, the wage setting equation would be

$$W_t^* = \mu^w Q_t^l \tag{13}$$

, where $\mu^w > 1$ is wage setting markup. In addition to monopolistic distortion, the characteristic of wage rigidity follows the study of Rotemberg (1982). The labour aggregator tries to minimize

$$\min_{W_t} E_0 \sum_{t=0}^{\infty} \beta^t \left[(W_t - W_t^*)^2 + \zeta^W \left(\triangle W_t - \triangle \bar{W}_{t-1} \right)^2 \right] \tag{14}$$

The first term describes a gap between W_t and W_t^* that labour aggregator try to minimize. The difference between wage increase, $\triangle W_t$, and aggregated wage inflation of previous period, $\triangle \bar{W}_{t-1}$, which is given by policy maker is shown in the second term. ζ^W expresses a wage rigidity. When ζ^W=0, no rigidity, nominal wage is set equal to optimal wage ($W_t = W_t^*$). The minimization problem of wage aggregator can be solved by applying the first-order condition with respect to W_t.

$$W_t = W_t^* + \zeta^W \left[- \left(\triangle W_t - \triangle \bar{W}_{t-1} \right) + \beta E_t \left(\triangle W_{t+1} - \triangle \bar{W}_t \right) \right] \tag{15}$$

The above equation, namely a wage setting, illustrates the three components of nominal wage that labour aggregator concerns. Three elements can be assumed as follows. The first element is an optimal wage, W_t^*, which will be solely presented in no rigidity case. The second part is difference between current period wage inflation, $\triangle W_t$, and last period wage inflation, $\triangle \bar{W}_{t-1}$. When wage inflation in the current period is greater than wage inflation in the previous period ($\triangle W_t > \triangle \bar{W}_{t-1}$), the nominal wage will reduce because of the negative sign of the second component, and vice versa. The last part is the different between next period expected wage inflation, $\triangle W_{t+1}$, and current period wage inflation, $\triangle \bar{W}_t$. When an expected wage inflation in next period is higher than a current period wage inflation ($\triangle W_{t+1} > \triangle \bar{W}_t$), households expect a rise in wage inflation in the future. Thus, the nominal wage will increase because of a positive sign of the last component coefficient.

The saving and borrowing decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}}{\partial D_t} = 0$

$$\lambda_t = \beta E_t \lambda_{t+1} \left[1 + R_t\right] \tag{16}$$

The above equation represents an optimal deposit which is chosen by households. A level of deposit is allocated after households make a decision on consumption and investment.

2.3.2 Financial openness

This thesis assumes that domestic capital market is open and any investor can buy both domestic and foreign debt. However, the domestic bonds are more risky than foreign. The domestic bond market is subjected to financial friction in the form of risk premium The foreign bonds are trades at international risk free rate and the domestic interest rate R_t is traded with risk premium as following

$$(1 + R_t) = (1 + R_t^*)\, E_t \left(dS_{t+1}\right) \left(\frac{S_t B_t^*}{2 P_t^D Y_t^N} \frac{1}{\psi}\right)^{\zeta^B} \upsilon_t \tag{17}$$

$$dS_{t+1} = \frac{S_{t+1}}{S_t} \tag{18}$$

, where $\zeta^B > 0$ reflects the elasticity of the home interest rate with respect to domestic risk of borrowing, the foreign debt in domestic currency, B_t, is given by

$$B_t = S_t B_t^*. \tag{19}$$

Where B_t^* is total foreign debt in foreign currency.

The difference between domestic interest rate and foreign interest rate composes of two components. The first part is the expected change of nominal exchange rate, which shows expected depreciation or appreciation of local currency. It is the difference between current period nominal exchange rate and the expected nominal exchange rate of the next period. Gärtner (2009) explains that when investors do not expect the change of exchange rate, $E_t dS_{t+1}$=1, the UIP suggests the equivalent of domestic interest rate, R_t, and foreign interest rate, R_t^*, $R_t = R_t^*$. If the nominal exchange rate is expected to depreciate $E_t dS_{t+1} > 1$ (i.e. in case of fixed exchange rate policy), the domestic assets became less desirable, the price for domestic bonds fall and the domestic interest rate interest will increase. The last part is a risk premium that arises when local debt to nominal GDP ratio is greater than a ratio of debt to GDP in steady-state, ψ. Term υ_t represents the shock to transaction costs.

The linkage between international trading and foreign debt in local currency is an important part of the present small-open economy model. The relation of the value of net export and households debt is defined by

$$B_t = (1 + R_{t-1})B_{t-1} - (P_t^X X_t - P_t^M M_t) \tag{20}$$

, where X_t and M_t represent export and import, P_t^X and P_t^M are prices for export and import in domestic currency.

The above equation is called the Law of Debt Motion, and it explains the dynamic of foreign debt in local currency. The first term shows that foreign debt grows at the rate of interest rate, R_{t-1}, over time. The second term is a trade balance, $TB = P_t^X X_t - P_t^M M_t$, which is equal to the value of the export of goods and service minus the value of the import of goods and service. Foreign debt and a trade balance have a negative relation, because the gain of the trade balance and the value of goods being exported is higher than the value of goods being imported ($P_t^X X_t > P_t^M M_t$). Therefore, the current period foreign debt falls.

2.3.3 Firms Sector

The essential role of firms is as goods producers for the economy. Two types of firms, namely, domestic firms, and export firms, are considered in the present DSGE model. A destination market is used for classifying firms' categories.

Domestic firms only produce goods for domestic market, while export firms only sell their goods in a foreign market. Nevertheless, both firms share a similarity in production technology. A Cobb-Douglas production function is the technology that both types of firms employ. The detail of each type is described as follows:

2.3.3.1 Domestic Firms

Domestic firms acquire resources for producing goods. Three factors of production are labour, L_t^D, a capital K_t^D, and raw imported intermediary goods such as raw material for domestic firms, M_t^D. Moreover, the production of domestic firms also depends on labour-argumented productivity, A_t. The production function of domestic firms can be described as follows:

$$Y_t^D = (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}, \tag{21}$$

, where Y_t^D is the output of domestic firms, γ_L^D denotes a labour income share, γ_M^D indicates an imported input income share and $1-\gamma_L^D-\gamma_M^D$ is a capital service income share. Domestic firms are exhibited as monopolistic competitive firms since they have the power to set their prices (Tanboon 2008).

The total costs, TC^D, and profits, Φ_t^D, of domestic firms can be presented as follows:

$$TC^D = \left(1+R_t^L\right) W_t L_t^D + P_t^M M_t^D + R_t^K K_t^D \tag{22}$$

$$\Phi_t^D = \left[P_t^D Y_t^D - (1+R_t^L) W_t L_t^D - P_t^M M_t^D - R_t^K K_t^D\right] \tag{23}$$

The cost of domestic firms' production, TC^D, is composed of three components: wage payments, the cost of raw imported material, and interest rate payments from the borrowing of capital. The wage bill is paid up-front and therefore has to be borrowed from financial institutes at a lending rate, R_t^L. The intermediary input,

M_t^D, is imported at an import price, P_t^M. The payment for a unit of capital, K_t^D, equals capital rental rate, R_t^K.

Domestic firms chose the composition of inputs (L_t^D, K_t^D and M_t^D) in order to minimize production costs subject to a production quantity constraint. The Lagrangian function is

$$\mathcal{L}^D = \left[\left(1 + R_t^L\right) W_t L_t^D + P_t^M M_t^D + R_t^K K_t^D\right] + Q_t^D \left[Y_t^D - \left(A_t L_t^D\right)^{\gamma_L^D} \left(M_t^D\right)^{\gamma_M^D} \left(K_t^D\right)^{1-\gamma_L^D-\gamma_M^D}\right] \tag{24}$$

The labour demand decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial L_t^D} = 0$

$$\left(1 + R_t^L\right) W_t L_t^D = \gamma_L^D Q_t^D Y_t^D \tag{25}$$

The raw imported material demand decision is obtained from deriving the first-order condition by using $\frac{\partial \mathcal{L}^D}{\partial M_t^D} = 0$

$$P_t^M M_t^D = \gamma_M^D Q_t^D Y_t^D \tag{26}$$

The capital service decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial K_t^D} = 0$

$$R_t^K K_t^D = \left(1 - \gamma_L^D - \gamma_M^D\right) Q_t^D Y_t^D \tag{27}$$

Combining the solution (25, 26, 27) with total costs (22), the Lagrange multiplier Q_t^D represents marginal costs. If price were flexible, and the price elasticity of substitution between domestic goods were σ_i, the price setting equation would be equal to the fixed mark-up over marginal costs.

$$P_t^{D*} = \mu^D Q_t^D \tag{28}$$

Where P_t^{D*} is the optimal price in flexible price economy, and $\mu^D = \frac{\sigma_i}{(\sigma_i - 1)}$ is the monopolistic mark-up.

However, the price rigidity follows the price rigidity from the study of Rotemberg (1982), and price updating is costly. Therefore, domestic firms set prices minimizing the following loss function:

$$\min_{P_t^D} E_0 \sum_{t=0}^{\infty} \beta^t \left[\left(P_t^D - P_t^{D*} \right)^2 + \xi^D \left(\triangle P_t^D - \triangle \bar{P}_{t-1}^D \right)^2 \right] \quad (29)$$

The first term represents the price gap between the price of goods, P_t^D and an optimal price, P_t^{D*}. Therefore, domestic firms try to set a price of goods as close to an optimal price as possible. The second term illustrates the cost of price adjustment, which is presented by a degree of price rigidities, ξ^D. The difference between the increase in firm's price index, $\triangle P_t^D$, and the previous economy-wide inflation, $\triangle \bar{P}_{t-1}^D$, creates a cost of price adjustment.

The minimization problem of price setting can be solved by applying the first-order condition with respect to P_t^D.

$$P_t^D = P_t^{D*} + \zeta^D \left[- \left(\triangle P_t^D - \triangle \bar{P}_{t-1}^D \right) + \beta \left(E_t \triangle P_{t+1}^D - \triangle \bar{P}_t^D \right) \right] \quad (30)$$

$$\triangle \bar{P}_t^D = \bar{P}_t^D - \bar{P}_{t-1}^D \quad (31)$$

The above equation represents the price setting of domestic firms. A domestic price, P_t^D, is divided into three essential components. The first part is an optimal price, P_t^{D*}, which is equal to a margin cost, Q_t^D, times a domestic price markup, μ^D. If there were no costs of price adjustment ($\zeta^D = 0$), the domestic firms would set their price equal optimal price. The second part appears, because firms want to minimize the current costs of price adjustment, and the last component shows that firms account for the future price adjustment costs.

2.3.3.2 Exporting Firms

The exporting firms only produce and trade goods in the export market. The production function of export firms requires three-factor inputs, which are labour, L_t^X, capital service, K_t^X and raw imported material, M_t^X. Export firms' production can be described as follows:

$$Y_t^X = (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X} \tag{32}$$

, where γ_L^X, γ_M^X and $1-\gamma_L^X-\gamma_M^X$ are shares of labour, imported input and capital service correspondingly. In contrast to domestic firms, export firms are price-takers since the considered economy is a small-open economy. Price is immediately adjusted to the international market price (Tanboon 2008).

A total cost of export firms is slightly different from a total cost of domestic firms. An important difference is the financing of labour cost. Export firms are assumed to have a substantial capital investment. It can raise funds for paying a labour cost without borrowing from a bank, which contrasts with domestic firms. Therefore, an interest rate component for a labour cost loan is absent from the total cost function. However, the other costs, which are a raw imported material cost and a cost of capital service, are similar to domestic firms' cost. In addition, Export firms profit, Φ_t^X, is a total export firms revenue less total cost of production. The cost of export firms' production, TC^X, and export firms profit, Φ_t^X, can be presented as follows:

$$TC^X = W_t L_t^X + P_t^M M_t^X + R_t^K K_t^X \tag{33}$$

$$\Phi_t^X = P_t^X Y_t^X - W_t L_t^X - P_t^M M_t^X - R_t^K K_t^X \tag{34}$$

Export firms try to maximize their profit with subject to a production function constraint. Their decision consists of a level of labour input, L_t^X, a capital service input, K_t^X and a raw imported material input, M_t^X. The Lagrangian function can be assumed as follows:

$$\mathcal{L}^X = \left[P_t^X Y_t^X - W_t L_t^X - P_t^M M_t^X - R_t^K K_t^X\right] - Q_t^X \left[Y_t^X - (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X}\right] \tag{35}$$

The labour demand decision for export firms is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^X}{\partial L_t^X} = 0$

$$W_t L_t^X = \gamma_L^X Q_t^X Y_t^X \tag{36}$$

The raw imported material demand decision is obtained from deriving the first-order condition by using $\frac{\partial \mathcal{L}^X}{\partial M_t^X} = 0$

$$P_t^M M_t^X = \gamma_M^X Q_t^X Y_t^X \tag{37}$$

The capital service decision is received from deriving the first-order condition by employing $\frac{\partial \mathcal{L}^X}{\partial K_t^X} = 0$

$$R_t^K K_t^X = \left(1 - \gamma_L^X - \gamma_M^X\right) Q_t^X Y_t^X \tag{38}$$

Price setting by export firms contrasts to price setting by domestic firms. Their goods are sold in a global market that is assumed to be a perfectly competitive market. Hence, export firms only receive a global market price for their price setting. The export firms' price, at equilibrium, can be expressed as follows:

$$Q_t^X = P_t^X \tag{39}$$

Q_t^X is a shadow price of export firms. P_t^X is a price of export firms in term of a local currency that is the product of nominal exchange rate, S_t, and the price of export goods in a foreign currency, P_t^{Xf}. The price of export firms can be expressed as follows:

$$P_t^X = S_t P_t^{Xf} \tag{40}$$

Similarly, P_t^M denotes a domestic import price which is the product of foreign import price P_t^{MF} and S_t.

$$P_t^M = S_t P_t^{MF} \tag{41}$$

The difference between import price and export price is called term of trade, T, and it can be assumed as follows:

$$T = \frac{P^X}{P^M} \tag{42}$$

The output of domestic firms and export firms is summed into gross domestic product (GDP), which can be assumed as follows:

$$Y_t^N = Y_t^D + Y_t^X \tag{43}$$

Y_t^N is the economy's real GDP.

2.3.4 Banks Sector

The essential role of the bank is lending money to borrowers, which are domestic firms. The bank acts as a financial intermediary between depositors and borrows. The banking model of Atta-Mensah & Dib (2008) is employed to be a foundation of the banking sector since monetary policy can be conducted through lending channels (Tanboon 2008). Capital is directly collected from a deposit of households, then a bank lends it to domestic firms for financing a labour cost at rate R_t^L. The risk premium which banks charge depends on the state of domestic economy.

$$R_t^L = \frac{sp}{\Lambda_t} R_t \tag{44}$$

Where sp is the steady-state risk premium and Λ_t is a deposit lent out to firm ratio. It is a cyclical component , defining as

$$\Lambda_t = \left[\frac{Y_t^D}{(1+\alpha)\, Y_{t-1}^D}\right]^\tau \tag{45}$$

The above equation illustrates that when the growth rate of national output increases, the credit spread declines and τ denotes an elasticity of lending spread to a growth rate of national output.

2.3.5 Government sector

The government sector is one of the important components of this present model. The important roles of government are consumption and supporting a sustainable economic growth. These government objectives require a well-planned government policy. The present model employs an automatic stabilizer process for the government sector. This process can minimize fluctuations in real GDP. The automatic stabilizer process can be managed by controlling a level of current-period government spending in response to a last-period government spending, government bond and a last-period national output. Hence, the size of government spending corresponds to the level of GDP in the previous period. Excessive government spending not only over stimulates economic activity, but it also creates a fiscal burden in the future. Therefore, a fiscal rule is introduced to the model for managing a rule of government expenditure. A fiscal rule can be assumed as follows:

$$G_t = \rho^G G_{t-1} + \rho^{G,b^G} b_{t-1}^G + \rho^{G,Y^N} \sigma Y_{t-1}^N \tag{46}$$

G_t is a real government expenditure in current period. A fiscal rule illustrates that government expenditure is composed of three main components. The first component is the last period government expenditure, G_{t-1}. A 1-period-lag government expenditure is adjusted by the persistence in government expenditure, ρ^G. The persistence in government expenditure illustrates the correlation between a previous period nominal government expenditure and a current period nominal government expenditure. The higher the value of ρ^G , the larger the persistence effect. In the second component, ρ^{G,B^G} is a feedback in government bond shock on government expenditure, and b^G_{t-1} is a real government bond in last period. Normally, the government negatively responds to the level of government bonds for curbing the future debt. Lastly, ρ^{G,Y^N} is a feedback in real GDP shock on government expenditure. σ shows a proportion of nominal government expenditure to GDP. In practice, government usually sets a size of nominal government expenditure to a certain percentage of GDP.

The government budget constraint, which is composed of a level of government spending, a total government revenue and a government bond, is adapted from Zubairy (2014). Her study employs a DSGE model with a rich fiscal policy block. The present model investigates three type of taxes, namely, a sales tax, a payroll tax and a capital tax. Each government revenue can be assumed as follows:

Sales tax revenue

$$T^s_t = \tau^s_t P^D_t C_t \tag{47}$$

Payroll tax revenue

$$T^w_t = \tau^w_t W_t L_t \tag{48}$$

Capital tax revenue

$$T^k_t = (1-\delta)\,\tau^k_t R^K_t K_t \tag{49}$$

The government budget constraint can be assumed as follows:

$$B^G_t = (1+R_{t-1})B^G_{t-1} + P^D_t G_t - \sum_{j=s,w,k} T^j_t \tag{50}$$

B^G_t is a government bond which is issued for financing government expenditure by fiscal authority. The government bond can be bought by household agents, domestic firms and foreign firms. There are two components of government bond. The first component is a bond in last period including interest rate payment. The second component is a primary government deficit, which is the difference between government expenditure and total government revenue. The sum of tax revenue is composed of a sales tax revenue, a payroll tax revenue and a capital income tax revenue. In addition, the real government bond, $b_t^G = \frac{B_t^G}{P_t^D}$, can be assumed as follows:

$$b_t^G = \frac{(1 + R_{t-1})}{\pi_t} b_{t-1}^G + G_t - \tau_t^s C_t - \tau_t^w w_t L_t - (1 - \delta)\,\tau_t^k r_t^K K_t \tag{51}$$

2.3.6 Central Bank Sector

The central bank is another significant authority in the model. The primary objective of the central bank is ensuring the economy's price stability by employing monetary policy. The monetary rule can be expressed as follows:

$$R_t = \rho^R R_{t-1} + \left(1 - \rho^R\right)\left[R^{ss} + \kappa\left(dP_t^D - \bar{\pi}\right)\right] \tag{52}$$

A policy interest rate, R_t, which is set by the central bank, is composed of two weighted components. ρ^R denotes a weight that assigns to each component. The first term is a weighted average of previous period interest rate, R_{t-1}. The central bank is assumed to acquire inflation targeting policy for their principle anchor. The second term is a weighted target policy rate in the current period. Target policy interest rate is composed of a steady-state nominal interest rate, R^{ss}, and a response of the different between expected inflation in the next period, dP_t^D, and a target inflation, $\bar{\pi}$. The degree of the central bank's reaction to an inflation deviation is called κ.

2.3.7 Definition of equilibrium

The model's equilibrium is made up of a series of prices and an allocation of households and production firms such that all of the first order conditions and a zero profit equilibrium of perfect competitive banks is achieved. The examples of the first order conditions are a maximization of discounted present value of utility of households and a maximization of the discounted present value of profit of firms. Both a simple fiscal rule of government and a simple monetary rule of the central bank are satisfied. All of the dynamic equations, which is presented as a law of motion, such as a law of debt motion, are fully accomplished. Lastly, a market's clearing condition is satisfied and a steady-state condition of all markets is cleared.

2.3.7.1 Market Clearing Condition

In New Classical economics, a market clearing condition refers to the market which has a level of goods supply equal to a level of goods demand. A price level that a level of supply meets a level of demand is called a market clearing price. Both price and quantity are freely adjusted until reaching a market clearing condition. Domestic output and export output under the market clearing condition can be expressed as follows:

$$Y_t^D = C_t + I_t + G_t \tag{53}$$

$$Y_t^X = X_t \tag{54}$$

Moreover, factors of production are also adjusted until they reach a market clearing condition. The following are market clearing conditions for factors of production:

$$L_t = L_t^D + L_t^X \tag{55}$$

$$M_t = M_t^D + M_t^X \tag{56}$$

$$K_t = K_t^D + K_t^X \tag{57}$$

The equilibrium on the loan market defines the demand for financing through domestic deposits.

$$D_t + B_t = W_t L_t^d + B_t^G \tag{58}$$

, where B_t^G is government debt.

2.3.7.2 Steady State Condition

After a period of adjusting, all macroeconomic variables reach the final condition, which is called a steady-state condition. In the steady-state, some properties of variable are unchanged, such as quantity and growth rate. An explosion or a collapse of macroeconomic variables can be averted when the growth rate of these variables is set to be a constant (Tanboon 2008). The steady-state condition of each macroeconomic variables can be assumed as Table 1

Table 1: Steady state condition of each macroeconomic variables

Variables	Growth rate (%)
Real Variables	
$Y^D, Y^X, Y^N, C, I, G, X, K^D, K^X, M^D, M^X$	α
L^D, L^X	0
Domestic Prices	
$P^D, P^X, P^M, R^K, Q^D, Q^X, Q^K$	π
R, R^L, R^*	0
W, Q^L	$\alpha + \pi$
Nominal Variables	
B, B^G	$\alpha + \pi$
Foreign Prices	
P^{XF}, P^{MF}	π^*
Exchange Rate	
dS_{t+1}	$\pi - \pi^*$

Most of the steady-state condition of the present DSGE model shares several features with Tanboon (2008)'s study. In the steady-state, all real variables, except labour supply, increase at a productivity growth rate, α, on the balance growth rate. The labour for domestic firms and labour for export firms are not grown, zero growth rate, for avoiding an explosion of the population. The growth rate of all domestic prices, except interest rate, labour loan interest rate, nominal wage, and shadow price of labour, are set at the target rate of inflation. All interest rates are fixed at a constant in the steady-state. Nominal wage and shadow price of labour are grown at the rate of $\alpha + \pi$. The growth rate of nominal variables, which are Y^N, B, B^G is $\alpha + \pi$.The foreign price of export and import goods grow at π^*. Lastly, the depreciation rate of the expected exchange rate is $\pi - \pi^*$.

2.3.8 Structure of Exogenous Processes

This section explains the dynamic of exogenous processes of selected exogenous variables, such as a government spending and tax rates. Exogenous processes are primary shocks that affect the economy. These processes occur once at the beginning of the examination. In the present model, the exogenous processes follow an automatic stabilizer process of selected exogenous variables. Although literature reviews have indicated that there was no specific structure of fiscal policy (Romer & Romer 2007), a structure of fiscal policy shocks in this model follows a fiscal study by Romer & Romer (2007) and Zubairy (2014). A government expenditure innovation and a taxation innovation are presented as follows:

2.3.8.1 Government expenditure shock

A government maintains expenditures with an automatic stabilizer process. This feature allows a minimizing of fluctuations in real GDP. Without specific new legislation, government spending is set to have a feedback response to three components: 1) the state of an economy, which is recognized by a one-period lag of GDP, 2) the level of government debt, which help to prevent a high debt situation, and 3) a one-period lag in government expenditures. Innovation processes for government expenditures can be assumed as:

$$G_t = \rho^G G_{t-1} + \rho^{G,B^G} b_{t-1}^G + \rho^{G,Y^N} Y_{t-1}^N + \varepsilon_t^G \tag{59}$$

A one-time increase in government expenditures is implemented for investigating an impact of fiscal policy on the small-open economy. This fiscal policy innovation represents a common government practice when a country faces an economic recession. The government expenditure process consists of three persistence parameters; namely, persistence in government expenditure shock, ρ^G, feedback in government bond shock on government expenditure, and feedback in real GDP shock on government expenditure, ρ^{G,Y^N}. These parameters are set in the range (-1,1), or $\left|\rho^{GS}, \rho^{G,B^G}, \rho^{G,Y^N}\right| < 1$ to achieve a stationary process. ε_t^G is a white noise process with a zero mean and constant variance, σ_ε^2.

2.3.8.2 Taxation shocks

Similar to government expenditure innovation, a government maintains taxation by the automatic stabilizer process. Taxation is also set to have a countercyclical process with three components: 1) the state of an economy, 2) the level of government debt, and 3) the one-period lag in government expenditures. The objectives of taxation policy are to establish long term economic growth and to control the level of fiscal deficit. Taxation innovation processes can be assumed as:

$$\tau_t^s = \rho^{\tau^s} \tau_{t-1}^s + \rho^{\tau^s,B^G} b_{t-1}^G + \rho^{\tau^s,Y^N} Y_{t-1}^N + \varepsilon_t^{\tau^s} \tag{60}$$

$$\tau_t^w = \rho^{\tau^w} \tau_{t-1}^w + \rho^{\tau^w,B^G} b_{t-1}^G + \rho^{\tau^w,Y^N} Y_{t-1}^N + \varepsilon_t^{\tau^w} \tag{61}$$

$$\tau_t^k = \rho^{\tau^k} \tau_{t-1}^k + \rho^{\tau^k,B^G} b_{t-1}^G + \rho^{\tau^k,Y^N} Y_{t-1}^N + \varepsilon_t^{\tau^k} \tag{62}$$

A one-time decrease in the tax rate is implemented for investigating the impact of fiscal policy on the small-open economy. Similarly, a reduction in the tax rate is usually introduced during economic slowdowns. Each taxation process consists of its feedback parameters, such as a feedback in tax rate shock, ρ^{τ^i}, a feedback in government bond shock on tax rate, ρ^{τ^i,B^G}, and a feedback in real GDP shock on tax rate, ρ^{τ^i,Y^N}, where i represents three types of taxation. To ensure the stationary process, the absolute value of all feedback is smaller than 1, as follows: $\left|\rho^{\tau^i}\right| < 1$. Moreover, $\varepsilon_t^{\tau^s}$, $\varepsilon_t^{\tau^w}$, $\varepsilon_t^{\tau^k}$is a white noise process with a mean of zero and constant variance, σ_ε^2.

2.3.9 Opportunities and limitations of the model

A DSGE model is constructed in order to imitate both long-run and short-run (business cycle) properties of a small open economy. Several model's features are employed to mimic Thailand economy such as habit formation specification, investment adjustment cost, price mark-up specification, and wage setting specification. For the business cycle property, the persistences in macro economic variable are important features of this DSGE model. The persistence shows how today economic shock affects the macroeconomic variables in the future. The persistence is commonly measured by autocorrelation function. The higher autocorrelation coefficient, the larger the persistence. According to Tanboon (2008), Thailand's detrend output, private consumption, and investment have a high first-order autocorrelation coefficient (approximately 0.6-0.7). The large first-order autocorrelation coefficient illustrates that Thailand economy has a significant degree of persistence in private consumption and investment. Therefore, including the habit formation specification and the investment adjustment cost in the DSGE model helps satisfying the business cycle property of this model.

The model incorporates the monopolistic distortions and the rigidities in the price and wage setting. The monopolistic distortion in wage arises in an imperfectly competitive labour market since the trade union has a collective bargaining power with firms to gain a wage mark-up. Thailand has a number of labour organization (1482 organizations in 2016)[3], for example, Public Enterprise Association, Labour

[3]Source: Yearbook of Labour Protection and Welfare Statistic 2016, Department of Labour

Union (Private Enterprise), Public Enterprise Labour Union Federation. Labour organization not only use their collective bargaining power to increase real wage but also improve welfare and living standards of their members. The monopolistic distortion in price occurs from several factors, such as when firms can differentiate their product when firms invent and acquire patents of a new product, and when firms' production function is an increasing return to scale (Judd 2002). A price mark-up can be computed from an input-output table as the ratio of the total value of production to the total cost of production. The National Statistical Office, Thailand, publishes the input-output table of Thailand economy annually. The calculation suggests that the price mark-up is not zero. Hence, the monopolistic distortions in price and wage are the important characters of Thailand economy.

The characteristic of wage and price rigidities follows the study of Rotemberg (1982). The price adjustment is costly for firms, for example, firms have to print new price tags. According to Levy, Bergen, Dutta & Venable (1997), the menu costs is approximately 0.70 percent of revenues and 35.2 percent of net margins of multistore supermarket chains. In addition, a recurrent price adjustment may bother customer's perception. A number of price rigidity studies agree that prices are sticky (Rotemberg 1982, Alvarez, Dhyne, Hoeberichts, Kwapil, Bihan, Lünnemann, Martins, Sabbatini, Stahl, Vermeulen et al. 2006). Rotemberg (1982) investigates U.S. postwar price and concludes that the hypothesis that price is not sticky is rejected. Alvarez et al. (2006) study price setting by using consumer price index and producer price index in Euro area. They find that a price stickiness in Euro area is higher than a price stickiness in the U.S.

Financial frictions in bank sector and bond market are included in the present DSGE model. The risk premium in bond market arises when foreign debt to nominal GDP ratio is greater than a ratio of debt to GDP in steady-state. Adolfson, Laséen, Lindé & Villani (2007) study the incomplete pass-through in Eurozone and add the premium on foreign bond holdings in the uncovered interest rate parity. They suggest that the risk premium shows an imperfect

protection and welfare, Ministry of Labour, Thailand.

integration in the global financial markets. The financial frictions in bank sector occur when there is a spread between a lending interest rate and deposit interest rate. This spread is larger during economic contraction as banks' willingness to lending is reduced and smaller during an economic boom. Atta-Mensah & Dib (2008) study the role of bank lending under alternative Taylor-type rules with financial friction in bank sector. They find that the financial friction magnified the responses of real variables to monetary policy, for example, output. Therefore, the financial frictions in bank sector and bond market are important features of the dynamic of the economy.

Fiscal rule and taxation shocks are presented as a persistence and feedback process. In contrast to monetary policy, fiscal policy is not generally specified. Government tries to maintain long-term economic growth and stabilize the economy when faces external shock. The fiscal rule of the present model follows Zubairy (2014). Fiscal rule and taxation shocks respond to the state of an economy, the level of government debt, and the one-period lag in government expenditures. The empirical data shows that Thailand fiscal rule is consistent with this process. For example, Thailand government expenditure to GDP increases from 16.3% in 2007 to 17.9% in 2009, as a response to the global financial crisis [4] and a high correlation of a government expenditure in the current and previous periods (0.85 during the 1989-2014 period).

The monetary rule of this model composed of two weighted components, namely, a persistence of one-period lag in interest rate, and a inflation targeting term. The bank of Thailand conducts inflation targeting policy for its principle anchor since 2000. The target range is set for a core inflation at 0-3.5 percent. The bank of Thailand deliberately raised policy interest rate when inflation is higher than the target inflation, for example, in 2006. This ensures the overall price stability in the long run.

Although this model employs several economic frictions, there are a number of friction that can be further investigated, for example, trade frictions (when the

[4] Source: The Databank, Worldbank, https://data.worldbank.org

law of one price does not hold).

2.3.10 Model Parameters Calibration

The DSGE model parameters can be determined from two extensively used methods. The first method is called an estimation. Even though an estimation can properly generate model parameters, this method has several drawbacks through estimating a corresponding likelihood, as it can create several local maxima and discontinuities (Tanboon 2008). Nevertheless, to remedy the problem of likelihood estimation, the Bayesian estimation has been lately introduced for DSGE models. The problems of identification and misspecification can be solved by using Bayesian approach (Canova & Sala 2009). The second method is a calibration which uses various empirical data for adjusting the model parameter. The calibration method is used for the present study, because it can conveniently describe the Thailand economy structure. The model parameters of this thesis are mostly obtained from Tanboon (2008) and calculated from raw data. The data for calibrating the Thailand economy is received from numerous sources, including The Bank of Thailand Structural Model for Policy Analysis (Tanboon 2008), Office of the National Economic and Social Development Board[5], the Bank of Thailand Macroeconometric Model, Fiscal Policy Office, and The Revenue Department of Thailand. The model parameters are summarized in Table 2.

The parameters of households are explained as follows. Discount factor, β, is calculated based on a real interest rate of 3% per year. The Discount factor is transformed from an annual parameter to an quarterly parameter through a power of $\frac{1}{4}$, where $\beta = \frac{1}{(1+0.03)^{1/4}} = 0.9926$. The consumption habit persistence factor, χ, is adopted from Tanboon (2008). He employs the Generalized Method of Moments (GMM) estimation, which is effectively applied with moment equation, for estimating of χ. The Euler equation is constructed from Thailand's

[5] http://www.nesdb.go.th/

Table 2: The model parameters

Symbol	Parameter	Value
β	Discount factor	0.9926
χ	Consumption habit persistence factor	0.85
φ^L	Scaling parameter of labour disutility function	1
η	Inverse of Frisch elasticity	3.0303
ξ^I	The elasticity of investment adjustment cost	0.9
α	Productivity growth rate	0
δ	Depreciation rate	0.0072
μ^W	Wage markup	1.05
ξ^W	The elasticity of wage adjustment cost	9
R^*	Foreign interest rate	0.0036
ξ^B	The elasticity of interest rate premium on foreign debt holdings	0.35
ψ	The foreign debt-to-GDP ratio at steady-state	0.299
υ	The gap between domestic and foreign interest rate	0.0025
γ_L^D	Labour income share of domestic firms	0.76
γ_M^D	Imported input income share of domestic firms	0.12
ξ^D	The elasticity of price rigidities	9
μ^D	Domestic price markup	1.02
γ_L^X	Labour income share of foreign firms	0.72
γ_M^X	Imported input income share of foreign firms	0.14
τ	The degree of bank willingness to lend subject to the relative GDP growth rate	0.6
ρ^G	The degree of government expenditure persistency	0.85
σ	The specific ratio of government expenditure to GDP	0.149
ρ^R	The degree of interest rate policy persistency	0.9
$\overline{\pi}$	Inflation target	0.0
κ	The sensitivity of interest rate policy to inflation	20
ρ^T	The degree of terms of trade persistency	0.8
π^*	Foreign inflation at steady stage	0.0

Table 2: The model parameters (continued)

Symbol	Parameter	Value
P^D	Domestic price of consumption and investment goods	1.0
P^{XF}	Foreign export price	1.0
P^{MF}	Foreign import price	1.0
τ^s	Sales tax	0.07
τ^w	Payroll Tax	0.131
τ^k	Return on capital Tax	0.1
ρ^{τ^s}	The degree of sales tax innovation persistency	0.9
ρ^{τ^w}	The degree of payroll tax innovation persistency	0.9
ρ^{τ^k}	The degree of return on capital tax innovation persistency	0.9
ρ^{G,B^G}	The feedback in government bond shock on government expenditure	-0.17
ρ^{τ^s,B^G}	The feedback in government bond shock on sales tax rate	0.020
ρ^{τ^w,B^G}	The feedback in government bond shock on payroll tax rate	0.029
ρ^{τ^K,B^G}	The feedback in government bond shock on capital tax rate	0.017
ρ^{G,Y^N}	The feedback in real GDP shock on government expenditure	-0.039
ρ^{τ^s,Y^N}	The feedback in real GDP shock on sales tax rate	0.100
ρ^{τ^w,Y^N}	The feedback in real GDP shock on payroll tax rate	0.132
ρ^{τ^k,Y^N}	The feedback in real GDP shock on capital tax rate	0.148

consumption data between 1994 and 2006, and his result illustrates the value of χ in the band of 0.84 to 0.88. The scaling parameter for labour disutility function, φ^L, which represents a wideness of distribution of disutility function, is set to 1. This implies no scaling for labour disutility function. The inverse of Frisch Elasticity, η, is computed from a Frish elasticity of Tanboon (2008). The researcher employed OLS estimation to a labour supply equation by using Thailand labour data. The estimated Frisch elasticity is 0.33, and this result is comparable with a range from 0.27 to 0.53 and 0.54, results which are respectively estimated by Reichling & Whalen (2012) and Chetty, Guren, Manoli & Weber (2011). Therefore, in this equation, $\eta = \frac{1}{0.33} = 3.0303$. The elasticity of investment adjustment cost, ξ^I, is set to 0.9 for compatibly adjusting the dynamic response of investment to Thailand's economy. This parameter measures the degree of investment adjustment cost when the growth rate of private investment, $(\frac{I_t}{I_{t-1}})$, is not equal to $1 + \alpha$, which is the growth rate of economic at balance growth path. The productivity growth rate, α, is set to 0 for the simplicity of the model. A depreciation rate, δ, is estimated from Thailand's gross capital stock and investment during 1980-2012. This calculation is derived from a capital accumulation equation as given.

$$\begin{aligned} K_{t+1} &= (1-\delta)\,K_t + F(I_t,I_{t-1}) \\ K_{t+1} &= (1-\delta)\,K_t + I_t \\ \delta &= \frac{K_t - K_{t+1} + I_t}{K_t} \end{aligned} \tag{63}$$

The estimation illustrates that Thailand average annual depreciation rate is 2.9% or 0.72% per quarter. The wage markup, μ^W, is employed from Tanboon (2008). The calculation is based on data from the National Statistic Office's website[6] and The Office of the National Economic and Social Development Board's website. Tanboon (2008) suggests that μ^W is 1.05. The elasticity of wage adjustment cost, ξ^W, represents the intensity of wage rigidity. For consistency with a dynamic response of Thailand's economy, ξ^W is set to 9. Foreign Interest Rate, R^*, is an average interest rate of Thailand's major trading partners, namely, the United States, the European Union, China and Japan. The average interest rate of Thailand's major trading partners as of 9 Feb. 2015 is 1.45%, thus, $R^* = \frac{1}{4}\ln(1+0.0145) = 0.0036$. The elasticity of interest rate premium on foreign debt holdings, ξ^B is set to 0.35 for elaborating the exchange rate's dynamic response in Thailand's economy. The foreign debt-to-GDP ratio at steady-state, ψ, is set to 29.9%, which is the average of Thailand Foreign Debt-to-GDP Ratio during 2005 to 2014. The gap between domestic and foreign interest rate, υ, is set to 0.0025, which implies one percentage point of gap between domestic and foreign interest rate, or $\upsilon = \frac{1}{4}\ln(1+0.01) = 0.0025$.

In addition, the parameters of both domestic and foreign firms are described as follows. The labour income share of domestic firms, γ_L^D, is set to 0.76 , which is selected from Guerriero (2012). She estimates the labour share of 89 countries, both developed countries and developing countries, during year 1970-2009. Moreover, his study also illustrates that the labour income share is varied over the time. The finding of Guerriero (2012) is comparable with 0.69 and 0.70,

[6] http://web.nso.go.th/

which are respectively estimated by Ahuja, Peungchanchaikul & Piyagarn (2004) and Tanboon (2008). The remaining income share of domestic firms is equally allocated to the imported input income share, γ_M^D, and capital income share, $1 - \gamma_L^D - \gamma_M^D$, or $\gamma_M^D = 1 - \gamma_L^D - \gamma_M^D = \frac{(1-0.76)}{2} = 0.12$. The labour income share of foreign firms, γ_L^X, is set at 0.72, slightly lower than one of the domestic firms. The main difference is a lower labour intensiveness in the production technology of foreign firms. Similarly, the remaining income share of foreign firms is uniformly assigned to the imported input income share, γ_M^X, and capital income share, $1 - \gamma_L^X - \gamma_M^X$, or $\gamma_M^X = 1 - \gamma_L^X - \gamma_M^X = \frac{(1-0.72)}{2} = 0.14$. Since the imported input income share of foreign firms is greater than one of the domestic firms, foreign firms use imported input more than domestic firms.

The elasticity of price rigidities, ξ^D, which represents the cost of the different of inflation expectation, is set to 9 for properly adjusting the dynamics of inflation to actual Thai data. The domestic price markup, μ^D, is employed from Tanboon (2008) and set to 1.02. The price markup is calculated based on an input-output matrix which is collected from the Office of the National Economic and Social Development Board. The degree of bank willingness to lend subject to the relative GDP growth rate, τ, is set to 0.6, which is located between 0.5 and 1.48 from the estimation of Tanboon (2008) and Atta-Mensah & Dib (2008), respectively. The spread of Thailand's deposit interest rate and borrowing interest rate is particularly uniform and corresponding with economic growth (Tanboon 2008). Thus, τ is calibrated for producing a realistic and dynamic response in Thailand's banking sector. The specific ratio of government expenditure to GDP, σ, is set to 0.149. This value reflects an average share of government expenditure, which, as the sum of government consumption and government investment at 1988 prices, is 14.9% during the 2005-2014 period.

The degrees of persistence and parameters of monetary policy authority is assumed as follows. The degree of interest rate policy persistency, ρ^R, and the sensitivity of interest rate policy to inflation, κ, is adjusted for illustrating the structure of interest rate channel of Thailand's economy. ρ^R is set to 0.9 and κ

is set to 20. The inflation target, $\overline{\pi}$, is set to 0, which implies zero inflation along the balanced growth path. Similarly, the foreign inflation at steady-state, π^*, is set to 0. The degree of terms of trade persistence, ρ^T, is set to 0.8. This parameter conducts the persistence of trade terms in a first-order autoregressive process. The domestic price of consumption and investment goods, P^D, foreign export price, P^{XF}, and foreign import price, P^{MF}, is normalized to 1.0.

For the exogenous processes of fiscal innovation, the degree of government expenditure persistence, ρ^G, is calculated from the Thailand's government expenditure during the 1989-2014 period. The result shows that ρ^G is 0.85, implying a considerably high correlation of a government expenditure in the current and previous periods. The degree of tax innovation persistence, namely , $\rho^{\tau^s}, \rho^{\tau^w}, \rho^{\tau^k}$, is set to 0.9. A setting of the persistence in government bond shock and the persistence in real GDP shock follows the approach of Zubairy (2014). She suggests that the fiscal persistence parameters should be set in order to curb the level of government debt during the next period taxed. Furthermore, a lower level of government expenditure over time is necessary for satisfying a government budget constraint and reaching the equilibrium. A numerical representation of the feedback is directly adopted from Zubairy (2014), such as, ρ^{τ^K,B^G}, ρ^{τ^w,Y^N}, ρ^{τ^k,Y^N}. The sales tax, τ^s, is set to 0.07, and is used to represent a Value-Added Tax (VAT) at 7% in Thailand. The payroll tax, τ^w, is calculated from Thailand's personal income tax in 2011. Since Thailand's personal income tax is collected based on the progressive rate, the payroll tax is the weighted average of Thailand's personal income tax. The number of taxpayers is used for determining the weight of each tax bracket. The finding shows that the weighted average personal income tax of Thailand is 13.1%. The capital income tax, τ^k, is set at 0.1. The return of capital can be received in the form of capital gains and dividends. In Thailand, a capital gain is not levied, while a dividend income is taxed at 10%.

2.4 FISCAL POLICY SHOCKS

This section illustrates the dynamic effects of fiscal policy shocks on a country with a small-open economy. The responses of macroeconomic variables towards new a steady-state after various shocks are computed. The calculation is composed of two essential procedures. The first step is an estimation of the steady-state condition of each equation in real terms. The steady-state value of all variables is computed on the balance growth path given zero productivity growth rate, $\alpha = 0$, and zero inflation, $\bar{\pi} = 0$. The second process is a log-linearizational equations, in real terms, by applying the Taylor first-order approximation. The details of the estimation of all log-linearized equations can be found in Appendix A.2. These Log-Linearlized equations will be used to describe the dynamic response of macroeconomic variables. After deriving Log-Linearlized equations, the Dynare[7] is employed for computing the transition dynamic of each variable to its new steady-state when several types of shocks are introduced. As part of this, a prospective increase in government spending shocks is also explained. Later, the taxation shocks, namely, sales tax shock, payroll tax shock, and a capital income tax shock, are illustrated and compared with other forms of tax. The x-axis and y-axis present the fiscal quarters after these fiscal shocks affect both the economy and the percentage deviation from the steady-state value respectively.

2.4.1 Government Expenditure Transmission

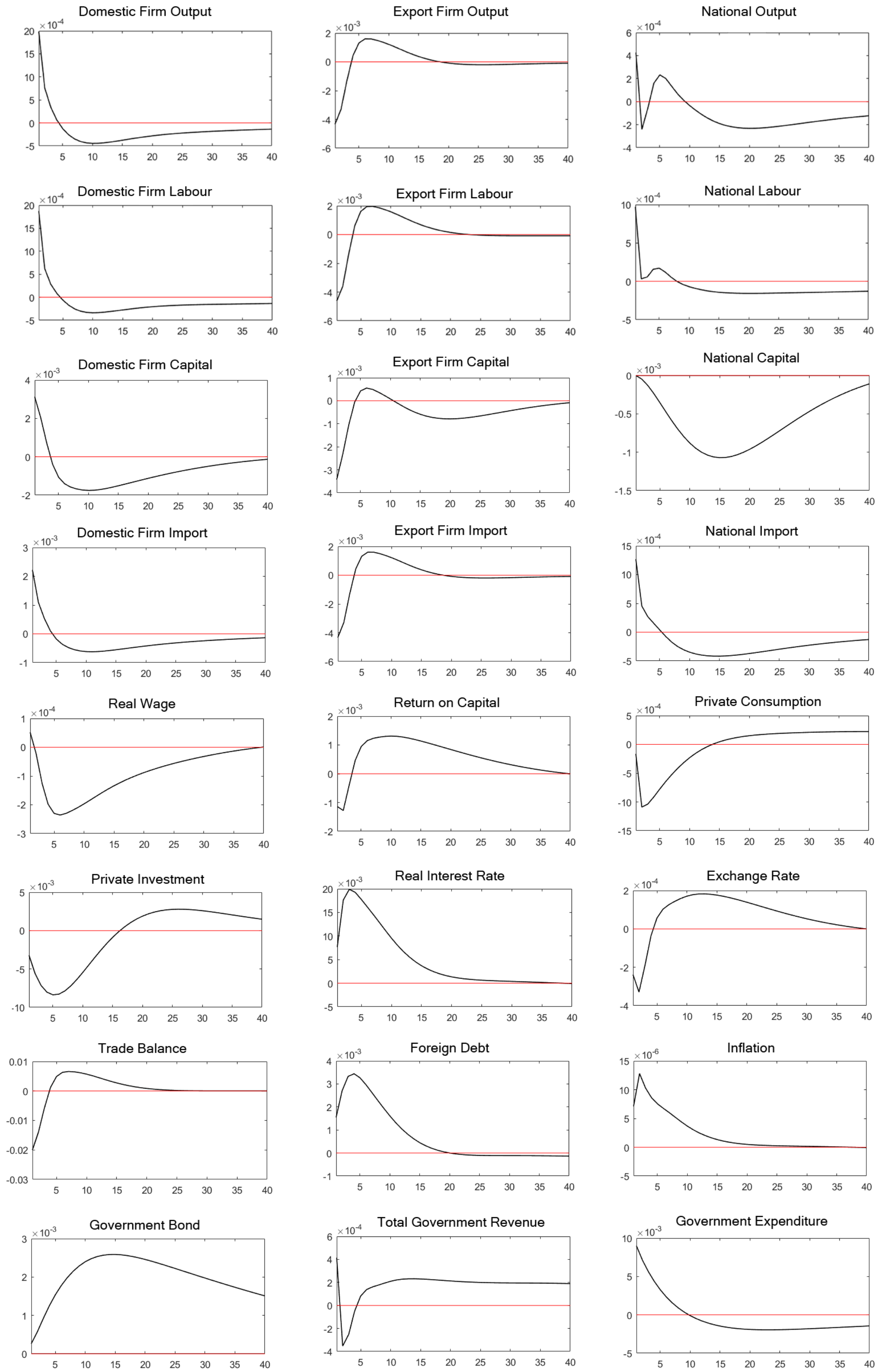
In order to investigate the transmission of government expenditures, the DSGE model introduces one standard deviation of increase in the government expenditure shock in period 1 to the small-open economy. This shock is temporary and follows an automatic stabilizer process. Hence, it gradually

[7]Dynare is a MATLAB software which is used to simulate economic models, in particular DSGE model. The calculation is relied on the rational expectation hypothesis.

diminishes during the following period. The expansion of government expenditures impacts both the internal and external sides of a small-open economy. Locally, domestic agents, such as households and domestic firms, would suddenly adjust to the government-implemented shock. In contrast, export firms will sensitively respond to external side variables, like the exchange rate and export price. An increase in government expenditure shock represents a sudden increase in government consumption and/or investment which is often implemented during a crisis or economic downturn. Figure 1 illustrates the impulse response function (IRF) of various macroeconomic variables, including output of domestic firms, output of export firms, households consumption, and households labour supply, etc. By comparing the output response of domestic firms and export, the opposite direction of output is clearly noticed. In this case, domestic firms facilitate government actions by producing more output when fiscal shocks affect the economy. Therefore, the output of domestic firms increases over the first period when the government increases its spending. All of the domestic firms' factors of production (labour, capital, and intermediate goods) then rise. The higher domestic firms's production places a pressure on the price of factors of production like real wages, which increase during the first period and then drop over time. Therefore, both domestic and export firms face a rise in their total costs. Unlike domestic firms, export firms cannot raise the price of their goods since a small-open economy is a price-taker. Those goods are thus sold to the global market at world price. Hence, the profit of export firms declines and their outputs fall in the first period. In addition, with regard to the market clearing condition, these factors of production are re-allocated from export firms to domestic firms; thus, the factors of production of export firms also drop. The decreasing of export firms' factor of production leads to a fall in the export firms' output. The return on capital falls after the introduction of government expenditure shocks. A decrease in the return on capital impacts the wealth of households, an outcome referred to as a wealth effect. The households who perceive a lower income consume less than the previous period. The decline of private consumption affirms a positive wealth effect, which is a positive relation between households income and private consumption. Nevertheless, private consumption slightly decreases in the early stage because the model adheres to habit-adjusted private consumption. Private consumption reaches its bottom in the second period. In addition to the wealth effect, the substitution effect is considerably noticed. When the real wage decreases, households move away from consumption and begin to work more. As a result, the domestic firms labour force rise. Private investment gradually falls in the first period because of an increase in the interest rate and a rise in the capital tax from automatic stabilizers. The lowering of private investment shows a crowding out effect from an increase in government spending.

In addition to the internal side effect, the expansion of government expenditures also affects the external stability of a small-open economy. Externally, the shock from government expenditures causes the exchange rate to appreciate in the first period due to a rise in interest rates. An appreciation of local currency reduces the export volume in the first period when the shock arrives at the economy, because the price of export goods in the foreign currency increases. A decrease in exports and an increase in imports worsen a trade balance. From the law of debt motion, foreign debt eventually increases when the trade balance worsens. Under UIP conditions, an increase in the foreign debt also contributes to a rise in the interest rate. When the impacts of both domestic firms output and export firms output are combined, a national output surges in the first period after an increase in government spending, and a price lever increases after fiscal shocks. An increase in government expenditures shifts the IS curve to the right and induces more aggregate demand. Since LM curve does not move, the new equilibrium has both a higher output and a higher price. An increase in the price level brings an inflationary pressure on the economy. The central bank consequently increases the interest rate in response to an increase in inflation, an action called a contractionary monetary policy, to reduce inflationary pressure. The contractionary monetary policy eventually lowers the

Figure 1: The impulse response's function of macroeconomic variables to a one percent increasing in government expenditures



production of domestic firms back to a steady-state level. All variables in the supply side, such as a supply of labour, intermediate goods, and capital for domestic firms also return to the pre-shock level. Subsequently, households' incomes revert to pre-shock levels because a real wage increase to the pre-shock level. Thus, as a result of the wealth effect, private consumption and private investment rise to their initial values. Considering the duration of government expenditure innovation, IRF shows that the positive impact of government expenditure expansion to domestic output is finally eliminated within 4 periods, or 1 year, on a quarterly basis after the shock is introduced.

The finding is consistent with the results of many studies on the DSGE model , including Ratto et al. (2009) who investigated the impact of fiscal policy and monetary policy on the Eurozone by using a DSGE model for an open economy with Bayesian estimation techniques and Zubairy (2014) who employed a DSGE model with fully fiscal policy elements and a channel of government expenditure innovations to calculate the fiscal multipliers of various fiscal shocks. Both studies confirm that an increase in government expenditure potentially leads to an expansion in the domestic output. In addition, the observed crowding out effects of interest-sensitive variables are also along the lines of earlier studies by Ratto et al. (2009) and Zubairy (2014) who find a crowding out in private investment after an increase in government expenditure, as well as Ratto et al. (2009) and Forni et al. (2009) who present a fall in the private consumption of Ricardian households as a result of the expansion of government spending. Forni et al. (2009) evaluate the effect on fiscal policy in the Eurozone by using DSGE model featuring a fraction of Ricardian and non-Ricardian agents. Their results illustrate a decrease in the private consumption of Ricardian households and an increase in the private consumption of non-Ricardian households after implementing a government spending expansion.

2.4.2 Taxations Transmission

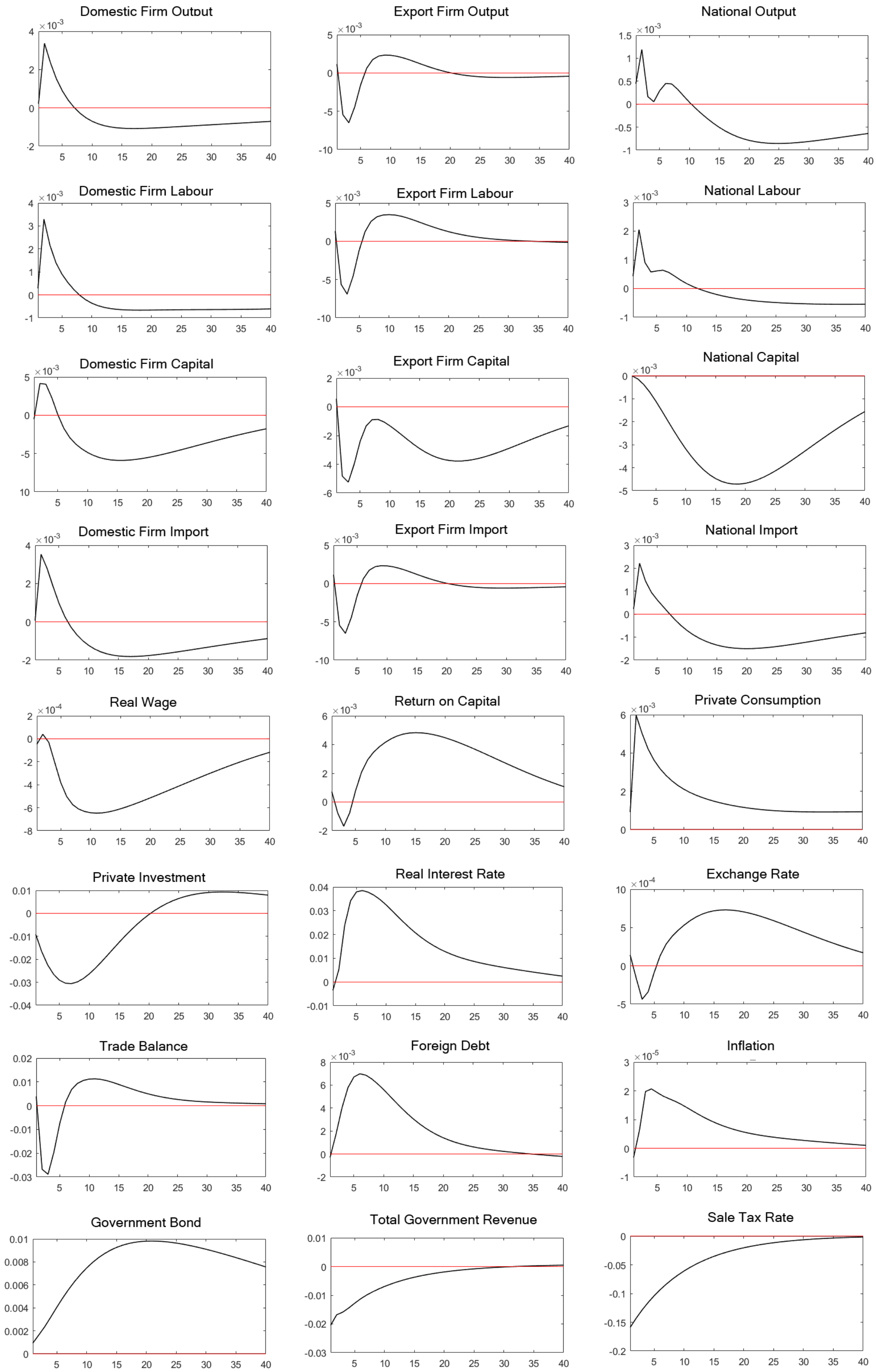
To examine the transmission of taxation, the taxation shocks, namely sales tax shock, payroll tax shock, and capital tax shock, are introduced to the DSGE model. A decrease of one percentage point of these taxation rates is introduced to the small-open economy in period 1. These shocks follow the automatic stabilizer process with a degree of tax innovation persistence at 0.9. Both the internal and external economy are affected by these innovations. The responses of macroeconomic variables to each taxation shocks are examined as follows.

2.4.2.1 Sales tax shock

A sales tax is collected from consumption base, for example, a Value Added Tax (VAT), which is imposed at a specific rate on every household's consumption. An increase in sales tax may directly affect the purchasing power of households and private consumption. Figure 2 presents the impulse response function of a reduction in sales tax shock on the small-open economy. Similar to government expenditure shock, there is a distinct difference between domestic firms' responses and export firms' responses, given the shock of a decrease in the sales tax rate. A one percentage point lowering of the sales tax rate prompts domestic firms to react with a moderate increase in their production during the first period. Later, the response in the domestic output to the tax shock gradually increase, which contrasts with a surge in the first period regarding the response of the domestic output to the government expenditure shock. Domestic output reaches its peak during the second quarter and a rise in domestic output requires more factors of production; thus, domestic labour, domestic capital and domestic intermediate goods are also increased. On the demand side, a lower sales tax rate directly affects private consumption, because, since an included tax price of goods decreases, households agents have higher purchasing power. Such agents can consume more goods with the same amount of income; thus, private consumption starts to rise. However, since a consumption habit persistently lowers the consequences of tax reduction on consumption within the first period, a private consumption moderately adjusts and peaks during the second period. The sales tax shock contributes to a positive wealth effect. In the early stage of the shock, the real wage and the real return on capital increase so that households who have higher wealth can consume more goods. Nevertheless, in the later period, a real wage sharply declines, while the real return on capital considerably rises. In addition, the substitution effect of sales tax shock is not presented. The households do not substitute away from consumption to supplying more labour. Sales tax shock also causes a crowding out effect on private investment, since private investment falls in the first period as a result of a rise in interest rate during the second period and an increase in the capital tax from automatic stabilizers.

Although a reduction in the sales tax rate is designed to stimulate the domestic side of the economy, an external side of the economy also responds to this shock. A response by foreign exchange to the sales tax shock is different from the government expenditure shock. The exchange rate depreciates in the first period, because of a decrease in the interest rate. In contrast, the exchange rate appreciates in the second period when the interest rate increases. Responding to an adjustment of the exchange rate, the export firms' output slightly rises in the first period then significantly falls later. In contrast to the government expenditure shock, the trade balance relatively improves during the first period. However, it is clear that a sales tax shock significantly worsens a trade balance after this policy is fully implemented. When combining a response in both domestic firms' output and export firms' output, it is clear that a national output increases significantly in the first period after a lowering of the sales tax rate. For the price level, after a reduction in the sales tax, inflation decreases because of a sudden drop in the price of goods. However, inflation significantly increases within the second period after an adjustment of aggregate demand. The central bank increases the interest rate following an increase in inflation and stabilizing the price level. The duration of

Figure 2: The impulse response's function of macroeconomic variables to a one percent decrease in sale tax rate



sales tax shock impact is significantly longer than the duration of the government expenditure expansion shock. IRF shows that the positive impacts of the sales tax shock on domestic output finally disappear within 7 periods, or almost 2 years, of a quarterly basis after the shock is introduced.

2.4.2.2 Payroll tax shock

A payroll tax is based on the wage payment of the households' labour supply. An innovation of the payroll tax primarily affects the labour supply of households or employment. Figure 3 shows an impulse response function of various macroeconomic variables when a one percentage point decrease in a payroll tax shock hits the small-open economy. In contrast to a sales tax shock, a payroll tax shock leads to a similar direction of the output response by domestic firms and export firms. Both types of firms increase their production when facing a lower payroll tax rate. A one percentage point lower payroll tax rate results in a large increase in domestic firms production in the first period and reaches its peak during the second period. For export firms, the same shock also leads to a rise in export firms production in the first period. In order to enhance the production, most of the factors of production of domestic firms and exports expand, and only domestic capital lowers. The important role of payroll tax shock is that a decrease in payroll tax rate substantially raises employment, with total labour rising suddenly in the first period and peaking in the second period. Therefore, a payroll tax can be a useful government instrument for mitigating a falling in employment during an economic downturn. Moreover, a payroll tax shock significantly causes a positive wealth effect. Household agents substantially increase their spending as a result of an increase in wealth from a higher return on capital. Private consumption gradually rises in the first period and reaches its peak in the second period. This slowly increase in private consumption results from a consumption habit persistence of household agents. Compared to a sales tax shock, the impact of the payroll tax on wealth effects is relatively large.

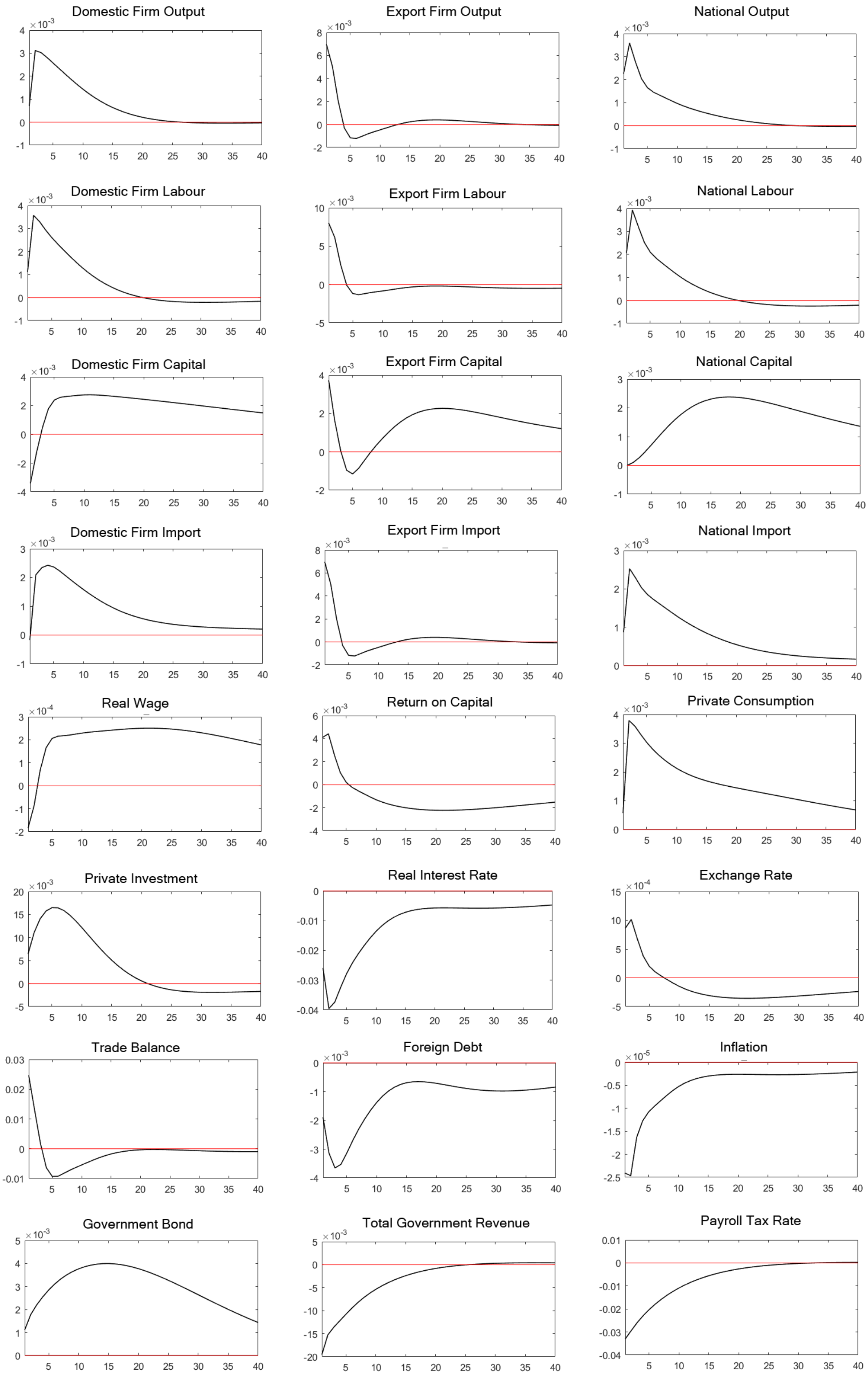
Additionally, the substitution effect of payroll tax shocks is not observed. Households do not switch from consumption to supplying more labour. Furthermore, private investment is definitely higher after a payroll tax shock is introduced. This adjustment presents a noticeable crowding in from the effect of the payroll tax cut. Since an interest rate declines, firms can smoothly expand their investments.

A payroll tax cut also impacts the external side of the economy. The exchange rate depreciates during the first period because of a decrease in the interest rate, similarly to the response of a sales tax shock. This movement of the exchange rate corresponds to a fall in interest rates. The depreciation of exchange rates lead to a rise in export firms' outputs. At the same time, an expansion of output production gives an increase in the importation of intermediate goods. In contrast to a sales tax shock, a payroll tax cut substantially improves the trade balance because an increase in exports is higher than an increase in imports. Since both the domestic firms' output and export firms' output are increased, a national output considerably increases over the first period after a lowering in the payroll tax rate. Another interesting finding is that the impact of cutting the payroll tax rate lasts longer than the impact of lowering the sales tax rate. It is apparent from the IRF that these impacts finally dissolve within 24 to 30 periods, or 6 to 7.5 years, on a quarterly basis, after the shock is first introduced.

2.4.2.3 Return on capital tax shock

A return on capital of households is taxed by a capital tax, such as a capital gain tax from security investments. An innovation of a capital income tax may alter levels of capital and household consumption. Figure 4 demonstrates the impulse response function of a one percentage point decrease in a capital tax rate on the small-open economy. The result shows that there are some differences between an IRF of a capital tax shock and an IRF of previous tax shocks. Similar to the sales tax shock, it is apparent that domestic firms and export firms

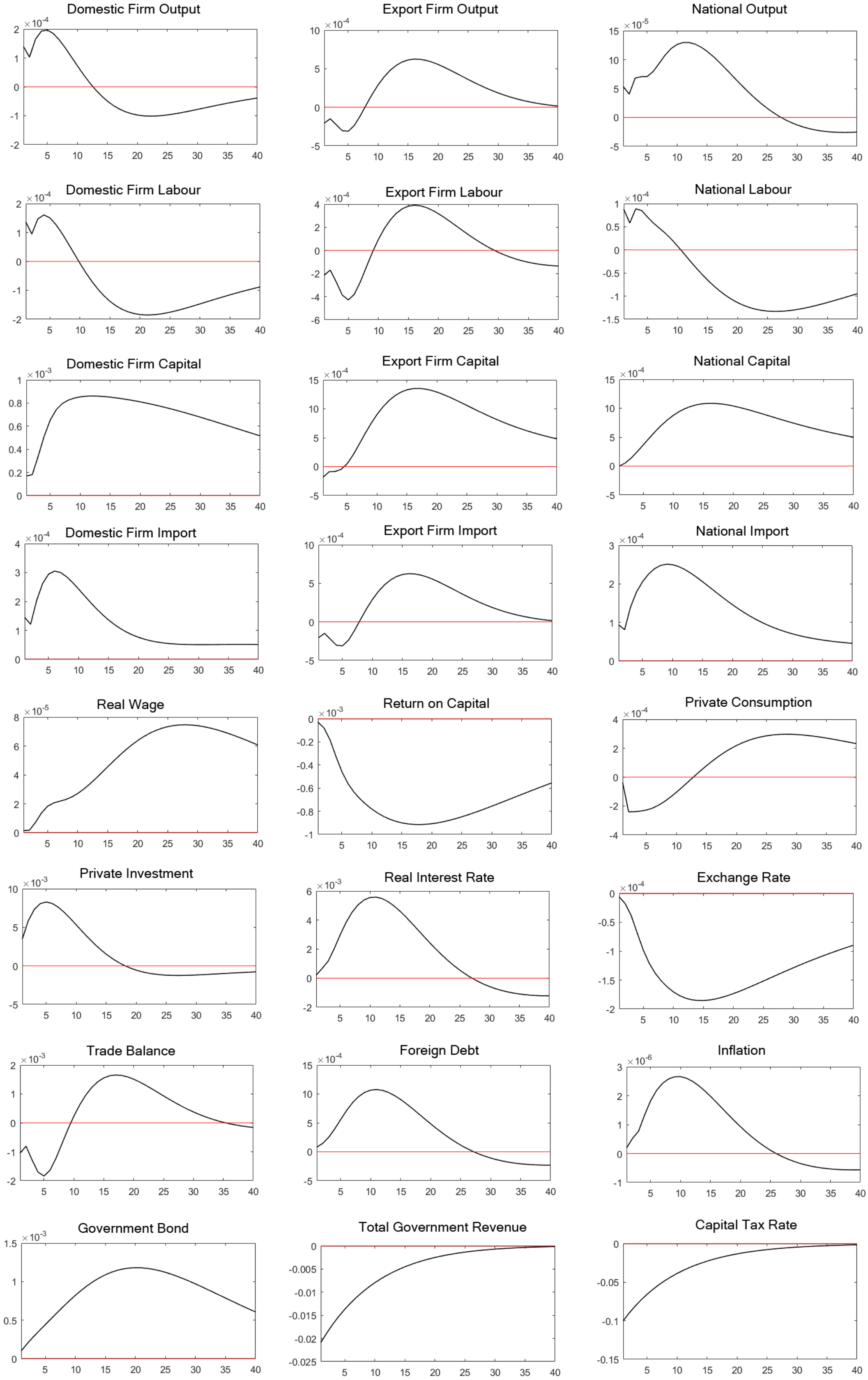
Figure 3: The impulse response's function of macroeconomic variables to a one percent decrease in payroll tax rate



respond to a reduction of the capital tax rate in different positions. The finding provides evidence that domestic firms react to a one percentage point lower capital tax rate with an increase in production during the first period. Then the domestic output is gradually increased to its peak within 5 periods, or 1 year and a quarter on a quarterly basis. This adjustment clearly contrasts with the response of domestic output when facing a government expenditure shock, which is a large surge in the first period. As a consequence of rises in the domestic output, all factors of production, such as domestic labour, domestic capital, and domestic intermediate goods are increased. A lower capital tax rate directly affects the capital of both domestic and export. Since a lowering of the capital tax rate can influence households' decisions regarding the utilization of capital, households gain extra returns on capital income after the capital tax rate is lowered, and, hence, the supply of capital clearly increases during the first period. This finding highlights a wealth effect of capital tax shock. A real return on capital falls in the first period while the real wage slightly increases. This can lower households' incomes and impact households' spending. Although the IRF of private consumption declines in the early stage of shock, it gradually rises again after 12 periods. Moreover, the result shows a substitution effect on households, as households transition from consumption to supplying more labour after the real return on capital falls. The capital tax shock also causes a crowding in effect, since private investment is higher in the first period. The higher private investment corresponds with the rise in capital.

On the external side, an innovation of capital tax impacts the financial market. Interestingly, in contrast with two prior tax shocks, a capital tax shock appreciates the small-open economy's exchange rate. The main influence is a rise in interest rates after the cutting of a payroll tax rate. In response to an appreciation of the exchange rate, the export firms reduce their output in the first period. Similar to a government expenditure shock and a sales tax shock, a capital tax shock worsens a trade balance, since an export declines while an import increases. A lowering of capital tax also affects price stability. When combined with a response

Figure 4: The impulse response's function of macroeconomic variables to an one percent decrease in capital tax rate



of both the domestic firms' output and the export firms' output, a decrease in the capital tax rate leads to an increase in national output in the medium term. Considering price level, a reduction in the capital tax rate results in a fair rise in inflation. The duration of this policy impact is also longer than the duration of the sales tax shock. The IRF presents that these impacts eventually vanish within 12 to 28 periods, or 3 to 7 years, on a quarterly basis after the shock is initially implemented.

The finding of three tax shocks are consistent with findings of past studies by Forni et al. (2009), Faia, Lechthaler & Merkl (2010), Fernández-Villaverde (2010), and Zubairy (2014) in various aspects. For example, a reduction of tax rates can potentially lead to a medium-term increase in output, a impact of sale tax cut on output growth is smaller than a impact of payroll tax cut (Fernández-Villaverde 2010), a reduction of payroll tax and capital tax shocks lead to a crowding in effect on private investment (Zubairy 2014), a reduction of payroll tax causes a crowding in effect on private consumption (Forni et al. 2009), and a reduction of capital tax lead to a crowding out effect of private consumption (Forni et al. 2009).

2.4.3 The Size of Fiscal Multipliers

The effect of fiscal shocks on macroeconomic variables is usually calculated in terms of multipliers. There are two general approaches for fiscal multiplier calculation, with the first being the impact multiplier, which is described as an increase in the level of output, ΔY_0 following a change in fiscal shock level when a fiscal shock, ΔF_0, is introduced. An impact multiplier shows the effect of fiscal innovations on output in a short time period. An impact multiplier is defined as

$$\text{Impact multiplier} = \frac{\Delta Y_0}{\Delta F_0} \tag{64}$$

In addition, the second approach for fiscal multiplier estimation is a present value multiplier. The advantage of this method is that it can examine the size of fiscal impacts in a longer term horizon. The fiscal shock's impact in every period is considered and totally summarized. An accumulative impact of fiscal shock is presented at a given period, N. Moreover, a present value multiplier also discounts the future effect by multiplying with the interest rate's discount factor. The formula of present value multiplier is employed by the studies from Mountford & Uhlig (2009) and Zubairy (2014).

$$\text{Present value multiplier (in } N \text{ period)} = \frac{E_t \sum_{j=0}^{N}(1+R)^{-j}\Delta Y_{t+j}}{E_t \sum_{j=0}^{N}(1+R)^{-j}\left|\Delta F_{t+j}\right|} \quad (65)$$

ΔY_{t+j} is the change of output from the steady-state value at time $t+j$ and ΔF_{t+j} is the change of fiscal shock variable, such as government expenditure shock, and taxation shock from the steady-state value at time $t+j$. The change of variable, namely ΔY_{t+j} and ΔF_{t+j}, from the steady-state value can defined as follows:

$$\Delta Y_{t+j} = \%Y_{t+j} \times Y^s \quad (66)$$

$$\Delta F_{t+j} = \%F_{t+j} \times F^s \quad (67)$$

Where $\%Y_{t+j}$ is a percentage deviation from the steady-state value of Y at time $t+j$, $\%F_{t+j}$ is a percentage deviation from a steady-state value of a fiscal shock variable, such as a shock of government expenditure, and a shock of tax revenue at time $t+j$. Meanwhile, Y^s and F^s represent the steady-state values of output and fiscal shock variables respectively. From the above definitions, an impact multiplier is equal to a present value multiplier in the first period, or quarter 1. Thus, the results are reported as current value fiscal multipliers.

Table 3 shows the calculated present value of fiscal multipliers for the domestic firms' output, the export firms output', and the national output. There are two signs of present value fiscal multipliers, where the positive sign of present value fiscal multipliers presents a stimulative effect of fiscal shock on output and

Table 3: The computed present value fiscal multipliers for domestic firm output, export firm output, and national output

Present Value Fiscal Multipliers	Quarter 1	$\frac{1}{2}$ Year	1 Year	2 Years	5 Years
Government Expenditure Multiplier for					
- Y^D	0.88	0.68	0.49	0.25	-0.37
- Y^X	-0.63	-0.62	-0.43	-0.10	0.19
- Y^N	0.25	0.06	0.06	0.14	-0.18
Sales tax Multiplier for					
- Y^D	0.03	0.27	0.32	0.22	-0.03
- Y^X	0.05	-0.11	-0.21	-0.10	0.01
- Y^N	0.08	0.17	0.11	0.12	-0.02
Payroll Tax Multiplier for					
- Y^D	0.09	0.26	0.37	0.44	0.46
- Y^X	0.28	0.27	0.17	0.08	0.06
- Y^N	0.37	0.52	0.54	0.52	0.52
Capital Tax Multiplier for					
- Y^D	0.18	0.16	0.22	0.28	0.16
- Y^X	-0.09	-0.08	-0.11	-0.11	0.20
- Y^N	0.09	0.08	0.11	0.17	0.35

Where Y^D is a domestic firm output, Y^X is a export firm output, $Y^N$is a national output

the negative sign of the present value fiscal multipliers presents either a contractional effect by the fiscal shock on output. The larger is the present value fiscal multipliers, the higher is the stimulative effect. This finding suggests that the present value of the government expenditure multiplier for domestic firms output, export firms output, and national output peak either in the first period or suddenly after the shock hits economy, which are 0.88, -0.63, and 0.25 respectively. These multipliers exponentially decay over the entire path. Interestingly, the result reveals the significant difference of the present value government expenditure multipliers between open and closed economies. The finding indicates that the present value government expenditure multiplier for the national output on the small-open economy is relatively small when compared to results from closed economy studies, such as Blanchard & Perotti (1999) and Zubairy (2014). The reason behind this difference is that the stimulative effect of an increase in government expenditure is noticeably mitigated by a sharp decline of the export firms' output, which can be clearly noticed from a negative present value government expenditure multiplier for export firms' output. However, the finding shows some similarities with the result from the closed economy model. As revealed in Table 3, a government spending multiplier for Y^D in this small-open economy is fairly similar (in both of the magnitude and the adjustment of multipliers) to the government spending multiplier for Y^N in closed economy studies. These include studies by Blanchard & Perotti (1999) and Furceri & Mourougane (2010), who examine the impact of fiscal policy in Eurozone by using the DSGE fiscal model with endogenous government bond yields, as well as Zubairy (2014). This similarity can imply that the present small-open economy DSGE model includes the characteristics of agents from the closed economy model.

In contrast to the present value government expenditure multiplier, the present value taxation multipliers of all tax shocks, namely, sales tax shock, payroll tax shock, and capital tax shock, improve over time. Most of the present value taxation multipliers reach their peak within one year after taxation shocks are introduced, except present value capital tax multipliers for the domestic firms' output and export firms' output, which slowly increase over time and reach their highest points in two years. Moreover, the result highlights that the payroll tax had the most stimulative effect on national output, since the present value payroll multipliers for national output is the largest among all taxation shocks. It reaches its peak at 0.54 within a year, a significantly greater figure than the 0.35 and 0.17 of present value multipliers associated with capital tax shocks and sales tax shocks, respectively. The cause of a significant high multiplier in the payroll tax shock is that both domestic firms and export firms respond to taxation shock in the same direction, which is a rise in their outputs. This outcome clearly contrasts with the effects of sales tax shock and capital tax shock, and both firms respond in the different direction: domestic firms increase their output while export firms reduce their output.

This result is consistent with findings from past studies both in the structural VAR literature and regarding the DSGE model within the closed economy literature in many aspects. For example, a stimulative effect of fiscal expansionary policies, such as an increase in government expenditure and a decrease in taxation rate, on national output and a considerable large government expenditure multiplier (close to 1.0), compared with a taxation multiplier, are also found by Furceri & Mourougane (2010) and Zubairy (2014). Furceri & Mourougane (2010) also found that a payroll tax rate shock has larger taxation multiplier than one from a sales tax shock and a capital tax shock. Furthermore, this finding is also along the lines of earlier studies by Furceri & Mourougane (2010) and Zubairy (2014) finding a decay of the effect of government expenditure shocks over time and an accumulative effect of taxation shocks along the horizon. Lastly, the focus of this paper, the analysis of the small-open economy country, is also investigated by Ilzetzki et al. (2013), who employ a structural VAR approach for studying the impact of fiscal policies in 44 countries. They also concluded that fiscal multipliers in open economies are smaller than fiscal multipliers in closed economies.

2.5 CONCLUSION

The present study has been designed to determine the effect of fiscal policies, including an increase in government expenditure shock and a reduction of various tax rate shocks (sales tax, payroll tax, and capital tax), on macroeconomic variables of small-open economies. The micro-founded medium-scale Dynamic Stochastic General Equilibrium model is employed for investigating the fiscal policy impacts on a small-open economy, which is calibrated to Thailand parameter. One of the more significant findings to emerge from this study is that an increase in government expenditures has a significantly positive impact on domestic firms' output. In contrast, export firms respond by lowering their output, which is an export value. Thus, the national output of the small-open economy increases moderately, which clearly contrasts with a number of cases that have been studied by using the closed economy model. An increase in government expenditures, moreover, crowds out interest-sensitive variables, such as the private investment and the private consumption. An external economic stability also adjusts after the implementation of an increase in government expenditure. Under flexible exchange rates, the finding shows that an exchange rate appreciates, while at the same time an export volume falls. This adjustment leads to a deficit in the trade balance. Most of the macroeconomic variables instantly respond to an increase in government spending; however, the effect decays over time. These findings enhance the understanding of the effect of fiscal policy on a small-open economy, which is an area that has been little discussed.

In addition, the reduction of the tax rate has a fair positive stimulative effect on domestic output and both positive and negative effect on export firms, depending on the type of tax. For example, a reduction of the payroll tax rate stimulates an export firm's output; in contrast, a reduction of the capital tax rate worsens an export firm's output. The results of this study indicate that a tax innovation directly affects households' consumption decisions. Most of the reductions of the tax rate, except a cutting of capital tax, result in a higher private consumption. Moreover, most of the lower tax rate measures, except a cutting of sales tax, lead to an increase in private investment. Similar to a government spending shock, the evidence from this study suggests that a taxation shock can also influence the external stability of a small-open economy. An exchange rate, export volume, and trade balance gradually respond to taxation shocks. Several important results are found from the estimation of fiscal multipliers. The impact multiplier of government spending on the national output of the small-open economy is rather small (0.25); while impact multipliers of sales tax, payroll tax, and capital tax are varied (0.08, 0.37, 0.09, respectively). The result reveals that the stimulative impact of tax cut measure accumulates over the horizon; in contrast, the impact of government spending continuously decays. After one year of the fiscal policy implementing, the effect of all reductions of the tax rate surpasses the effect of an increase in government expenditures. Lastly, the present value of taxation multipliers examined by this study indicate that lowering the payroll tax is the most stimulative fiscal policy for the small-open economy.

Part 3

Optimal Taxes in a Small-Open Economy with Imperfectly Competitive Market and Habit Formation Preferences.

3.1 INTRODUCTION

This part studies the optimal taxation, namely the optimal capital income tax and the optimal labour income tax, in a small-open economy with an imperfectly competitive market and habit formation preferences. An imperfectly competitive market arises from several factors, such as when firms invent a new product and acquire patents or copyrights, when firms have increasing returns to the scale production function, and when firms differentiate their product (Judd 2002). In this case, firms can influence the price setting, rather than be price takers, and they set a positive price mark-up over marginal costs. Since this condition can affect the firms' optimization behaviour, it changes the optimal capital income tax rate. Additionally, habit formation preferences are important in explaining consumers' behaviour (Ravn et al. 2006, Ljungqvist & Uhlig 2000). The households with habit formation tend to smooth their consumption over the time and gradually adjust their consumption when confronted with an income shock (Dynan 2000). This type of preference obviously changes the households' optimization problem and the dynamics of the demand facing the firms, which in turn changes firms' investment strategies. A change in the ways that firms behave can alter the optimal tax policy, and this paper investigates this effect.

Early studies of optimal taxation consider a perfectly competitive market and suggest that the optimal capital income tax on it is appeared to be zero (Chamley 1981, Judd 1985, Chamley 1986, Lucas 1990, Chari et al. 1991)[8]. Later, Judd (1997) find that the optimal capital income tax is negative in a closed economy with an imperfectly competitive market, where production and investment are below the competitive level and capital income subsidies can partly eliminate monopolistic distortions. Guo & Lansing (1999) extends Judd (1997) 's study by examining the effect of monopolistic power on the optimal capital income tax rate. They assume that capital income gains should be taxed at the same rate as profit. Their neoclassical growth model suggests that the optimal tax on capital can be negative, positive or zero depending on two opposing effects, namely an under-investment effect and a profit effect. The under-investment effect occurs when firms invest less than the optimal level, since the interest rate is lower than the marginal product of capital in an imperfectly competitive market, as in Judd (1997), whereas the marginal product of capital is equal to the return on capital in the perfectly competitive market. The profit effect arises from the relatively low distortion generated by the profit tax. The government can set a high profit tax, because it does not affect the household's decision on whether to consume or invest. They conclude that the sign of optimal capital tax depends on several factors, such as the degree of imperfect competitiveness in the market and the size of government spending. They find that the optimal capital income taxes can be in the range of -10 percent to 20 percent depending on the model's parameters. A positive capital income tax can be optimal in a model with heterogeneous agents, as shown in Conesa, Kitao & Krueger (2009). They quantitatively analyze the optimal capital income and labour tax by using an overlapping generation model. Their results indicate considerable positive optimal capital income and labour taxes at 36 percent and 23 percent, respectively.

It is interesting to see the effect of economic openness on the optimal capital

[8]Lucas (1990) investigates the effect of tax change on long-run economic growth by developing the human capital accumulation and endogenous growth to model of Chamley (1986).

income tax. In an open economy, the trade of goods and services can potentially impact the exchange rate's adjustment and interest rate's response to fiscal policies. Realizing the gap in the extant literature, more research is needed to investigate the optimal capital income tax in small-open economy. This paper seeks to address the following questions: i) "Is optimal capital income tax in a small-open economy with an imperfectly competitive market different from the optimal capital income tax in a closed economy?", ii) "Does it require the same level of tax subsidy as in a closed economy?", and iii) "How do habit formation preferences affect capital taxation?". According to Ravn et al. (2006), deep habits preferences create a negative correlation between the price mark-up and economic growth (countercyclical mark-up). The price mark-up is lower in an economic boom, because firms have incentives to buy habits when aggregate demand is high. Therefore, firms reduce their prices below the level that maximizes the current profit in order to gain more market shares and generate higher profits in the future. Hence, it is worthwhile to investigate the effect of deep habit preferences on optimal capital tax in an imperfectly competitive market.

This thesis employs a small-open economy framework adopted from Tanboon (2008). The Ramsey problem is employed as the principle approach to investigate an optimal capital income and labour taxes. The Ramsey problem involves household utility maximization in an economy with several constraints imposed by households' behaviors, firms' profit maximization and budget implementability. This paper chooses Thailand, a small-open economy country with an imperfectly competitive market for calibrating the model's parameters. In addition, this paper discusses the factors that affect optimal taxation in a small-open economy, including price mark-up, habit-formation, government debt, and government expenditure.

The study is composed of two parts: model simulation and the analysis of the results. In the first part, the Ramsey problem is solved numerically in order to calculate the optimal capital income and labour income taxes. The procedure consists of maximizing the households' utility subject to necessary constraints, deriving the first-order conditions of the Lagrangian problem with respect to involved variables, calculating steady-state equations, and solving for the optimal capital income and labour tax rates. The model is parameterized by using economic data on Thailand.

The analysis investigates the factors that influence the simulation's results regarding optimal taxation. Several simplifications are made to ensure the tractability of the model, such as applying a zero investment adjustment cost and a fully flexible wage and price. The focusing factors are trade openness, an imperfectly competitive market and habit preferences. There are three models in the analytical section, which are i) a simple closed economy model with an imperfectly competitive market, ii) a closed economy model with an imperfectly competitive market and deep habit preferences, and iii) a small-open economy model.

This study contributes to our knowledge by addressing three important issues. Firstly, it discovers the optimal capital income and labour tax in a small, open economy with an imperfectly competitive market and habit-formation. The finding can be utilized as guidance by the fiscal policy-makers of a small-open economy country, such as Thailand. Secondly, the result illustrates the role of an imperfectly competitive market for the optimal capital income and labour tax rates in a small, open economy. The optimal taxation can help to mitigate the distortion in domestic firms' production and improve economic welfare. Lastly, the present paper explores the effect of habit formation, including deep habit preferences, on optimal taxation.

The paper is divided into five sections. Section 3.2 summarizes the relevant economic literature. It thoroughly examines different types of economic model assumptions that influence the level of the optimal capital income tax rate. It also reviews different approaches for estimating optimal tax design. Finally, it revises the main findings. Section 3.3 explains the structure of the small-open economy model used for the numerical investigation. The model shares a number of components with the first part of this paper, which is an extension of Tanboon

(2008). It includes habit-adjusted consumption, nominal and real rigidities in wage and prices, the exporting sector and financial frictions. The economic behaviors of five economic agents, namely, households, firms, lenders, government and the central bank, are described. Moreover, the market clearing conditions, the steady-state conditions, and the model parameters' calibration, which is the best explanation of Thailand's economy, are thoroughly presented. Section 3.3 also puts forward the Ramsey approach to optimal taxation. The approach is composed of constructing the Ramsey problem, which involves households' utility maximization. This section also shows a steady-state equation and how to solve for the optimal capital income tax, optimal labour tax and the Lagrange multipliers by reducing the number of equations. Section 3.4 shows the simulation results of the optimal capital income tax and labour income tax, as well as the sensitivity analysis of the relationship between the domestic price mark-up and the optimal capital income tax. Section 3.5 analyses the numerical results by investigating a number of simplified models. It presents the analytical results of the closed economy and small-open economy models. Section 3.6 concludes the study of optimal taxation in a small-open economy with an imperfectly competitive market condition and habit-formation preferences.

3.2 LITERATURE REVIEW

This section reviews the main literature on optimal taxation. Firstly, it describes various economic theories used in the design of the tax code. It explains the principle of optimal taxation, which will be a great value for exploring the remaining chapters. Then, it provides a more focused review of the optimal capital income tax literature.

3.2.1 Theory of optimal taxation

Most forms of taxation distort the economy. Labour income taxes disincentives workers, distort the labour market and eventually lead to an inefficiency in production. Sales taxes cause higher prices and discourage buyers from purchasing goods and services. Capital income taxes potentially reduce investment.

However, Pigou (1920) argues that some taxation improves welfare, as it can reduce negative externalities by equalizing the private and social costs of economic actions. Forms of taxation, such as the environmental pollution tax, can increase efficiency in resource allocation (Sandmo 1976). Another tax that does not distort is a land value tax, which applies levies undeveloped land. This tax does not distort the economy, because the land supply is not affected by introducing this land value tax; the land supply is typically fixed. The estate's owner cannot pass on higher costs to tenants or consumers.

Setting an appropriate tax rate under a specific environment is an important task for policymakers. As mistakes can be very expensive, policymakers usually analyze the impact of new tax policies prior to implementation. The aggregate welfare of the taxpayers and macroeconomic variables (taxpayers' consumption, capital accumulation, and labour supply, for example) should be thoroughly investigated in both the short-term and long-term (Hubbard, Judd, Hall & Summers 1986). To minimize the distortion, an optimal tax theory is introduced. The optimal taxation is the theory of planing the tax system that decreases inefficiency and distortions in the economy (Slemrod 1989). A distortion can arise from taxation and increase the cost of production. The rise in cost leads to a higher retail price, which affects both firms and households. The objective of optimal taxation is to minimize this distortion while maintaining sufficient funds for government spending. The optimal tax theory suggests how the government sets the level of tax rates that maximise the households' utility, subject to economic constraints. The economy constraints are composed of several optimization problems faced by economic agents, such as a decision on the labour supplied by households, a decision on the production of firms, and a decision on capital usage.

In some models, taxes are used for the efficient redistribution of resources. For example, in an economy with heterogeneous earnings, redistribution can improve social welfare, as a small loss to the rich can generate a large gain to the poor in terms of utility. This is because of the convexity of the households' preferences with respect to their consumption. In addition, a redistribution tax may improve welfare, as it provides an insurance against illness or other losses of income that are above the control of economic agents.

The least distorting taxes are collected in the form of lump-sums, which means that the tax duty does not depend on economic activities. Because of this characteristic, lump-sum taxes do not affect the behaviour of consumers and producers; therefore, they do not distort the economy (Sandmo 1976). However, Sandmo (1976) explains that a lump-sum tax cannot be implemented for long period in a heterogeneous economy, as a household with different earnings should be subjected to different tax duties. In an economy that has an elasticity of total tax to total income greater than one, rational households may change their behavior on consumption or work after realizing that the current tax scheme is a progressive tax scheme.

In 1972, the theory of optimal taxation was introduced by Frank P. Ramsey. He proposes the theory for the optimal commodity sales tax that allows the government to raise certain tax revenues while minimizing the loss to households' utility (Ramsey 1927). The result shows that the consumption tax rate should be set in inverse relation to the sum of the price elasticities of demand and supply. His study has become an extensive foundation for optimal taxation theory. There are a number of notable studies built upon Ramsay, such as Diamond & Mirrlees (1971), Chamley (1986), Lucas (1990) and Chari et al. (1991). This paper will also use Ramsey's approach in investigating the optimal capital income tax.

3.2.2 Capital income tax

Depending on a model's assumption, the optimal capital income tax can be positive, negative, or zero. Chamley (1986) adopted neoclassical growth models with infinitely lived agents. He used a general form utility function to assess efficiency and concludes that the optimal capital income tax rate is zero in the long run. Afterwards, a number of studies have expanded his findings in several models, such as a life-cycle model, an endogenous growth model with human capital accumulation, and an open economy model (Hubbard et al. 1986, Lucas 1990, Chari et al. 1991, Razin & Sadka 1995). Their findings indicate a zero optimal capital income tax.

Hubbard et al. (1986) 's study employs the life-cycle model with liquidity constraints to investigate the impact of liquidity constraints on a taxpayers' consumption, saving, and labour supply in both the short-run and long-run. Their result shows that a decrease in capital income taxation, which is financed by an increase in labor income taxation, contributes to an increase in taxpayer welfare. In addition, the welfare gain is sensitive to a taxpayer's saving and the ability of taxpayers' borrowing to finance rising labour income taxes. Another well-known optimal capital taxation study is by Lucas (1990). He uses the human capital accumulation and endogenous growth model to investigate the effect of tax changes on long-run economic growth. His model is based on the infinitely lived agent models by Chamley (1986). He argues that removing the U.S. capital income tax can raise long-run capital stocks and long-run consumption by around 35 and 7 percent, respectively. Moreover, when translating into welfare gain, the eliminating of capital taxation can improve the United States' welfare by about 1 percent. The explanation of his zero optimal capital tax result is that, under the Ramsey taxation problem, policymakers should tax identical goods equally. The value of current consumption equal to the discounted value of the future consumption is converted from savings and rewarded with the interest rate. Therefore, the net present value of savings is equal to the value of the current consumption. Since the capital income tax targets the next period's consumption greater than the current period's consumption, the capital income tax is not optimized for economy and should be eliminated (Aiyagari 1995). Lucas (1990) 's study has strongly influenced the standard view held by most economists in favour of abolishing the capital tax. Friedman (2009) suggests that eliminating a corporate tax can be the most essential and effective measure for minimizing the firms' monopolistic power. The reform of tax laws is a necessary step.

The literature on optimal taxation has expanded to include the open economy model, as seen in studies such as Gordon (1992), Razin & Sadka (1995), Correia (1996) and Chari & Kehoe (1999). The open economy model's main differences in comparison with others are that it allows international transaction between two countries and includes a capital flow. Most of the literature's findings on optimal capital taxation in an open economy are not different from its findings regarding a closed economy. Most of the studies' results present a zero optimal capital tax in an open economy. Gordon (1992) studies the optimal capital income tax in a small-open economy with the double taxation convention. His model finds a zero optimal capital tax in a country without a dominant capital exporter. Razin & Sadka (1995) follows the infinitely lived agent model of Lucas (1990) in the analysis of a small-open economy. Their result presents a zero optimal capital income tax in a small-open economy in every period when capital is perfectly mobile. However, introducing a zero optimal capital income tax in a steady-state and non-steady-state may not satisfy a treasury and government in terms of revenue collection. Correia (1996) studies the effect of perfect capital mobility on optimal capital taxation. She employs an infinite horizontal model similar to Razin & Sadka (1991). Her open economy model shows a similar result, a zero optimal capital income tax, with the closed economy model. Chari et al. (1991) uses a primal approach to calculate optimal taxation. Their approach describes how to plan both fiscal policy and monetary policy in the long-run. The results show a high optimal capital income tax in the first period and a continually zero optimal capital income tax after the first period. The optimal labour income tax is approximately constant over the horizon.

By contrast, some recent studies suggest that setting a capital tax rate at zero may not be optimal. Judd (1997), Guo & Lansing (1999) and Judd (2002) find a negative optimal capital income tax in an imperfectly competitive market. Judd (1997) examines the optimal taxation problem in the closed economy with an imperfectly competitive market. He finds that the most optimal capital income tax is negative. Subsidies for purchasing capital goods help to reduce the distortion in an imperfectly competitive market, which raises capital goods' prices higher than their marginal costs. In addition, he suggests that the sectors with higher mark-ups should receive more tax credits. For example, when equipment has a higher tax mark-up than its construction. An investment tax credit should be provided that is more than the equipment's construction.

A study by Judd (1997) is extended by Guo & Lansing (1999). They introduce the neoclassical growth model to investigate the effect of monopolistic power on the optimal capital income tax. They state that a monopoly fosters an inefficient market that has both less capital and output than a perfectly competitive market. The results show that the steady-state optimal tax on capital can be negative, positive or zero. The sign of optimal capital tax is dependent on two opposing effects, namely the under-investment effect and the profit effect. The under-investment effect causes a negative capital income tax. This effect occurs when firms invest less than the optimal level, because the interest rate is lower than marginal product of capital in an imperfectly competitive market. In contrast, the marginal product of capital is equal to the return on capital in the perfectly competitive market. The profit effect leads to a positive capital income tax. The profit effect arises when the monopolistic firms generate profit. The government can tax all of these profits, because the profit of monopolistic firms does not affect the households' decisions. They conclude that the signs of optimal capital tax depend on several factors, such as the degree of a market's imperfect competitiveness, the level of tax on the monopolistic firms' profits, and the size of government spending. Moreover, their empirical results shows that optimal capital income taxes are in the range of -10 percent to 20 percent.

Additionally, Aiyagari (1995) and Conesa et al. (2009) indicate a positive optimal capital income tax. Aiyagari (1995) uses the Bewley class of models, including the incomplete insurance markets and borrowing constraints. He suggests that an optimal tax rate on capital income is positive, even in the long-run. Lowering the capital income tax to zero can worsen economic welfare. Conesa et al. (2009) quantitatively applies the overlapping generations model to find the optimal capital and labour income taxes. Their model includes a tight borrowing constraint subject to uninsurable idiosyncratic income risk. Their result shows a significantly positive optimal tax on both capital income tax and labour income tax at 36 percent and 23 percent respectively.

The diverse findings on optimal capital income may arise from certain assumptions in the model frameworks. The studies that presents a negative capital income tax mostly include an imperfectly competitive market in their model. The negative capital income tax may reduce the distortion in an imperfectly competitive market by narrowing the profit gap between firms. On the other hand, most of the positive optimal capital tax literature has two important assumptions. The first assumption is related to the households' borrowing constraints. According to Conesa et al. (2009), households desire to accumulate capital stock under the incomplete insurance market. The households may face borrowing constraints that influence them to accumulate more capital in the next period. This accumulation of capital brings a smaller pre-tax return on capital than a rate of time preference. Therefore, to balance the rate of pre-tax returns on capital and the rate of time preference, the positive capital tax should be employed for eliminating a capital accumulation (Aiyagari 1995). The second assumption is the type of calculated model. A number of the studies that employ the life cycle models, also called the overlapping generations models, mostly find a positive optimal capital income tax. A further research on above assumptions will be useful and valuable for taxation analysis. This thesis aims to discover the influence the optimal capital income tax.

3.3 OPTIMAL TAXATION IN SMALL OPEN ECONOMY

This section explains the procedure for deriving the optimal taxation in a small-open economy. The optimal taxation model is same as the model presented in the previous chapter, which is the extension of Tanboon (2008). Now, we assume that the government maximizes a representative household's welfare function by choosing a payroll tax and a capital income tax. The government has a new fiscal rule and budget constraint. All equations describing private behavior are summarized in Appendix B.1. All equations except stated are presented in real terms.

This section explains the procedure for deriving optimal taxation in a small-open economy. The first step is constructing the Ramsey problem. The households' utility is maximized subject to constraints imposed by the private sector's behavior. The second step is finding the first-order conditions of the Lagrangian problem with respect to endogenous variables. This step provides several important equations that are used to derive the optimal tax rate.

3.3.1 Ramsey problem

The government's problem is how to choose an optimal taxation system that maximizes the discounted and expected lifetime household utility. In order to solve for optimal taxation, the Ramsey problem is written in the Lagrangian form. This equation aims to find a tax rate that maximizes the households' welfare by giving the optimized behavior of households and firms.

The Ramsey equilibrium requires solving the following problem

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{ U(\tilde{C}_t) + V(L_t) \right\} \tag{68}$$

, subject to the households' decision constraint equation (5), (157), (160), (161), (163), (164), (165), debt balance constraint equation (184), domestic firms' decision constraint equation (21), (30), (169), (170), (171), export firms' decision constraint equation (32), (175), (176), (177), banks decision constraint equation (44), government constraint equation (182), (183), central bank constraint equation (52), and market clearing condition constraint equation (53).

For clarity, the Lagrangian form of the Ramsey problem ($\mathcal{L}$) is presented as follows:

$$
\begin{aligned}
\mathcal{L}_1 \quad = \quad & E_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\chi) \log \frac{C_t - \chi C_{t-1}}{1-\chi} - \varphi^L \frac{(L_t^D + L_t^X)^{1+\eta}}{1+\eta} \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{1t} \left[-d_t + \frac{[1+R_{t-1}]}{\pi_t} d_{t-1} + (1-\tau_t^w) w_t (L_t^D + L_t^X) \right. \\
& \left. + (1-(1-\delta)\,\tau_t^k) r_t^K (K_t^D + K_t^X) + Y_t^D \left(1 - \frac{1}{\mu^D}\right) - C_t - I_t \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{2t} \left[-(K_{t+1}^D + K_{t+1}^X) + (1-\delta)\,(K_t^D + K_t^X) + \left[1 - \frac{\xi^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{3t} \left(-q_t^K \left[1+R_t\right] + \left[\left[1-(1-\delta)\,\tau_t^k\right] r_{t+1}^K \pi_{t+1} + q_{t+1}^K \pi_{t+1} (1-\delta) \right] \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{4t} \left[- \left[1 - \xi^I \frac{I_t}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} - 1 \right) - \frac{\xi^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] q_t^K (1+R_t) \right. \\
& \left. + \left[1 + R_t - \xi^I E_t q_{t+1}^K \pi_{t+1} \left(\frac{I_{t+1}}{I_t} \right)^2 \left(\frac{I_{t+1}}{I_t} - 1 \right) \right] \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{5t} \left[-w_t (1-\tau_t^w) + (C_t - \chi C_{t-1})\, \mu^w \varphi^L \left(L_t^D + L_t^X \right)^\eta \right. \\
& \left. + (1-\tau_t^w) \zeta^W \left[- \left(\frac{w_t}{w_{t-1}} \pi_t - \frac{w_{t-1}}{w_{t-2}} \pi_{t-1} \right) + \beta \left(\frac{w_{t+1}}{w_t} \pi_{t+1} - \frac{w_t}{w_{t-1}} \pi_t \right) \right] \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{6t} \left[-\pi_{t+1} (C_{t+1} - \chi C_t) + \beta (C_t - \chi C_{t-1}) [1+R_t] \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{7t} \left[-(1+R_t) + (1+R_t^*)\, E_t \left(\frac{s_{t+1}}{s_t} \frac{\pi_{t+1}}{\pi_{t+1}^*} \right) \times \left(\frac{b_t}{2\psi (Y_t^D + Y_t^X)} \right)^{\zeta^B} \upsilon_t \right]
\end{aligned}
\tag{69}
$$

$$
\begin{aligned}
\mathcal{L}_2 \quad = \quad & E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{8t} \left(b_t^G + w_t L_t^D - d_t - b_t \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{9t} \left(- \left(1 + R_t^L \right) w_t L_t^D + \frac{1}{\mu^D} \gamma_L^D Y_t^D \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{10t} \left(-s_t \frac{P_t^{MF}}{P_t^{XF}} M_t^D + \frac{1}{\mu^D} \gamma_M^D Y_t^D \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{11t} \left(-r_t^K K_t^D + \frac{1}{\mu^D} \left(1 - \gamma_L^D - \gamma_M^D \right) Y_t^D \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{12t} \left(-1 + \mu^D q_t^D + \zeta^D \left[- \left(\pi_t - \pi_{t-1} \right) + \beta \left(E_t \pi_{t+1} - \pi_t \right) \right] \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{13t} \left(-w_t L_t^X + \gamma_L^X s_t Y_t^X \right) + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{14t} \left(- \frac{P_t^{MF}}{P_t^{XF}} M_t^X - \gamma_M^X Y_t^X \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{15t} \left(-r_t^K K_t^X + \left(1 - \gamma_L^X - \gamma_M^X \right) s_t Y_t^X \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{16t} \left(-(1 + R_t^L) \left[\frac{Y_t^D}{Y_{t-1}^D} \right]^{\tau} + 1 + R_t \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{17t} \left(-G_t + \rho^G \left(\frac{G_{t-1}}{\pi_t^D} \right) + \left(1 - \rho^G \right) \sigma \left(Y_t^D + Y_t^X \right) \right) \qquad (70)
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L}_3 \quad = \quad & E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{18t} \left(- \left[1 + R_t \right] + \left[1 + R_{t-1} \right]^{\rho^R} \left(1 + R^{ss} \right)^{\left(1 - \rho^R \right)} \left(\frac{\pi_t}{\bar{\pi}} \right)^{\kappa \left(1 - \rho^R \right)} \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{19t} \left(-Y_t^D + C_t + I_t + G_t \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{20t} \left(-b_t^G + (1 + R_{t-1}) \frac{b_{t-1}^G}{\pi_t} + G_t - \tau_t^w w_t (L_t^D + L_t^X) \right. \\
& \left. - \left(1 - \delta \right) \tau_t^k r_t^K (K_t^D + K_t^X) \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{21t} \left(-Y_t^X + (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1 - \gamma_L^X - \gamma_M^X} \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_{22t} \left(-Y_t^D + (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1 - \gamma_L^D - \gamma_M^D} \right) \qquad (71)
\end{aligned}
$$

, where $\mathcal{L} = \mathcal{L}_1 + \mathcal{L}_2 + \mathcal{L}_3$, λ_{it} for $i = \{1, 2, ..., 22\}$ are the Lagrangian multipliers from the i constraint.

3.3.2 The first-order condition

This step involves finding the first-order conditions of the Lagrangian problem ($\mathcal{L}$) with respect to considered variables, which are C, d_t, I_t, π_t, w_t, L_t^D, L_t^X, r^K, q_t^D, q_t^K, b_t, b_t^G, K_t^D, K_t^X, R^L, s_t, Y_t^D, Y_t^X, M_t^D, M_t^X, G_t, $(1+R_t)$, τ_t^k, τ_t^w. The detail of 24 first-order conditions of the Lagrangian problem are shown in Appendix B.3 .

3.3.3 The steady-state condition

This section illustrates how steady-state conditions are constructed. Firstly, the growth rates for all variables in all agents' decision equations and the Ramsey problem equations are set at zero, which implies that a quantity of all variables does not change over time. The steady-state of variable x_t is expressed by

$$\frac{x_t}{x_{t-1}} = \alpha. \tag{72}$$

Where $\alpha = 1$. x_t denotes all model variables in current period and x_{t-1} denotes all model variables in previous period.

Similarly, the change of the price level, namely inflation, is also set to zero ($\pi_t = 1$). This condition ensures that all variables must not explode or collapse. Secondly, the steady-state equations are arranged by grouping and ordering the Λ terms. This is useful for solving variables in the next section. In the present model, there are 24 steady-state equations of the first-order condition. The details of all steady-state equations are described in Appendix B.4.

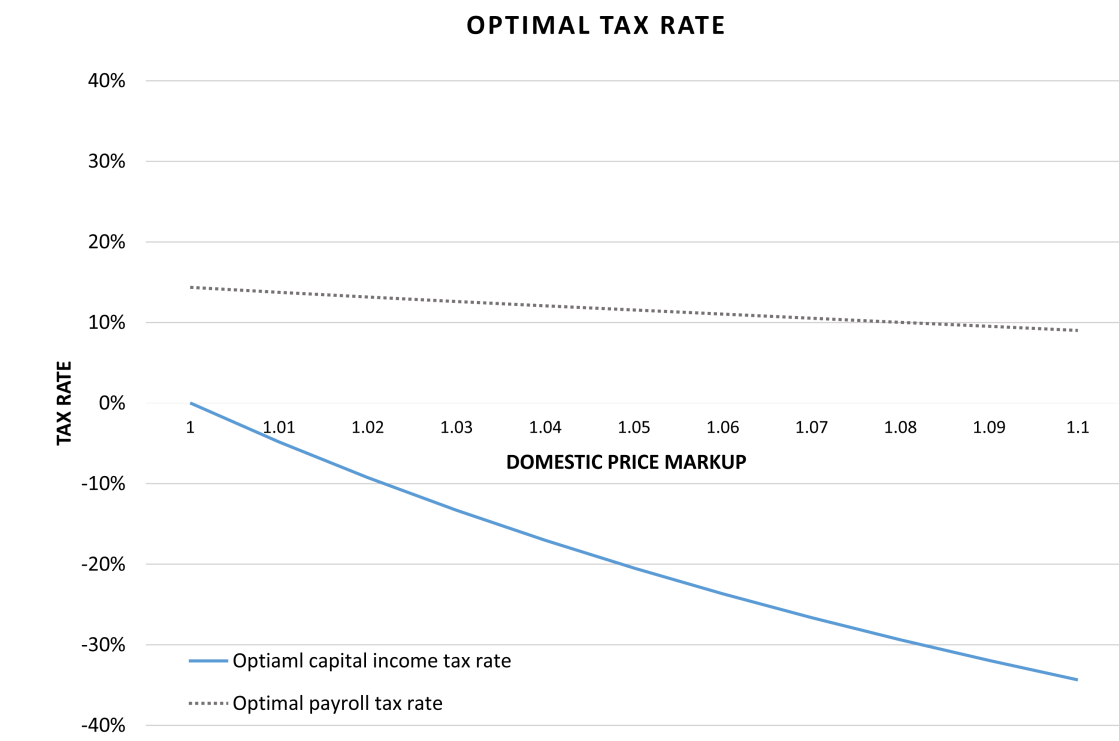
3.4 SIMULATION RESULTS OF OPTIMAL TAXES

This section explains the process of calculating the optimal capital income tax and the payroll tax. In order to solve for optimal taxation, all unknown variables of non-linear equations system have to be calculated. There are three essential steps to determine all unknown variables. The first step is finding the steady-state value of all variables in the steady-state equations of the small-open economy model (using Table 18). This procedure is similar to the one in the first part, as it includes reducing the number of equations by equation substitutions and establishing a value for each parameter in the model. After reducing the number of equations to four, the steady-state system can be simply solved by using numerical computation software such as Matlab. The second step involves compacting the system of steady-state equations of the Ramsey problem's first-order condition. Similarly, the process of reducing the size of this model is equation substitution. Since substituting 24 equations is a complicated task, a symbolic mathematical computation programme, such as Wolfram Mathematica, is used for reducing the number of equations. In the present paper, the number of equations is decreased to 5 equations. The third step is solving for the 24 unknown variables $(\Lambda_1, \Lambda_{2,...}, \Lambda_{22}, \tau_t^k, \tau_{t+1}^w)$. A numerical computation programme (Matlab) is employed for solving the 5 equations model from the previous step. The software determines the 5 unknown variables and calculates the value of all 24 variables.

The numerical result suggests that the optimal capital income tax is -7.97%. The result is consistent with the findings of Guo et al. (1995), Judd (1997), Judd (2002), Schmitt-Grohé & Uribe (2006) and Koehne & Kuhn (2013), which indicate a negative optimal capital income tax. The optimal capital income tax is in the range of Guo & Lansing (1999) and Domeij (2005) findings, as it is between -10% to 20% and -8% to 8% respectively. The negative value of the optimal capital income tax shows that, at steady-state, the government has to subsidize the taxation on the capital owner. However, interestingly, this result is contrary to former study conducted by Chamley (1981), Judd (1985), Chamley (1986), Hubbard et al. (1986), Lucas (1990), Chari et al. (1991) and Razin & Sadka (1995), which conclude that the optimal capital income tax is zero. The contrasting results may arise from the difference between the model's characteristics and those of previous models. The studies that find a negative optimal capital income tax shares some similar features such as inherent distortion. Their models allow an imperfectly competitive market in the economy while the papers that found a zero optimal income tax study a perfectly competitive market. The intuitive explanation is that, under the Ramsey taxation problem, policymakers should tax identical goods equally in a perfectly competitive market. According to Atkinson & Stiglitz (1976) and Lucas (1990), the value of current consumption equal to the discounted value of the future consumption. Saving is used as a channel to transfer consumption to the future. If government use positive capital tax, the consumption in the next period will bring a higher implied capital tax rate than the capital tax rate today, which is not optimized for economy. Under the first welfare theorem and iso-elastic utility, it is optimal to set uniform commodity taxation and, hence, zero optimal capital tax for the second best optimum. In contrast, the first welfare theorem does not hold in the imperfectly competitive market. Firms invest under the optimal level, because the interest rate, which influences films' decision on investment, is lower than a marginal product of capital (Guo & Lansing 1999). Under-investment directly leads to the inefficient economy. The usage of capital is lower than in the perfectly competitive market; therefore, the output decreases (Guo et al. 1995). To remove the monopolistic distortion and restore production and investment, the government has to subsidize the capital income tax, since subsidizing this tax can stimulate investment by firms and eliminate the inefficient in the production.

In addition, the present study's result shows that the optimal payroll tax is 13.32%. This implies that the government has to tax payroll income in order to

Figure 5: Optimal tax rate over the range of the domestic price markup.



raise revenue, since the present model does not allow lump-sum taxation. In contrast to capital income tax, which is used to correct the distortion of monopolistic power in an imperfectly competitive market, the payroll tax is employed for financing most of the government spending. The finding is consistent with those of previous studies by Guo et al. (1995) and Judd (1997). They find a positive optimal payroll tax under both an imperfectly competitive market and a perfectly competitive market.

The effect of a domestic price mark-up on the optimal taxation is shown in figure 5. In the perfectly competitive market, where the domestic price markup is equal to one, the result illustrates that the optimal capital income tax is zero. This finding is consistent with the studies of Chamley (1986) and Lucas (1990). In contrast, when the domestic price markup greater than 1, the optimal capital income subsidy (negative tax) is higher, as the domestic price markup increases. This result is consistent with the finding of Guo et al. (1995) and Domeij (2005) in an imperfectly competitive market. Intuitively, the government has to provide more subsidies when the firms have higher monopolistic power. This effort tries to eliminate the distortion in an imperfectly competitive market.

With regard to the negative capital income tax result, it is important for policymakers to interpret the numerical result with caution. The negative capital income tax may satisfy an optimal taxation problem with an imperfectly competitive market in theory but not a government revenue collection in practice. In policy-making, policymakers (such as civil officers) and academics may have different conclusions regarding the same problem, since they have different assumptions and constraints. Learning from each other provides useful interpretations when policy-making in the real world. Translating a theoretical result to an effective implementation is an important task. In addition, there are several factors that support a positive capital income tax, such as tax avoidance. A negative capital taxation can be used for tax avoidance. Implementing a negative capital taxation will attract more firms to report their income as a return on capital.

However, apart from an imperfectly competitive market, the factors that lead to the negative optimal capital income tax may arise from other components. It is interesting to deeply investigate the effect of those parameters on optimal taxation. A careful examination of the cause of negative optimal capital income taxation is introduced in the next section, the analytical results.

3.5 ANALYTICAL RESULTS

This section thoroughly investigates the factors that cause a negative optimal capital income taxation in a small-open economy, as indicated in the previous section. Since the small-open economy model consists of a large number of equations (counted for 48 equations), it is important to explore how each of the assumptions affects the size of the optimal income taxes. In order to analyze the pure effect of some distortions, the others are taken out of the model. For example, we will examine the model without investment adjustment cost, wage and price rigidities. In particular, we will analyze three factors that can potentially cause economic distortion: imperfect competition, the government's need to implement a sustainable budget without lump-sum taxation and the external effect on prices due to economic openness.

This section is divided into two parts. The first part analyzes the simple closed economy. This part examines the effect of openness of economy on the optimal tax. The result will be compared to the small-open economy model. In addition, the effect of the amount of government debt is explored. The second part investigates the simple small-open economy. The role of monopolistic power is considered here. The effect of domestic price markup on the optimal taxation is studied.

The main findings can be summarized as follows. An optimal capital income tax rate negatively depends on price mark-up (an inverse of real marginal cost) in all models, which are 1) closed economy with an imperfectly competitive market ($\mu^D > 1$) and budget constraint, 2) open economy with an imperfectly competitive market and 3) closed economy with deep habit preferences. In the case of constant price mark-up, μ^D is not varied over the time, and the economy has a tax smoothing. Both capital and labour income are smooth and do not fluctuate over the time horizon. In contrast, the closed economy with deep habit preferences has a variable price markup, μ_t^D, which can be vary with shocks such as a productivity shock. Therefore, the optimal capital income tax is not constant over time and it is not smooth. The details of these findings are described in the following section.

3.5.1 The simple closed economy model with an imperfectly competitive market

In this section, the simple closed economy is constructed by setting the following assumptions: domestic firms (without the export firms) are the producers, there are no investment adjustment costs, there are no wage adjustment costs, and there are no domestic price rigidities. The model is reduced to the simple small model, which is composed of 10 equations. The model details are shown as follows.

The households budget constraint.

$$C_t+I_t+d_t = [1+R_{t-1}]\,d_{t-1}\frac{1}{\pi_t}+(1-\tau_t^w)w_tL_t+\left[1-(1-\delta)\,\tau_t^k\right]r_t^kK_t+Y_t^D\left(1-\frac{1}{\mu^D}\right) \tag{73}$$

The capital accumulation

$$K_{t+1} = (1-\delta)\,K_t + I_{t,} \tag{74}$$

The capital decision

$$1 = \beta E_t\frac{C_t}{C_{t+1}}\left[\left[1-(1-\delta)\,\tau_{t+1}^k\right]r_{t+1}^K + (1-\delta)\right] \tag{75}$$

The labour supply decision

$$(1-\tau_t^w)w_t = \mu^w\varphi^L L_t^\eta C_t \tag{76}$$

The optimal deposit

$$\frac{1}{C_t} = \beta r_{t+1}\frac{1}{C_{t+1}} \tag{77}$$

The domestic firms production function

$$Y_t^D = (A_tL_t^D)^{\gamma_L^D}(K_t^D)^{1-\gamma_L^D} \tag{78}$$

The domestic firms labour demand

$$\mu^D w_t L_t^D = \gamma_L^D Y_t^D \tag{79}$$

The domestic firms capital decision

$$\mu^D r_t^K K_t^D = \left(1-\gamma_L^D\right)Y_t^D \tag{80}$$

The market clearing condition for domestic output

$$Y_t^D = C_t + I_t + G_t \tag{81}$$

The government budget constraint

$$d_t = r_t d_{t-1} + G_t - \tau_t^w w_t L_t - (1-\delta)\,\tau_t^k r_t^K K_t \tag{82}$$

Equation 82 can be rewritten in the implementability constraint form as below (See details in Appendix B.5).

$$\begin{aligned} -A_0 \;=\; & \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \varphi^L L_t^{\eta+1} C_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(\mu^D - 1\right)(w_t L_t) \\ & + \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} \left(\mu^D - 1\right)\left(r_{t+1}^K K_{t+1}\right) \end{aligned} \tag{83}$$

Where A_0 is the initial wealth of consumer ($A_0 > 0$) and assumed as

$$A_0 = \frac{1}{C_0} r_0 d_{-1} + \frac{1}{C_0}\left((1-\delta) + (1-\delta)\,\tau_0^k r_0^K + \mu^D \left(r_0^K\right)\right) K_0 \tag{84}$$

The Ramsey equilibrium requires solving the following problem

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{U(C_t) + V(L_t)\right\} \tag{85}$$

subject to the households' decision constraint equation (73), (74), (75), (76), (77), the domestic firms' decision constraint equation (78), (79), (80), government constraint equation (82), and the market clearing condition constraint equation (81).

The Lagrangian form of the Ramsey problem ($\mathcal{L}^c$) and the first-order conditions of the Lagrangian problem ($\mathcal{L}^c$) with respect to considered variables, which are C_t, L_t, K_{t+1}, Y_t, r_{t+1}, r_t^k, τ_{t+1}^k, τ_t^w, w_t, are presented in Appendix B.6. It is important to realize that Γ of the implementability constraint is not dependent on time, which is contrasted to λ_t and $\Gamma < 0$ (optimality condition).

At steady-state, the first-order conditions of K_t and L_t are as follows:

$$0 = \beta\left[\mu^D r^K_{t+1} + (1-\delta)\right] - 1 + \Gamma\frac{(\mu^D - 1)}{\mu^D}\left[\beta\left(\mu^D r^K_{t+1} - \frac{Y}{C}\left(\mu^D r^K_{t+1} + (1-\delta)\right)\right) + \frac{Y}{C}\right] \tag{86}$$

$$0 = -(1-\tau^w_t) + \mu^D + \Gamma(\eta+1)(1-\tau^w_t) - \Gamma\left(\frac{Y}{C} - 1\right)\left(\mu^D - 1\right) \tag{87}$$

The above equations show that some parameters and exogenous variables may affect the optimal tax rate, such as a domestic price markup (μ^D), an implementability constraint multiplier (Γ), and a government debt level (d). The next section explains the investigation of the effect of those parameters and exogenous variables on the optimal taxation.

3.5.1.1 The optimal taxation of the simple closed economy model with an imperfectly competitive market

This section studies the effect of a domestic price mark-up (μ^D), an implementability constraint multiplier (Γ), and a government debt level (d) on two types of economies: i) The closed economy with an imperfectly competitive market ($\mu > 1$) and lump-sum transfers ($\Gamma = 0$), ii) the closed economy with perfectly competitive market ($\mu = 1$). The details of the closed economy model calculation and the optimal taxation results of each environment are shown as follows.

1) The closed economy with an imperfectly competitive market and lump-sum transfers

Proposition 1 *In the closed economy with an imperfectly competitive market ($\mu^D > 1$) as described above, if lump-sum transfers are allowed (government does not concern to any costs of debt ($\Gamma = 0$), the implementability constraint multiplier is equal to zero. It is optimal to subsidize both the labour tax and capital income tax. Both tax rates are negative.*

Proof. *When $\Gamma = 0$, equations (86) and (87) are reduced to*

$$\frac{1}{\beta} = E_t \frac{C_t}{C_{t+1}} \left[\mu^D r_{t+1}^K + (1-\delta) \right] \tag{88}$$

$$\tau_t^w = 1 - \mu^D < 0 \tag{89}$$

From equation (75)

$$\frac{1}{\beta} = E_t \frac{C_t}{C_{t+1}} \left[\left[1 - (1-\delta) \tau_{t+1}^k \right] r_{t+1}^K + (1-\delta) \right]$$

Since the left-hand side of equation (75) and equation (88) are both equal to $\frac{1}{\beta}$, it can show that

$$\begin{aligned} E_t \frac{C_t}{C_{t+1}} \left[\left[1 - (1-\delta) \tau_{t+1}^k \right] r_{t+1}^K \right] &= E_t \frac{C_t}{C_{t+1}} \left[\mu^D r_{t+1}^K \right] \\ \tau_{t+1}^k &= \frac{1-\mu^D}{1-\delta} < 0 \end{aligned} \tag{90}$$

■

The calculation illustrates that, in a closed economy with an imperfectly competitive market ($\mu^D > 1$) and lump-sum transfers ($\Gamma = 0$), both the optimal labour tax and optimal capital income tax are negative. It is optimal for the government to subsidize both taxes, since subsidizing the capital income tax can mitigate the resulting distortion in an imperfectly competitive market. In addition, the subsidy in the labour tax is available because the lump-sum tax is allowed in this economy. The result also shows that the optimal taxation of the closed economy with an imperfectly competitive market and lump-sum transfers smooths over time. The optimal labour tax and capital income tax depend on price mark-up, which does not change over time. The cost of government revenue raising to finance a fluctuation in the government expenditure is minimized.

2) The closed economy with perfectly competitive market

Proposition 2 *In a closed economy with a perfectly competitive market ($\mu =$*

1) *as described above, if lump-sum are not available (which is often a realistic assumption), it is optimal to set the capital tax to zero and use the labour tax as a debt sustainable measure.*

Proof. When $\mu = 1$, equation (86) and (87) are reduced to

$$\frac{1}{\beta} = r^K_{t+1} + 1 - \delta \tag{91}$$

$$\tau^w_t = 1 - \frac{1}{(1 - \Gamma(\eta + 1))} \tag{92}$$

Since the optimality condition implies that $\Gamma < 0$, thus, $\tau^w_t > 0$. From equation (75)

$$\frac{1}{\beta} = E_t \frac{C_t}{C_{t+1}} \left[\left[1 - (1 - \delta) \tau^k_{t+1} \right] r^K_{t+1} + (1 - \delta) \right]$$

Since the left hand side of equation (75) and equation (91) are both equal to $\frac{1}{\beta}$, it can show that

$$\begin{aligned} E_t \frac{C_t}{C_{t+1}} \left[\left[1 - (1 - \delta) \tau^k_{t+1} \right] r^K_{t+1} + (1 - \delta) \right] &= r^K_{t+1} + 1 - \delta \\ \tau^k_{t+1} &= 0 \end{aligned} \tag{93}$$

■

Hence, in a closed economy with a perfectly competitive market where $\mu^D = 1$ and lump-sum transfers are not available, the optimal capital income tax is zero and the optimal labour tax is positive. In this case, it is optimal for the government to set the capital income tax to zero and use the labour tax as a debt sustainable policy.

3.5.2 The simple closed economy model with an imperfectly competitive market and deep habit preferences

This model extends Judd (1997) 's study on optimal capital income tax by introducing deep habit formation preferences. The main difference in deep habit formation preferences and standard habit formation preferences, which is employed in the first paper, is that the deep habit formation preferences consider the habit over individual varieties of goods while standard habit formation preferences deal with a habit of aggregate goods. Agent forms deep habit over particular categories of goods, for example, favorite travel place, preferred automobile (Ravn et al. 2006). The deep habit formation preferences changes firms' decision as a future sale is depended on today sale. The empirical study of Chintagunta, Kyriazidou & Perktold (2001) confirms that the consumer's brand choice in the past crucially influences today consumer's brand choice. According to Ravn et al. (2006), a price mark-up and economic growth are negatively correlated under deep habit formation preferences, or price markup is counter-cyclical. Therefore, it can be expected that the optimal capital income tax for a closed economy with an imperfectly competitive market and deep habit preferences should be higher during economic growth and lower during recessions. In order to test this hypothesis, the model is constructed as follows.

3.5.2.1 Households

There is a continuum of infinitely-lived households, each of which consumes a basket of continuum differentiated goods, $C_t(i)$, $i \in [0, 1]$. Following Ravn et al. (2006), this paper assumes that the value of the consumption basket, X_t, depends on the depth of the household habits.

$$X_t^{\frac{\eta-1}{\eta}} = \int_0^1 \left[\theta C_t(i) - \chi \overline{C_{t-1}}(i)\right]^{\frac{\eta-1}{\eta}} di \tag{94}$$

Where $\overline{C_{t-1}}(i)$ is an aggregate consumption in the previous period, which is exogenously given. θ and $\chi \in [0,1]$ is habit persistence and $\theta \geq \chi$. The parameter $\eta > 1$ is the elasticity of substitution between goods indexed i. Ravn et al. (2006) shows that the habit persistence implies the following aggregated demand function for good i

$$C_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\eta} \left(C_t - \frac{\chi}{\theta} C_{t-1}\right) + \frac{\chi}{\theta} \overline{C_{t-1}}(i) \tag{95}$$

, where $p_t(i)$ is the price for good i,

The aggregated price index, P_t, and the aggregated consumption, C_t, are assumed as

$$P_t = \left[\int_0^1 (p_t(i))^{1-\eta} di\right]^{1/(1-\eta)} \tag{96}$$

$$C_t = \int_0^1 [C_t(i)]^{\frac{\eta-1}{\eta}} di \tag{97}$$

The representative household maximizes the expected discounted sum of instantaneous utilities.

$$E_0 \sum_{t=0}^{\infty} \beta^t \{U(X_t) - V(L_t)\} \tag{98}$$

Where $\beta \in (0,1)$ is the households' discount factor and L_t is labour. Households own the capital, K_t, which is rented to the producer. Households own the firms and they can trade firms' equity shares s_t. The capital income net of depreciation is taxed at the rate τ_t^k. Hence, the representative household's budget constant can be written as

$$C_t+I_t+B_t+q_ts_t = R_{t-1}B_{t-1}+(1-\tau_t^w)w_tL_t+\left[1-\tau_t^k(1-\delta)\right]R_t^kK_t+(q_t+d_t)\,s_{t-1} \tag{99}$$

, where I_t is investment, B_t is risk-free government bonds which pay the gross interest R_t, K_t is the capital stock let to the productive firm at price R_t^k, δ is the depreciation rate, τ_t^w is the labour income tax rate, w_t is the real wage, d_t are the dividends per share paid by the firms and q_t is the share price. The capital accumulation constraint is defined similarly as in equation (5).

Following Ravn et al. (2006), the investment process is subjected to deep habits features and the demand for a particular investment good $I_t(i)$ is given by

$$\theta I_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\eta}(\theta I_t - \chi I_{t-1}) + \chi I_{t-1}(i) \tag{100}$$

The first-order conditions of the household maximization of equation 98 (subject to constraints), equations 5, 94, and 99 are given by

$$\rho_t = \theta U'(X_t); \tag{101}$$

$$\rho_t = \beta E_t\rho_{t+1}\left[\left[1-\tau_t^k(1-\delta)\right]R_t^k+(1-\delta)\right]; \tag{102}$$

$$(1-\tau_t^w)\rho_t w_t = V'(L_t); \tag{103}$$

$$\rho_t = \beta R_t E_t\rho_{t+1}; \tag{104}$$

$$\rho_t q_t = \beta E_t\rho_{t+1}(q_{t+1}+d_{t+1}); \tag{105}$$

where ρ_t is the Lagrange multiplier attached to the budget constraint in equation 99. Modified Euler equations for bonds, equation 104, deliver the stochastic discount factor $D_{t,t+j} = \beta^j E_t\frac{\rho_{t+1}}{\rho_t}$. In equilibrium, the equity market is cleared and $s_t = 1$.

3.5.2.2 Firms

Firms employ the Cobb-Douglas technology and acquire resources for producing goods. There are two factors of production, namely labour, $L_t(i)$, and capital, $K_t(i)$. Production by firms also depends on labour-argumented productivity, A_t. The production function can be described as follows:

$$Y_t(i) = (A_t L_t(i))^{1-\gamma}(K_t(i))^{\gamma} \tag{106}$$

where $\gamma < 1$ is a capital income share and capital input share.

Firms choose labour and capital inputs in order to minimize the real costs subject to the production possibility constraint, equation 106.

$$\min_{L_t(i),K_t(i)} w_t L_t(i) + r_t^k K_t(i) - \omega_t \left[(A_t L_t(i))^{1-\gamma}(K_t(i))^{\gamma} - Y_t(i) \right].$$

, where ω_t defines a Lagrange multiplier.

The first-order conditions of the cost-minimizing problem define the demand for inputs as follows:

$$w_t = \omega_t (1-\gamma) \frac{Y_t(i)}{L_t(i)} \tag{107}$$

$$r_t^K = \omega_t \gamma \frac{Y_t(i)}{K_t(i)} \tag{108}$$

Combining equation (107) with equation (108), the Lagrange multiplier ω_t represents the economy-wide marginal cost.

$$mc_t = \omega_t \tag{109}$$

The deep habits assumption implies that the demand function faced by the individual producer depends on the past sales.

$$\theta Y_t(i) = \left(\frac{p_t(i)}{P_t} \right)^{-\eta} (\theta Y_t - \chi Y_{t-1}) + \chi Y_{t-1}(i) \tag{110}$$

Firms set prices to maximize the present discounted value of the future stream of real profits

$$\Psi_t(i) = \max_{p_t(i),Y_t(i)} E_0 \sum_{t=0}^{\infty} \beta^t \frac{\rho_t}{\rho_0} \left[\frac{p_t(i)}{P_t} Y_t(i) - mc_t Y_t(i) \right]$$

taking into account the persistence of demand, equation (110), which is implied by the deep habits feature. The first-order conditions for the firm optimization problem are

$$\frac{\partial \Psi_t(i)}{\partial p_t(i)} = \frac{p_t(i)}{P_t} Y_t(i) - \eta \nu_t \left(\frac{p_t(i)}{P_t} \right)^{-\eta} (\theta Y_t - \chi Y_{t-1}) \quad (111)$$

$$\frac{\partial \Psi_t(i)}{\partial Y_t(i)} Y_t(i) = \frac{p_t(i)}{P_t} Y_t(i) - mc_t Y_t(i) - \nu_t \theta Y_t(i) + \beta \nu_{t+1} \frac{\rho_{t+1}}{\rho_t} \chi Y_t(i) = 0 \quad (112)$$

, where ν_t is the Lagrange multiplier to the constraint, equation (110).

In equilibrium, all firms choose optimal price and output as follows:

$$\frac{p_t(i)}{P_t} = 1 \quad (113)$$

$$\frac{Y_t(i)}{Y_t} = 1 \quad (114)$$

Therefore, the first-order conditions deliver the following dynamics for the real marginal cost.

$$mc_t = \frac{\eta - 1}{\eta} - \frac{1}{\eta} \frac{\chi}{\theta Y_t / Y_{t-1} - \chi} + E_t \frac{1}{\eta} \beta \frac{\rho_{t+1}}{\rho_t} \frac{\chi Y_{t+1}/Y_t}{\theta Y_{t+1}/Y_t - \chi}. \quad (115)$$

In cases when habits are not deep, $\chi = 0$, the price mark-up is constant over time: $\mu = \frac{\eta}{\eta - 1}$. Equation 115 shows that the real marginal cost, mc_t, increases with the growth rate of output Y_t/Y_{t-1}. Hence, the price mark-up, $\mu_t = 1/mc_t$ is negatively correlated with output growth, which explains why it moves counter-cyclically. This equation is a crucial finding, since it presents a negative relationship between price mark-up and economic growth. As discussed in Ravn et al. (2006), the mark-up declines, because firms reduce prices below the instantaneous profit maximization level in order to invest in habits that they will exploit in the future. The volatility of a price mark-up over the business cycle tends to initiate a non-smooth and counter-cyclical behavior in the optimal capital income tax rate.

The resource constraint implies that

$$Y_t = C_t + I_t + G_t. \tag{116}$$

Where G_t is exogenously given government spending.

3.5.2.3 Implementability constraint

The government can only use distortionary taxes to finance its budget. Following Chari & Kehoe (1999), the implementability constraint is derived by integrating forward the household budget constraint, equation 99, which is multiplied by the stochastic discount factor $\beta^s \rho_{t+s}$. In the Appendix B.7, it is combined with household behavior conditions and proves proposition 3.

Proposition 3 *The debt sustainability assumption is imposed by the implementability constraint for the government budget which is equivalent to restriction,*

$$E_0 \sum_{t=0}^{\infty} \beta^t \rho_t C_t - E_0 \sum_{t=0}^{\infty} \beta^t V'(L_t) L_t = \rho_0 A_0 \tag{117}$$

, where A_o is the initial household's wealth assumed as

$$A_0 = \left[\left[1 - \tau_0^k \left(1 - \delta \right) \right] R_0^k + \left(1 - \delta \right) \right] K_0 + R_{-1} B_{-1} + q_0 + d_0 \tag{118}$$

Proposition 3 derives the implementability constraint for a model with deep habits that appears very similar to the standard formula as in Christiano, Eichenbaum & Evans (1999). The only difference is discount factors. In an economy without habit formations, $\chi = 0$, the discount factor becomes $\rho_t = U'(C_t)$, and the constraint equation (117) gets a familiar presentation

$E_0 \sum_{t=0}^{\infty} \beta^t U'(C_t) C_t - E_0 \sum_{t=0}^{\infty} \beta^t V'(L_t) L_t = U'(C_0) A_0$, as in Christiano et al. (1999).

3.5.2.4 Optimal income tax rate

Consider a Ramsey policy maker who sets tax rates to maximize the households' utility, equation (98), subject to households' decisions and the constraints equation (5), (94), (101), (102), (103), (104); firms' decisions equation (106), (107), (108), the resource constraint equation (116), and the budget implementability constraint equation (117). The optimal Ramsey tax policy rate is given in Proposition 4.

Proposition 4 *The optimal labour and capital income tax rates are assumed as*

$$\tau_t^k = \frac{1}{(1-\delta)}(1-\mu_t) \tag{119}$$

$$\tau_t^w = 1 - \frac{1-(1-\sigma)\Gamma}{1+(1+v)\Gamma}\mu_t \tag{120}$$

where $\sigma = \frac{-U''(X_t)X_t}{U'(X_t)} > 0$, $v = \frac{V''(L_t)L_t}{V'(L_t)} > 0$, Γ *is a shadow price for the government's implementability constraint equation (117), and* μ_t *is the markup,* $\mu_t = \frac{1}{mc_t} > 1$, *where* mc_t *follows the dynamics equation (115). In an economy where lump-sum taxes are available and the implementability constraint is not binding,* $\Gamma = 0$, *it is optimal to subsidize labour,* $\tau_t^w = 1 - \mu_t < 0$.

Proof. See the Appendix B.8 ■

The proposition 4 establishes that the optimal capital income tax is negative. Capital tax subsidies are required to offset the price markup imposed by monopolistic firms. This outcome is consistent with the results of Judd (1997) and Judd (2002). Similarly, the optimal capital income subsidy rate converges to zero as an economy becomes more competitive, ($\mu_t \rightarrow 1$). However, in an economy with deep habits, the mark-up is not fixed and can be volatile over time; consequently, tax smoothing is not optimal. Since the optimal taxes are negatively correlated with the markup, it is optimal to increase the taxes when the economy grows and reduce them during a recession. Therefore, the closed economy with an imperfectly competitive market and deep habit preferences should move capital income tax in phase with the growth of real output. This means that a deep habits framework provides very strong support for the fiscal policy's counter-cyclicality.

3.5.3 The simple small-open economy model

In this part, the simple small-open economy is formulated by setting the following assumptions: no investment adjustment costs are present, no wage adjustment cost are present, no aboard borrowing occurs ($b^G = d$), export firms receive zero profits in a perfectly competitive global market, no domestic price rigidities exist, and a zero trade balance persists. The model is reduced to a simple small model which is composed of 24 equations. The model details are shown as follows.

The households budget constraint.

$$\begin{aligned} C_t + I_t + d_t &= R_{t-1}d_{t-1} + (1-\tau_t^w)w_t\left(L_t^D + L_t^X\right) \\ &\quad + \left[1-(1-\delta)\,\tau_t^k\right] r_t^k \left(K_t^D + K_t^X\right) + p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \end{aligned} \tag{121}$$

The capital accumulation

$$K_{t+1}^D + K_{t+1}^X = (1-\delta)\left(K_t^D + K_t^X\right) + I_{t,} \tag{122}$$

The capital decision

$$1 = \beta E_t \frac{C_t}{C_{t+1}} \left[\left[1-(1-\delta)\,\tau_{t+1}^k\right] r_{t+1}^K + (1-\delta)\right] \tag{123}$$

The labour supply decision

$$(1-\tau_t^w)w_t = \varphi^L \left(L_t^D + L_t^X\right)^\eta C_t \tag{124}$$

The optimal deposit

$$\frac{1}{C_t} = \beta R_t \frac{1}{C_{t+1}} \tag{125}$$

The domestic firms production function

$$Y_t^D = (A_t L_t^D)^{\gamma_L^D} (K_t^D)^{1-\gamma_L^D} \tag{126}$$

The domestic firms labour demand

$$\mu^D w_t L_t^D = \gamma_L^D Y_t^D \tag{127}$$

The domestic firms capital decision

$$\mu^D r_t^K K_t^D = \left(1 - \gamma_L^D\right) Y_t^D \tag{128}$$

The export firms production function

$$Y_t^X = (A_t L_t^X)^{\gamma_L^X} (K_t^X)^{1-\gamma_L^X} \tag{129}$$

The export firms labour demand

$$\mu^X w_t L_t^X = \gamma_L^X p^X Y_t^X \tag{130}$$

The export firms capital decision

$$\mu^X r_t^K K_t^X = \left(1 - \gamma_L^X\right) p^X Y_t^X \tag{131}$$

The aggregate consumption

$$C_t^\theta = \left(C_t^D\right)^\theta + \left(C_t^M\right)^\theta \tag{132}$$

The aggregate investment

$$I_t^{\theta} = \left(I_t^D\right)^{\theta} + \left(I_t^M\right)^{\theta} \tag{133}$$

The aggregate price

$$\left(p^D\right)^{-\frac{\theta}{1-\theta}} + \left(p^M\right)^{-\frac{\theta}{1-\theta}} = 1 \tag{134}$$

The aggregate government expenditure

$$G_t^{\theta} = \left(G_t^D\right)^{\theta} + \left(G_t^M\right)^{\theta} \tag{135}$$

The domestic consumption

$$C_t^D = C\left(p^D\right)^{-\frac{1}{1-\theta}} \tag{136}$$

The domestic investment

$$I_t^D = I_{t,}\left(p^D\right)^{-\frac{1}{1-\theta}} \tag{137}$$

The domestic government expenditure

$$G_t^D = G_{t,}\left(p^D\right)^{-\frac{1}{1-\theta}} \tag{138}$$

The import consumption

$$C_t^M = C\left(sp_t^m\right)^{-\frac{1}{1-\theta}} \tag{139}$$

The import investment

$$I_t^M = I_t\left(sp_t^M\right)^{-\frac{1}{1-\theta}} \tag{140}$$

The import government expenditure

$$G_t^M = G_t\left(sp_t^M\right)^{-\frac{1}{1-\theta}} \tag{141}$$

The market clearing condition for domestic output

$$
\begin{aligned}
Y_t^D &= C_t^D + I_t^D + G_t^D \\
Y_t^D &= (C_t + I_t + G_t)\left(p^D\right)^{-\frac{1}{1-\theta}}
\end{aligned} \tag{142}
$$

The market clearing condition for export output (zero trade balance)

$$
\begin{aligned}
p^X Y_t^X &= p^M\left(G_t^M + C_t^M + I_t^M\right) \\
p^X Y_t^X &= s^{\frac{-1}{1-\theta}}\left(C + I_t + G_{t,}\right)\left(p_t^M\right)^{\frac{-\theta}{1-\theta}}
\end{aligned} \tag{143}
$$

The equation substitution of this model is shown in Appendix B.9.

The government budget constraint

$$
d_t = r_t d_{t-1} + G_t - \tau_t^w w_t L_t - (1-\delta)\,\tau_t^k r_t^K K_t. \tag{144}
$$

Equation (121) can rewrite in the implementability constraint form as below (See details in Appendix B.10)

$$
\begin{aligned}
& A_0 - \frac{1}{1-\beta} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu}\right) \\
= \; & 0,
\end{aligned} \tag{145}
$$

where $A_0 = \frac{1}{C_0} R_{-1} d_{-1} + \frac{1}{C_0}\left(\left[1-(1-\delta)\,\tau_0^k\right] r_0^k - \beta(1-\delta)\right)\left(K_1^D + K_1^X\right).$

The Lagrangian form of the Ramsey problem ($\mathcal{L}^o$) and the first-order conditions of the Lagrangian problem ($\mathcal{L}^o$) with respect to considered variables, which are K_t^D, Y_t^D, C_t, and L_t^D are presented in Appendix B.11.

The first-order condition with respect to L_t^D shows that

$$
\Gamma = \frac{1}{(\eta+1)}\left[1 - \lambda_{1,t} \frac{\gamma_L^D (A_t L_t^D)^{\gamma_L^D} (K_t^D)^{1-\gamma_L^D}}{\varphi^L \left(L_t^D + L_t^X\right)^{\eta} L_t^D}\right]. \tag{146}
$$

1) The small-open economy with perfectly competitive market

Proposition 5 *In the small-open economy with a perfectly competitive market* ($\mu^D = 1$) *and lump-sum transfers (the government does not concern to any costs of debt* ($\Gamma = 0$)*), it is optimal to set the capital tax to zero and use the labour tax as a debt sustainable measure.*

Proof. See Appendix B.12

$$\tau^k_{t+1} = 0 \tag{147}$$

$$\tau^w_t = 0 \tag{148}$$

■

The calculation illustrates that in a small-open economy with a perfectly competitive market ($\mu^D = 1$) with the lump-sum transfer ($\Gamma = 0$), the optimal capital income tax and optimal labour tax are zero. In this case, the government does not have to correct the distortion in the perfectly competitive market; therefore, it is optimal for the government to set the zero capital income tax. In addition, the lump-sum transfer allows the government to use the zero payroll income tax.

2) The small-open economy with an imperfectly competitive market and lump-sum transfers

Proposition 6 *In the small-open economy with an imperfectly competitive market* ($\mu^D > 1$) *and lump-sum transfers (the government does not concern to any costs of debt* ($\Gamma = 0$)*), it is optimal to subsidize both the labour tax and the capital income tax. Both tax rates are negative.*

$$\tau^k_{t+1} = \frac{1 - \mu^D}{(1 - \delta)} < 0 \tag{149}$$

$$\tau^w_t = 1 - \mu^D \tag{150}$$

Proof. *See Appendix B.13* ■

The calculation shows that in a small-open economy with an imperfectly competitive market ($\mu^D > 1$) and lump-sum transfers ($\Gamma = 0$), both the optimal labour tax and the capital income tax are negative. The government can optimally subsidize capital income taxes, since doing so helps to mitigate the distortion in an imperfectly competitive market. Moreover, they can subsidize the labour income tax because the lump-sum tax is allowed in this type of economy.

3.6 CONCLUSION

This chapter investigates the optimal capital tax and the optimal labour income tax in a small-open economy. The model parameter is adopted from economic data of Thailand, which is a small-open country in South East Asia. The Ramsey problem is constructed in order to examine the optimal capital income and labour taxes. The present model also includes imperfectly competitive market conditions. The following conclusions can be drawn from the present study. Firstly, the optimal capital income tax in a small-open economy with an imperfectly competitive market is negative. The optimal capital income tax of Thailand is -7.97%, which is consistent with the results of past studies by Guo et al. (1995), Guo & Lansing (1999), Judd (1997), Judd (2002), Domeij (2005), Schmitt-Grohé & Uribe (2006) and Koehne & Kuhn (2013). The government has to subsidize capital income tax for eliminating the monopolistic distortion, because subsidizing the capital income tax can stimulate investment by firms. In addition, the sensitivity analysis shows that the optimal capital income tax is increasingly negative as the domestic price mark-up increases. This finding is clearly contrary to the former study, which concluded that the optimal capital income tax is zero. Secondly, the optimal payroll tax in a small-open economy with an imperfectly competitive market is positive, equal to 13.32% for Thailand's economy. Since the present model includes government constraints and does not allow lump-sum taxation, the government has to apply a levy on payroll income in order to raise its revenue. The finding of a negative optimal capital income tax can enhance understandings of the optimal taxation in a small-open economy with an imperfectly competitive market, which is an area that has been little discussed.

This paper also illustrates the analytical result by considering a number of simple models, namely the simple closed economy model with an imperfectly competitive market and deep habit preferences and the simple small-open economy model with an imperfectly competitive market. Some assumptions are simplified; for example, there are no investment adjustment costs, no wage adjustment costs, and no domestic price rigidities. The simple model can investigate the effect of some parameters to optimal taxation.

The following conclusions can be drawn from the simple closed economy. Firstly, in the closed economy with an imperfectly competitive market, if lump-sum transfers are allowed, it is optimal to subsidize both the labour tax and the capital income tax. Both optimal tax rates are negative. Secondly, in the closed economy with a perfectly competitive market, if the lump-sum is not available (which is a common realistic assumption), it is optimal to set the capital tax to zero and use the labour tax as a debt sustainable measure. Thirdly, in a closed economy with an imperfectly competitive market and deep habit preferences, the optimal capital income tax is negative and should be adjusted in phase with the growth of the real output, because the price mark-up is counter-cyclical under a deep habit preferences economy. For the small-open economy, the analytical result can lead to the conclusion that when the lump-sum transfers are allowed to implement the budget, the optimal capital tax and the optimal labour tax are the same as in a closed economy. They are negative and are used to offset the monopolistic mark-up.

Part 4

Government Spending on Health and Economic Growth

4.1 INTRODUCTION

This part studies the impact of government health spending on economic growth by analyzing the improvement of the national health condition. Worldwide health data reveal that the global population's life expectancy at birth has significantly risen by approximately 20 years over the last five decades (Becker, Philipson & Soares 2005, Oster et al. 2013). This improvement of global health provides an immense benefit in worldwide welfare. Assuming that this historical trend continues, life expectancy at birth will increase to 100 years by 2060 for developed countries (such as the United States) and by 2300 for the majority of countries (Oeppen & Vaupel 2002, Nations 2004, Olshansky et al. 2005). The factors that mainly contribute to increases in life expectancy are composed of development of more effective medications, nutrition and public health care. The state has important role in improving national health through providing, for example, inclusive access to health care and nutrition services, reducing health gaps between different population groups and ensuring sustainable public health financing.

The effectiveness of government spending on national health can be measured by improvements in nation health status, such as decreases in infant or child mortality rates. However, many studies find that the effect of government spending on nation health is positive and small, (Filmer & Pritchett 1999, Gupta et al. 2002). Filmer & Pritchett (1999) conclude that the impact of government spending on the mortality rate is relatively small when compared with other independent variables such as per capita income, income distribution and female education. Similarly, Gupta et al. (2002) use cross-sectional data of 50 countries to investigate the relationship between government spending on health and infant and child mortality rates. Their findings show a weak relationship between government spending on health and mortality rates. In contrast, a study that employs a different approach finds another result. Baldacci et al. (2003) utilizes a latent variable model to analyze developing country data. Its findings shows a more robust result than the traditional technique's. An increase in government spending on health significantly leads to a decrease in mortality rates. Therefore, the impact of government spending on health on mortality rate, as discussed by these studies, is ambiguous. More research needs to be done to investigate the effectiveness of government spending on national health.

In addition, the previous literature reviews show that most studies disregard the role of private spending on health, because the data is unavailable or because of the existence of insufficient sample sizes. Private health spending also has an essential role in improving national health. Due to the presence of governmental budget constraints, private health spending can substitute public spending on health when the state's revenue is limited. Both private and public health spending can promote healthy life of population. Psacharopoulos & Nguyen (1997) study the importance of private health spending and address its benefits. High participation by private sector in health can increase the efficiency of the health service market. Health providers try to reduce their service costs to be more competitive and to meet customers' needs. Realizing this gap in the literature, this paper includes private health spending in its model and estimates the total effect of private spending on national health.

Improvement in national health is believed to contribute to economic growth by increasing human capital in the form of health. Healthy employees can be more productive and effective when working and have fewer health problems during work hours (Bloom et al. 2004). Gary S. Becker, who has received the 1992 Nobel Prize in economic science, states that investment in human capital is as important as investment in construction and equipment. A healthy person who has a longer life expectancy tries to train more often and has a higher ability than those have shorter life expectancies (Becker 1993). Barro & Lee (1994) and Oster et al. (2013) confirm that a longer life expectancy promotes human capital investments such as skills training and enhance workers' habits. In addition, a number of empirical studies support the positive effect of health and economic, such as Barro et al. (1996), Bloom et al. (2004), Well (2007), Baldacci, Clements, Gupta & Cui (2008) and Aghion, Howitt & Murtin (2010). Instead of using mortality rates, Barro et al. (1996) use a log of life expectancy at birth to measure the overall health status of the countries. The paper illustrates a strong linkage between an increase in national health and economic growth. A one-standard deviation improvement in life expectancy contributes to a 1.5 percent rise in a country's economic growth rate. Furthermore, a young and healthy population can gain more human capital through schooling (Weil et al. 2013). However, some recent studies conclude that national health has a small impact on economic growth. Acemoglu & Johnson (2007) uses mortality rate as a health indicator and argues that the impact of increased life expectancy on output is considerable small. Therefore, more research needs to be done to examine the impact of improvement in national health on economic growth.

Apart from traditional health indicators (life expectancy and mortality rates), non-medical determinants of health have been recently introduced as indicators, such as tobacco consumption, alcohol consumption, sugar supply and total fat supply. In developed countries, the health gap between different population groups is low. Most of population have healthy lives, long life expectancies and low mortality rates. The traditional health indicators may not clearly portray the nation's health and lifestyles. Therefore, non-medical determinants of health can reveal individual routine activities and lifestyles in developed countries (Larson & Mercer 2004). This paper contributes to the literature by using non-medical determinants of health to estimate the production functions and test whether non-medical determinants of health are appropriate indicators for human capital in the form of health of developed countries or not.

This paper aims to find the impact of government health spending on economic growth by analyzing the improvement of the national health condition. The study composed of two parts. The model is estimated from panel data, which is the most up-to-date and includes observations of over 200 countries (including both developed and developing countries). The first part examines the effect of government health spending on national health by choosing life expectancy, which has been disregarded in previous studies on government spending on health, as a dependent variable. Moreover, two types of mortality rates, namely infant mortality and under-five mortality, are also used as dependent variables in order to compare the model's results with those of previous studies. The regression is estimated by using the two-stage least-squares approach (2SLS), which is applied for dealing with the reserve causality problem. For example, an increase in government spending on health may cause an increase in life expectancy, but higher demand for better health, as indicated by a higher life expectancy, may lead to a push for higher government spending on health (Gupta et al. 2002). The instruments of the two-stage least-squares approach are government spending on defense, government spending on education, government spending on public service and total government spending. Two types of models are constructed (the fixed-effectes model and random effects model) in order to find suitable regressions for representing health status. Moreover, in order to fulfill the gap in previous studies on government spending on health, this paper introduces private health spending as a new independent variable in order to explain the cross-country variation of health status. The role of the private sector in national health will be revealed. Other independent variables are GDP per capita and improvement in sanitation facilities.

The second part investigates the effect of health on economic growth by estimating the production function models. This section's research question is "Does improving in national health, such as longer life expectancy, contribute to an economic growth?". The models are constructed by using three data sets (global data, developed countries data, and developing data) in order to compare the effect of difference countries' incomes on national health and economic growth. Life expectancy is used to represent the nation's health status. Additionally, the present paper introduces a new health status variable, namely non-medical determinants of health. The selected non-medical determinants of health variables are tobacco consumption, alcohol consumption, sugar supply and total fat supply. This model measures the role of non-medical determinants of health on economic growth.

This paper's contributions are useful for planning future expenditures by governments on health and maintaining sustainable economic growth in the long term. This study's findings will provide an understanding of how government spending on health impacts human capital in the form of health and economic growth in developed and developing countries. The findings of the impact of private spending on health can be valuable for annual government budget planning. The government can reallocate certain types of unnecessary government health spending that are similar to private health expenditures for other necessary categories, such as education. In addition, the new finding of the effect of non-medical determinants of health on economic growth can be used for improving health policy planning in developed countries. Government can choose which health policies efficiently promote both national health and economic growth, by deciding, for example, between seeking to reduce tobacco or alcohol consumption.

This article is divided into 5 sections. Section 4.2 reviews the literature on the impact of public health spending on national health status and the effect of gains in national health status on economic growth. The consequences for economic growth by boosting health status are described. Moreover, the effect of the composition of government expenditures on output is explained. Section 4.3 explains the main structure of the health model and the production function model. The definitions and sources of the data are described and explained. Section 4.4

shows the empirical results of these models. Each model is composed of several regressions conducted through different estimation approaches, such as the fixed-effects model, the random effects model, the two-stage least-squares method, and the mean group estimator. Section 4.5 concludes by providing the findings and policy recommendations for governments.

4.2 LITERATURE REVIEW

This section is composed of two parts. The first part explains the concept of a composition of government expenditure and output. The second part reviews various related academic research from recent and influential journals. This part also compares methodologies and models of each study and reveals the advantage and disadvantage of each well-known papers. Henceforth, the most suitable methodologies for estimating the impact of government health spending on economic growth can be determined.

4.2.1 A composition of government expenditure

This part explains how the composition of government expenditures affects output. Government spending is composed of several types of expenditures that are based on areas including defense, education and health. The effects of each type of government spending on economic growth may be considerably different. Devarajan, Swaroop & Zou (1996) introduces a theoretical framework for explaining the impact of different types of government expenditure on long term economic growth. The paper argues that the correct composition of capital and current expenditures can positively affect economic growth. It separates government expenditures into two types of imperfectly substitutable and complementary components: (g_1) and (g_2). There are three factors of production: private capital (k), productive expenditure and unproductive expenditure. The production function form is the constant elasticity of substitution (CES).

$$Y = (\gamma K^{-\zeta} + \phi g_1^{-\zeta} + \rho g_2^{-\zeta})^{-\frac{1}{\zeta}} \tag{151}$$

Y denotes the output of the CES production function, K is capital stock, and γ, ϕ, and ρ are factors of the production coefficient that are greater than 0. Where $\gamma + \phi + \rho = 1$ and $\zeta > 0$, and $\phi > \rho$, it can say that expenditure g_1 is more productive than g_2. The relative productivity, $\frac{\partial Y/\partial g_1}{\partial Y/\partial g_2} = \frac{\phi}{\rho}\frac{g_1^{-(\zeta+1)}}{g_2^{-(\zeta+1)}}$, should be 1 at the optimum level of output, given that both expenditures have the same costs for the budget.

$$\frac{g_1}{g_2} = \left(\frac{\phi}{\rho}\right)^{\frac{1}{\zeta+1}} < \frac{\phi}{\rho} \tag{152}$$

Condition 152 illustrates that an optimal steady-state growth rate is achieved when the shares of government spending are distributed more evenly than their contributions to production. Based on this they argue that the governments of some developing countries invest too heavily into capital expenditure and too little into areas like education and health.

4.2.2 Related Research

The empirical literature on the impact of health on economic growth has developed significantly over the past two decades. An early study from Barro et al. (1996) uses a log of life expectancy at birth to measure the country's overall health status. He finds a noticeable linkage between an increase in national health status and economic growth. The coefficient of life expectancy at birth is 0.042, showing a significantly positive effect of life expectancy at birth on per capita growth rate. After Barro et al. (1996)'s study, the literature of national health on economic development has been broadened to include various concepts, for example Barro & Lee (1994), Zhang, Zhang & Lee (2003), Bloom et al. (2004), Well (2007), Baldacci et al. (2008), and Aghion et al. (2010). Most findings confirm the positive effect of health status on output level.

Barro & Lee (1994) investigates the source of growth of 116 countries from 1965 to 1985. Five factors are used to isolate the difference between a high growth country and low growth country, including, for example, the ratio of real per-capita to initial human capital level on education and health, the ratio of investment to GDP, size of government, market distortion from governmental policy and political uncertainty. They find a significant effect of life expectancy on economic growth. An increase in life expectancy on standard deviation leads to a 1.5 percent increase in the annual economic growth rate. Bloom et al. (2004) uses a production function that consists of household health and labour experience to investigate aggregate economic growth. Their production function is composed of three factors of production: physical capital, labour and human capital. Human capital covers three important dimensions, which are education, working experience and health. The panel data is collected from 1960 to 1990. Their results show that excellent health has a large, positive effect on aggregate output. For example, the aggregate output can increase by 4 percent when national life expectancy increases for one year. They also conclude that the impact of life expectancy on aggregate output growth is caused by a labor productivity effect, not an increasing work experience effect. Well (2007) expands on the effect of human capital in the form of health to the microeconomic level. He estimates the impact of individual health on their income to formulate a macroeconomic estimate of the effect of national health on per capita aggregate output. The return on health is determined from cross-country factors of individual health, such as height and survival rate. He finds that removing the national health gap among countries can benefit from lowering a variance of output per worker by 9.9 percent and decreasing output per worker from 20.5 to 17.9 or the 90th percentile to the 10th percentile. Similarly, Baldacci et al. (2008) confirms that government spending on health has a positive and sizable effect on human capital in the form of health, and, hence, government spending on health can indirectly encourage the growth of the aggregate output. They broaden the observation's scope by using a data series of 118 developing countries from 1971 to 2000. The baseline model is a fixed-effect model. Their results illustrate that a 1 percentage increase of government health spending to GDP can raise the under-five survival rate and annual GDP per capita growth by 0.6 percent and 0.5 percent respectively. These positive effects are immediate. However, the quality of government has a crucial role in the advantage of government spending on health. In the case of a country with deficient governance, the positive impact of government health spending can fully vanish. They also show that government spending on health has a diminishing return, especially for countries with high levels of healthcare spending.

The literature on the effect of human capital in the form of health has expanded to study the differences between developed and developing countries. Accounting for the impact of human capital in the form of health can explain the limited growth rate of GDP in high income countries, such as OECD countries. Aghion et al. (2010) investigates the relationship between the growth rate of aggregate output and national health by using a modern endogenous growth theory. The panel data covers the period from 1960 to 2000. Their results show that, in OECD countries, only lowering the under-40 mortality rate increases the productivity of output, while other health indicators do not have a significant impact on economic growth. Aghion et al. (2010) 's result confirms the positive long-term effect of a healthier youth population on labour productivity. In a microeconomic framework, workers who have good health when they were young tended to gain more skills, hence their individual rates of productivity were enhanced. Aísa, Pueyo et al. (2004) explains that lengthening life expectancy in a developed country, which usually has a long life expectancy, is a difficult and expensive effort. Consequently, improving health in a developed country may result in a negative effect on economic growth in the long-term.

Better health can have a positive effect on economic growth via improving the education and skill of people. Oster et al. (2013) examines human capital theory by analyzing the behaviour of limited life expectancy individuals who are at risk for Huntington disease (HD). This inherited genetic disease shortens life expectancy to near 60. Their finding shows that changes in life expectancy potentially affect human capital investment. A limited life expectancy person is likely to have less education and skill training. They measure the effect of lower life expectancy on education by calculating a demand elasticity for school completion with respect to life expectancy. This elasticity is close to 1.0. Life expectancy can describe roughly 20 percent of differences in school completion among country samples. Moreover, limited life expectancy has an impact on individual behaviour regarding health related activities, such as smoking and participating in cancer screenings.

In addition, health and social welfare are close connected. Better health, as represented by longevity, promotes welfare by improving the quality of life (Becker et al. 2005). The study of Becker et al. (2005) examines a full economic growth rate that includes advantages from health related issues. Their findings show that a longer life expectancy significantly contributes to enhancing global welfare with data from 1960 to 2000. This study illustrates interesting results that contrast with traditional findings. In low income countries, health accounts for 40 percent of the total welfare gains, while health only accounts for 15 percent of the total welfare gains in high income countries.

Another approach for estimating the impact of health on economic growth is the overlapping generations model. Zhang et al. (2003) employs the overlapping generations model to evaluate the impact of decreasing adult mortality on economic growth. Their result illustrates a net positive effect of lowering adult mortality on economic growth. In contrast, lowering the adult mortality rate in an industrialized country, which normally has a moderately low adult mortality rate, has a negative effect on economic growth.

The linkage of improvements in national health and increases in economic growth is explained in the literature of human capital and health in many aspects. The notable study of Gary S. Becker, an early pioneer of human behavior analysis and recipient of the 1992 Nobel Prize in economic science, explains that investment in human capital is as important as investment in construction and equipment (Becker 1993). Individuals who have higher life expectancies tend to gain more training and working ability than those who have lower life expectancies. Barro & Lee (1994) and Oster et al. (2013) affirm that longer life expectancy induces human capital investment from skill training and improves workers' work practices.

An increase in human capital expands economic growth. Zhang et al. (2003) explains the three channels that improve of health effects the economic growth. Firstly, healthy people who live longer tend to save more money for consumption after retirement. The increase in saving leads to increases in the rate of physical capital accumulation. Secondly, in low-longevity countries, better health may cause median voters to increase tax for education spending. However, in high-longevity countries, median voters tend to decrease tax for education spending, thus human capital finally drops in the later stage. Thirdly, higher longevity, which is associated with better health, may lower accidental bequest. Therefore, investment and the rate of physical capital accumulation decrease.

Aísa et al. (2004) also confirms the linkage of longer life expectancy and higher saving. They construct a theoretical model to examine the linkage of longer life expectancy and increase in economic growth over various linkages. Moreover, they describe a linkage between longer life expectancy and labour market. The size of the workforce increases from higher life expectancy, and, hence, aggregate output is stimulated. Nevertheless, improvements in health and economic growth compete for the same limited resources. Apart from life expectancy, mortality rate can be used to describe the relationship between health and economic growth. In high mortality rate countries, such as most developing countries, governments require less resources for lowering mortality rates. Therefore, investing in health is likely to be a favorable measure for developing countries. At the same time, a country with a low mortality rate, such as a developed country, may gain less benefit from lowering the mortality rate and its economy may even slow down as a result.

Lorentzen, McMillan & Wacziarg (2008) illustrates that high mortality rate affects economic activity by shortening the individual time horizon. In high adult mortality rate areas, individuals usually engages in high risk tasks and do not accumulate both physical capital and human capital, thus lowering private investment. A rise in mortality by one standard deviation leads to a fall in economic growth by between 8 to 14 percent. This can be a main source of a global poverty trap.

By contrast, some recent studies claim that health may have a small impact on economic growth. Acemoglu & Johnson (2007) argues that the impact of life expectancy on GDP is relatively small. The predicted mortality rate, which is collected from several diseases of global intervention, is used as a model instrument. They find no evidence that links life expectancy and income per capita. However, their model shows that a one percent increase in life expectancy raises population by between 1.7 and 2 percent. In addition, life expectancy itself may not be an appropriate demographic indicator for analyzing the impact of health on economic growth. Life expectancy can represent aspects of human health condition but not a complete picture of the population's health. Additional variables are useful for examining alongside life expectancy and have more potential to investigate the effect on economic growth, such as the share of the population aged over 65 and dependency ratios (An & Jeon 2006).

The impact of government spending on health to health status is investigated in a number of studies, such as Filmer & Pritchett (1999), Gupta et al. (2002), and Baldacci et al. (2003). Most studies use life expectancy and child mortality to present health status. The literature on the impact of government spending on health reveal ambiguous results.

Gupta et al. (2002) examines the effectiveness of government expenditure on education and health in 50 developing countries. They use both infant mortality rate and child mortality rate as a social indicator to measure the effect of government spending on health. They claim that allocating government spending to productive spending can significantly reduce corruption. The finding shows that an increase in public spending on health care leads to a decrease in the infant mortality rate and child mortality rate. The health regression includes a number of control variables, like per capital income, adult illiteracy rate, access to sanitation and urbanization. However, their study disregards important control variables, such as private spending towards health, because of an insufficient sample. Psacharopoulos & Nguyen (1997) raises the important role of private spending for health. They claim that spending by private entities on health can promote economic growth and tackle poverty. Both government spending and private spending on health complement each other when developing human capital. An increase in the private sector's participation, such as through planning and financing health, can increase the market's efficiency. Providers try to reduce their cost in order to better compete and meet the needs of their customers. Moreover, private sector involvement can induce more government spending for an omitted sector like health because the associated fiscal burden is lifted. Another different approach is presented by Baldacci et al. (2003). Their study applies a latent variable model to developing countries. Unobserved health status is presented by social indicators. The model yields a more robust result than the traditional technique. The results significantly show a positive impact of government spending on health. An increase in government spending on health leads to a decrease in the mortality rate.

In contrast, Filmer & Pritchett (1999) find that the impact of government spending on health and health status is relatively small and insignificant. They use cross-country data to examine the impact of government spending on health, the infant mortality rate and the under-five mortality rate. The result reveals that government spending on health can explain only a seventh of 1 percent of a variation in mortality rate across countries, while per capita income, education of women, income inequality, ethnic fragmentation and majority religion can explain more than 95 percent of variations in mortality rate.

Apart from the literature on the effect of government health spending on health status, a few studies examine the overall effect of government spending on health for economic growth, such as Aisa & Pueyo (2006). They use the endogenous longevity model to investigate a linkage between government spending on health and economic growth. The result suggests that government spending on health has two opposite effects on economic growth. Firstly, an increase in government spending on health raises life expectancy. Consumers with higher life expectancy save more for the future. Higher saving encourages economic growth. Secondly, increasing government spending on health affects resource allocation. It undermines capital accumulation and thus weakens economic growth. In developing countries, where life expectancy is low and the impact of government spending on health status is high, the former effect dominates the negative effect. An increase in government spending on health results in longer life expectancy and enhancing economic growth. On the other hand, the second effect is larger in a developed country. An increase in government spending on health not only impairs productive government spending but also lowers economic growth in developed countries.

4.3 MODEL AND DATA

This section describes two regression models: 1) the health model of government and private spending on health and 2) the production function model of aggregate output growth, including health indicators such as life expectancy and mortality rate. The first model shares several techniques with Gupta et al. (2002) , such as employing a two-stage least square estimation for dealing with causality problem. The main differences in this paper and Gupta et al. (2002) are 1) in addition to mortality rates, this paper selects a life expectancy as a new alternative health indicator while Gupta et al. (2002) employs infant mortality and child mortality as health indicators, 2) this paper uses four estimation techniques, which are fixed-effects model, random-effects model, two-stage least-squares within an estimator, and two-stage least-squares random-effects estimators while Gupta et al. (2002) estimates regressions from two estimation techniques (Ordinary least squares and two-stage least-squares), 3) private spending on health variable, which is disregarded in the study of

Gupta et al. (2002), is added in the health regression. 4) the sample of this paper is acquired from global data (over 200 countries), in contrast, Gupta et al. (2002) study 50 developing and transition countries.

The second model employs a production function with human capital from Bloom et al. (2004). The relation of the growth of the level of input and the aggregate output growth are examined. The main differences in this paper and Bloom et al. (2004) are 1) this paper adds new health indicator, namely, non-medical determinants of health such as tobacco consumption, alcohol consumption, sugar supply, and total fat supply, which may better reflects life-style and health of developed countries, 2) this paper separate data in to three groups, which are global data, developing countries, and developed countries, in order to compare the impact of human capital in the form of health among different countries groups while Bloom et al. (2004) uses single data set, 3) three estimation techniques, which are fixed-effects model, random-effects model, and augmented mean group estimator, are used while Bloom et al. (2004) employs nonlinear two-stage least-squares estimators.

The details of each model are explained as follows:

4.3.1 The health model

The health model investigates the role of government and private spending on health through heath status indicators, such as life expectancy, infant mortality rate and under-five mortality rate. The health model can be expressed as follows:

$$H_{it} = f(G_{it}, X_{it}) \tag{153}$$

, where H_{it} is health status of population in country i at time t , including life expectancy, infant mortality rate and under-five mortality rate. G_{it} is government spending on health as percentage of GDP in country i at time t. X_{it} is a vector of socioeconomic independent variables in country i at time t, including GDP per capita, improved sanitation facilities (% of population with access) and private spending on health as a percentage of GDP. These independent variables are selected in order to compare with previous studies on government spending on health. The socioeconomic independent variables are taken from official and credible sources, such as OECD.Stat [9], The Databank of the World Bank [10], Global health expenditure database of World Health Organization (WHO)[11], IMF Data[12], Reuter datastream and Penn World Table[13].

The panel data is the most up-to-date and has been observed in over 200 countries[14] (including developed countries and developing countries) from 1980 to 2014. List of developed countries are presented in Appendix C.4.

The national health status is proxied by life expectancy at birth, infant mortality rate and under-five mortality rate. Life expectancy measures the human population's average expected lifespan. It is commonly measured from birth or a specific age. Life expectancy is used as a health indicator in many studies on health, such as Bloom et al. (2004), and Aghion et al. (2010). According to Murray & Chen (1992) and Crimmins, Hayward & Saito (1994), better health (low morbidity rate) is accompanied with longer lives. Figure 6 shows life expectancy from 1960 to 2014. Global life expectancy significantly

[9] OECD.Stat provides data and metadata for OECD countries and chosen non-member OECD countries. The OECD.Stat URL is https://stats.oecd.org

[10] The Databank of the World Bank includes the important world development indicators. Various economic and social indicators are provided with an analysis and visualization tool.
The Databank of the World Bank URL is http://databank.worldbank.org/data/home.aspx

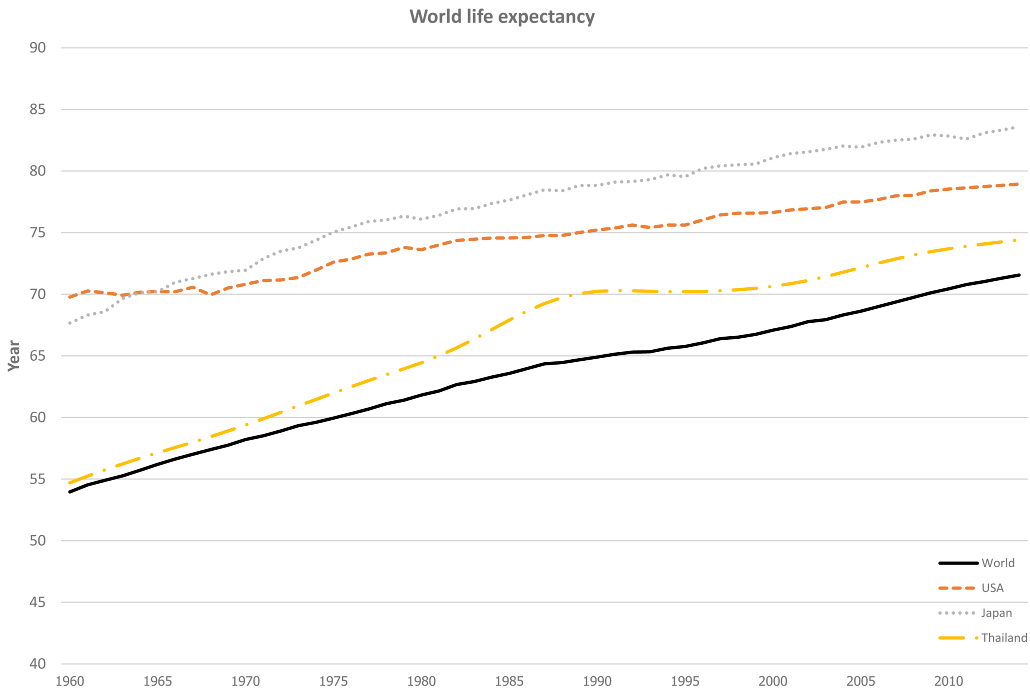
[11] Global health expenditure database of WHO provides international health expenditures and various health indicators.
The Global health expenditure database URL is http://apps.who.int/nha/database/Home/Index/en

[12] The IMF Data is the online database of international monetary fund which provides world macroeconomic and financial data. In additional, the database has a variety of government sector indicators.
The IMF Data URL is http://http://data.imf.org

[13] Penn World Table, version 9.0 is available on www.ggdc.net/pwt. The website also shows how these data were constructed and the different collection concepts. Further details: Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2015), "The Next Generation of the Penn World Table" American Economic Review, 105(10), 3150-3182

[14] Due to the limitation of certain variables, the number of country in each regressions are varied upon group of data.

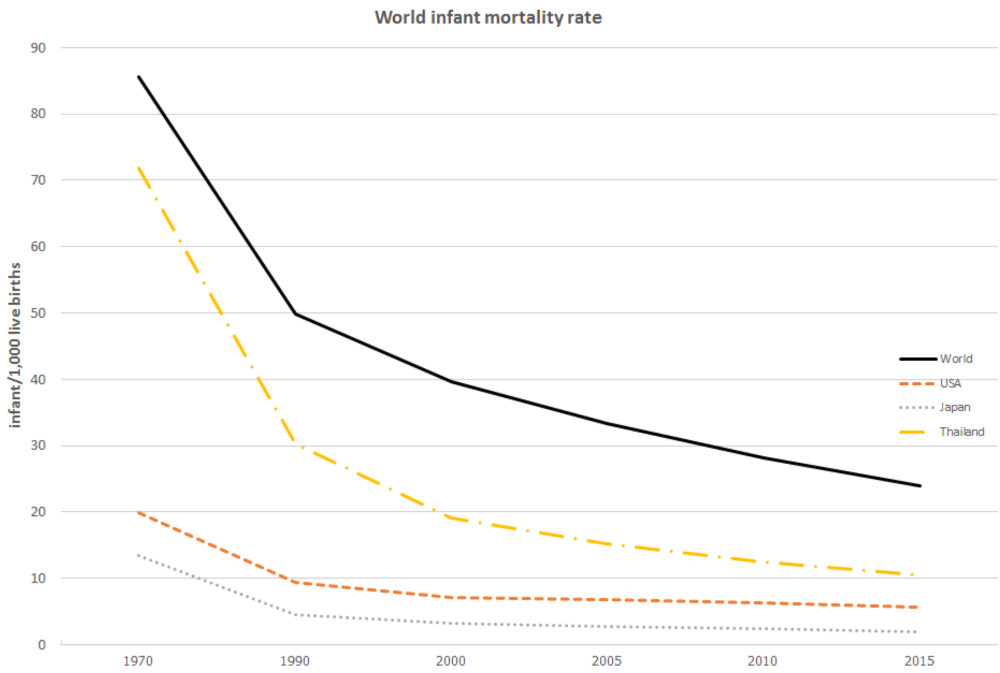
Figure 6: The world life expectancy during 1960 - 2014



increases from 53.96 years in 1960 to 71.55 years in 2014. The global population has lived 17.6 years longer over the last five decades. However, increases in life expectancy are different among countries. The increase in life expectancy for developed countries is relatively lower than the increase in life expectancy for developing countries, as improvement in the United States and Japan are 9.17 years and 15.92 years respectively, while the increase Thailand's life expectancy is 19.72 years over the last 54 years (See figure 6). In 2014, the country with the highest life expectancy is Hong Kong, at 83.98 years. In contrast, the country with the lowest life expectancy in 2014 is Swaziland, at 48.94 years.

Apart from life expectancy, mortality rate is employed as a proxy health indicator. The results of the mortality regression can be compared with the result of the life expectancy regression. Mortality rate measures the number of deaths compare to the total population by a specific cause or during a certain period. Mortality rate is commonly presented as the number of deaths per 1,000 members of the population in a year. The present paper employs two types of mortality rates, which are infant mortality rate and under-five mortality rate. Infant mortality rate shows a number of deaths of infants (age 0-1 year(s)) per

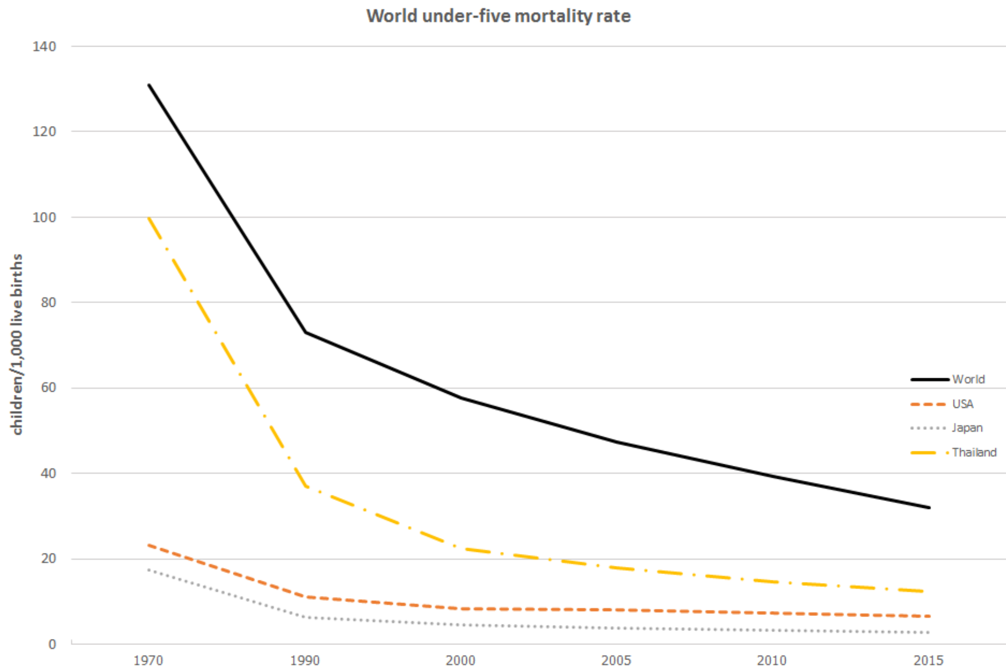
Figure 7: The world infant mortality during 1970 - 2015



1,000 newborns. Under-five mortality rate expresses the number of deaths (0-5 years of age) per 1,000 newborn. Mortality rate is employed as a health indicator in several studies on health, such as Filmer & Pritchett (1999) and Gupta et al. (2002). Figure 7 and 8 shows the infant mortality rate, alongside the global under-five mortality rate, of the United States, Japan, and Thailand in the 1970 to 2015 period. The world infant mortality and under-five mortality rates have significantly fallen over the last 45 years, dropping from 86.5 and 130.9 to 24.0 and 31.9 respectively. The mortality rate in developed countries tends to be lower than in developing countries, suggesting that mortality rate may be associated with economic development to some extent. The present paper also investigates this relationship. The difference in mortality rate between developed countries and developing countries has decreased considerably over the past five decades (see figure 7 and 8). In 2015, the country that had the lowest infant mortality rate and under-five mortality rate was Luxembourg at 1.5 and 1.9 respectively. Meanwhile, Angola had the highest infant mortality rate and under-five mortality rate at 96.0 and 156.9, respectively.

Government expenditures are expressed in percent to GDP for comparing

Figure 8: The world under-five mortality during 1970 - 2015



between countries. Government expenditures are classified by function, such as expenditures on education, social protection, health, defense and general public services. The source on government expenditures is the Government Finance Statistic (GFS) and IMF Data, which contain detailed data on the government sector.

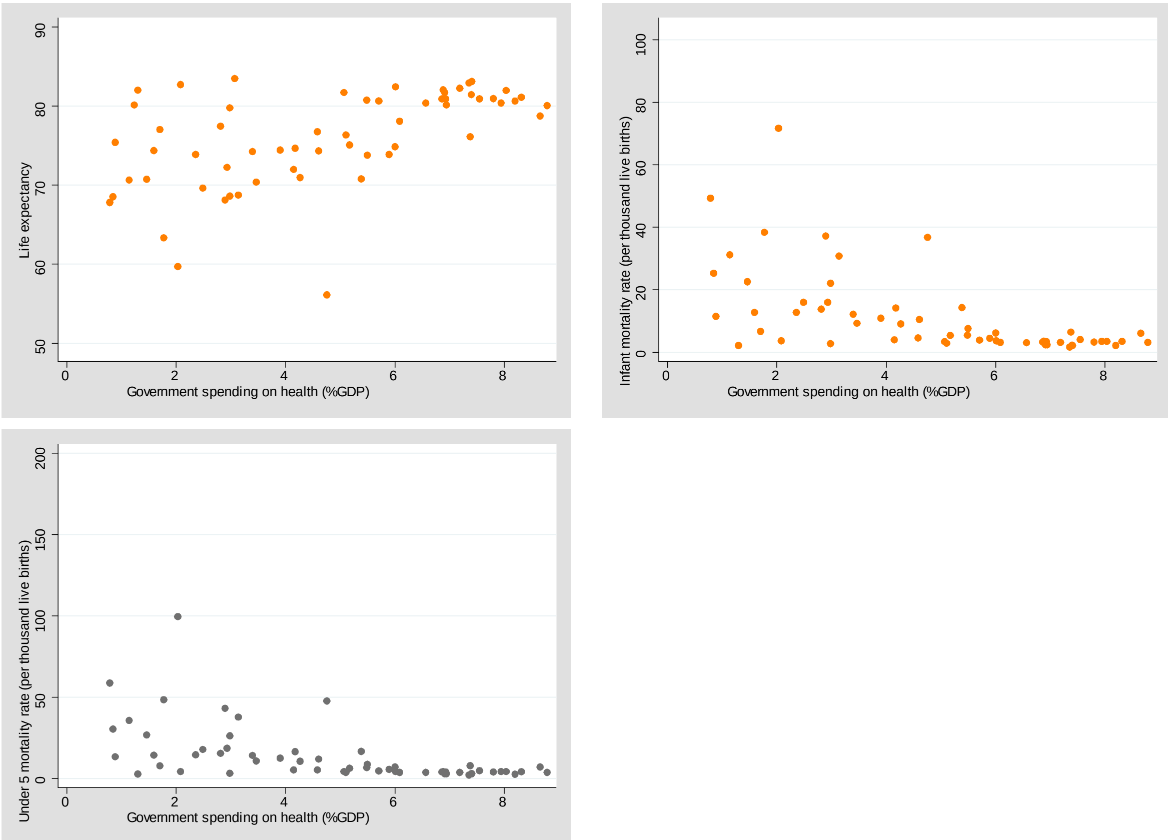
The scatter plot of government spending on health and health status (life expectancy, infant mortality rate, and under-5 mortality rate) is shown in Figure 9. The figure shows a positive relation between life expectancy and government spending on health and a negative relation between both mortality rates and government spending on health.

The independent variables of health regression is composed of the following:

Per capita income present income level of households. It is calculated from real GDP at chained purchasing power parity (PPP) (in mil. 2011US$) dividing by population. The source of real GDP and population is the Penn World Table. According to Filmer & Pritchett (1999) and Gupta et al. (2002), an increase in per capita income significantly improves health.

Sanitary and safe water facilities are proxied by improved sanitation facilities.

Figure 9: The scatter plot of life expectancy, infant mortality rate, under-5 mortality rate, and government spending on health in 2012



Safe water facilities are important for child development. Poor access to safe water facilities causes several fatal diseases, including diarrhoea, soil-transmitted nematode infections, guinea-worm disease and malnutrition (Huttly 1990). Moreover, previous studies find that increases in access to sanitation are associated with better health (Huttly (1990) and Kim & Moody (1992)). Improved sanitation facilities are expressed as a ratio of the population with access to sanitation facilities to the total population.

Private spending on health is a socioeconomic variable that may be associated with health. Private spending on health can substitute or complement a government's spending on health. Increases in private spending on health create more human capital related to health (Psacharopoulos & Nguyen 1997). Private spending on health is expressed as a percent to GDP. Since the data on private health spending is limited, previous studies have not included this variable in their regressions (Gupta et al. 2002).

The health model is estimated by using four estimation techniques, which are fixed-effects model (FE), random-effects model (RE), two-stage least-squares within an estimator (2SLS FE), and two-stage least-squares random-effects estimators (2SLS RE). The two-stage least-squares estimator is employed in order to deal with endogeneity problem, which is emerged from the correlation between the independent variable and the residual term. The causes of endogeneity problem can be a lack of some independent variable and a dynamic panel data model with lagged dependent variables (Generalized method of moments, GMM, should be applied with a dynamic panel data model). The two-stage least-squares technique introduces additional instrumental variables regression in the model to control an endogenous regressor.

The results of FE and RE model are compared by employing a Hausman test. The Hausman test is used to decide whether a fixed-effects model or a random-effects model is preferable. The null hypothesis is

$$\boxed{H_0 : \text{the difference in coefficients not systematic}}$$

which indicates that the preferred model is a random effects model.

4.3.2 The production function model

The production function model examines the role of human capital in the form of health on aggregate output growth . Human health capital is proxied by the life expectancy and mortality rates. The production function model adapts from Bloom et al. (2004)'s study. The production function has two source of growth, namely factor of input and total factor productivity (TFP). The factor of input is composed of labour, physical capital and human capital. The production function is expressed as follows:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}e^{\theta_1 H_{it}+\theta_2 NH_{it}} \tag{154}$$

, where Y is aggregate output. A is total factor productivity, K is physical capital, L is a number of labour and H is average level of health status, which is represented by life expectancy. Apart from health status, the present paper introduces a new variable: non-medical determinants of health, NH_{it}. This study will examine the role of non-medical determinants of health on human capital in the form of health. The selected non-medical determinants of health variables are composed of tobacco consumption, alcohol consumption, sugar supply and total fat supply. These variable are essential health indicators that can reveal individual routine activities and lifestyles in developed countries (Larson & Mercer 2004). The human capital in the form of health is defined in exponential term because it can properly present a microeconomic foundation, such as a logarithm of wage that depends on the level of national health status (Bloom et al. 2004). α is a capital income share, and β is labour income share, while θ_1 and θ_1 are coefficients of health status and non-medical determinants of health, respectively. In order to estimate the regression model, the production function is divided by total population and transformed to a logarithm function. Using per capita terms can exclude the effect of population growth. The logarithmic form of production function is

$$y_{it} = a_{it} + \alpha k_{it} + \beta l_{it} + \theta_1 H_{it} + \theta_2 NH_{it} \tag{155}$$

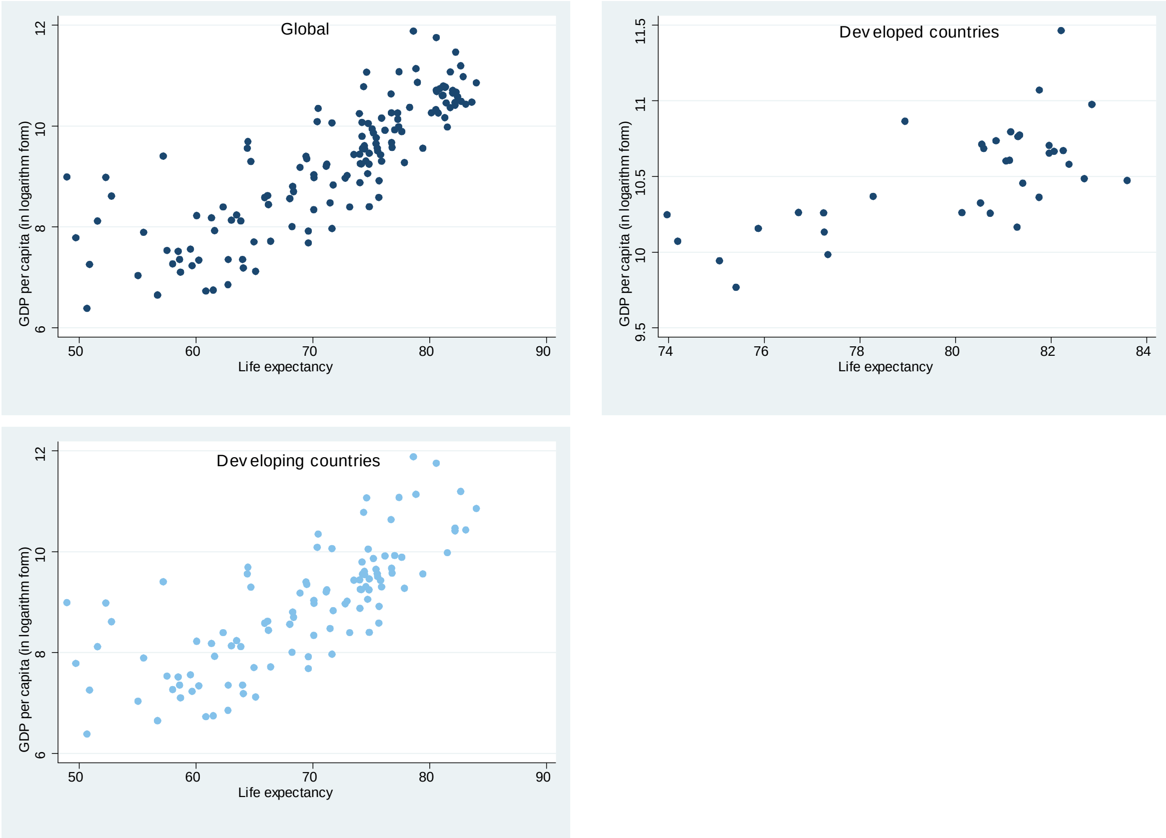
, where y_{it}, k_{it}, and l_{it} are logarithms of the per capita terms of Y_{it}, K_{it}, L_{it} respectively. a_{it} is a constant term that represents total factor productivity. Equation (155) is transformed into a growth equation as follows:

$$\Delta y_{it} = \Delta a_i + \alpha \Delta k_{it} + \beta \Delta l_{it} + \theta_1 \Delta H_{it} + \theta_1 \Delta NH_{it} \tag{156}$$

Equation (156) represents the source of aggregate output growth, which is composed of three components, namely growth of TFP, growth of the input factor and growth of human capital in the form of health. The variables are obtained from official sources, such as the Penn World Table, Reuter datastream and OECD.Stat. However, the global data on non-medical determinants of health variables are limited, because the data are only available for OECD countries. The production function model is estimated by using two estimation techniques, which are the fixed-effects model (FE), the random-effects model (RE).

The aggregate output, labour force, and capital stock are expressed in per capita term and obtained from the Penn World Table. The non-medical determinants of health variables are composed of tobacco consumption, alcohol consumption, sugar supply, and total fat supply, which are received from OECD.Stat. According to OECD.Stat, tobacco consumption refers to the annual consumption of tobacco items, such as cigarettes, snus, and cigars, per person aged 15 years and above. The tobacco consumption unit of measurement is grams per person. The amount of tobacco contained in a cigarette and cigar is approximately 1 gram and 2 grams, respectively. Alcohol consumption is annual consumption of pure alcohol per person aged 15 years and above. The conversion ratio of alcoholic drinks to pure alcohol is as follows (% pure alcohol equivalent): 40% for spirits, 11-16% for wines, and 4-5% for beers. The alcoholic consumption

Figure 10: The scatter plot of life expectancy and GDP per capita (in logarithm form) of the world, developed countries, and developing countries in 2014



unit of measurement is litres per person. The sugar supply is all forms of sugar and sweeteners consumed in a year. The sugar supply unit of measurement is kilos per person. Total fat supply is all types of fat consumed in a day. The fat supply unit of measurement is grams per person. The primary source of sugar supply and fat supply data is the Food and Agriculture Organization of the United Nations (FAO)[15].

The scatter plot of life expectancy and GDP per capita (in logarithm form) of the world, developed countries, and developing countries in 2014 are shown in Figure 10. The figure shows a positive relation between life expectancy and GDP per capita for all data sets.

[15] FAOSTAT, Food Balance Sheets: Food supply quantity. http://www.fao.org/faostat/en/#data/FBS

4.3.3 Data labels and sources

The source of variables of two models are listed in Table 4. The descriptive statistics of all variables are presented in Appendix C.3.

Table 4: The list of variables's source

Descriptions	Labels	Source
Government expenditure (percentage of GDP)	gov	IMF Data
Government expenditure on defense (percentage of GDP)	$govdef$	IMF Data
Government expenditure on education (percentage of GDP)	$govedu$	IMF Data
Government expenditure on public service (percentage of GDP)	$govpub$	IMF Data
Government expenditure on health (percentage of GDP)	$govhealth$	IMF Data
Government expenditure on social protection (percentage of GDP)	$govsocial$	IMF Data
GDP per capita (in thousands 2011US$/person)	$gdpcap$	Penn World Table
Private health expenditure (percentage of GDP)	$phealthgdp$	WHO
Improved sanitation facilities (percentage of population with access)	$sani$	World Bank
Life expectancy at birth (year)	$life$	Reuter datastream
Population (in millions)	pop	Penn World Table
Infant mortality rate (per thousand live births)	$motainf$	World Bank
Under 5 mortality rate (per thousand live births)	$motaunder5$	World Bank
Labour force (in millions)	$capital$	Penn World Table
Capital stock at constant 2011 (in mil. 2011US$)	$labour$	Penn World Table
Tobacco consumption (Grams per capita (15+))	$tobacco$	OECD.Stat
Alcohol consumption (Liters per capita (15+))	$alcohol$	OECD.Stat
Total fat supply (Grams per capita per day)	fat	OECD.Stat
Sugar supply (Kilos per capita per year)	$sugar$	OECD.Stat

4.4 EMPIRICAL RESULT

This section explains the empirical results of two models: the health model and the production function model. Before estimation, all variables are analyzed through performing a panel-data unit root test for checking the stationary process. The present paper employs the Fisher-type unit root test (See Choi (2001) for more details). The null hypothesis of the Fisher-type unit root test is that all the panels contain a unit root. The results of the Fisher-type unit root test are present in Appendix C.1 and C.2. The non-stationary variable is transformed by applying the first difference before estimating the model. The models are estimated by using the fixed-effects model (FE), the random-effects model (RE), the two-stage least-squares within estimator (2SLS FE), and the two-stage least-squares random-effects estimator (2SLS RE).

The two-stage least-square approach is applied when dealing with a reserve causality problem. According to Gupta et al. (2002), the reverse causality problem can arise in the relationship of government spending on health and health status. The increase in government spending on health may lead to an increase in life expectancy. At the same time, greater demand for better health, as represented by higher life expectancy, may lead to a push for higher government spending on health. However, the two-stage least-square approach can eliminate this error correlation problem. When an error term is correlated with a regressor variable, the ordinary least squares (OLS) technique may produce an inconsistent coefficient.

4.4.1 The health models

The empirical results of the health model are produced from three models, depending on the selected dependent variables. These models are a life expectancy regression, an infant mortality regression and an under-five mortality regression. In order to compare the results, each regression is estimated through four approaches, namely FE, RE, 2SLS FE and 2SLS RE. The instruments of

Table 5: The correlation of government spending by function of government in 2010-2014

Variable	*gov*	*govhealth*	*govdef*	*govedu*	*govpub*
gov	1.000				
govhealth	0.704	1.000			
govdef	0.348	-0.147	1.000		
govedu	0.549	0.557	-0.062	1.000	
govpub	0.285	0.204	-0.078	0.233	1.000

two-stage least-squares approach are adapted from Gupta et al. (2002). They suggest that, according to the studies of Looney Robert E (1996) and Gbesemete & Gerdtham (1992), the share of government spending on defense may define the difference in the share of government spending on health across countries. In order to verify this relation, the correlation of government spending by the function of government is estimated. Table 5 present the correlation of government spending by government function (percentage to GDP), which are listed *gov*, *govhealth*, *govdef*, *govedu*, *govpub*. Government spending on health, total government spending and government spending on education are all high correlated. The defence expenditure is negatively correlated with government spending on health, education and general public services. This result is consistent with the study of Looney Robert E (1996) that finds a negative correlation between defence expenditure and socioeconomic expenditure. Therefore, the present paper selects *gov*, *govdef*, *govedu*, *govpub* as instruments for *govhealth*.

Life expectancy, infant mortality, and under-five mortality regression are reported in Table 6, 7, and 8, respectively[16]. The explanatory variables can explain 70-80% of cross-country variation in the health status. The F-Statistic of all regressions, which shows the model's overall significance, is significant at the 1% level. This value implies that the chance for all regression parameters to equal zero is less than 1%.

In addition, all regressions are diagnosed for cross-sectional dependence and

[16] In order to deal with heteroskedasticity, the robust standard errors is used for fix effect model and random effect model. The robust standard errors relaxes the main assumption of OLS that the error term are both independent and identically distributed.

heteroskedasticity. The problem of cross-sectional dependence usually occurs for a macroeconomic panel data with a time period of over 20 years. The cross-sectional dependence is a cause-of-bias estimator in regression (Torres-Reyna 2007). The Breusch-Pagan LM test of independence is employed to test for cross-sectional dependence[17]. The null hypothesis of this test is that no correlation exists among residuals across entities. The test result show that there is no cross-sectional dependence in the life expectancy regression, the infant mortality regression and the under-five mortality regression because of a small number of common observations across panels. The heteroskedasticity test is conducted for all FE models. The modified wald statistic for group-wise heteroskedasticity is calculated[18]. The null hypothesis of this test is homoskedasticity (constant variance) in the variable. The results show a presence of heteroskedasticity in all fixed-effect models . Therefore, the regression is re-estimated by using the "robust" command in order to obtain heteroskedasticity-robust standard errors as recommended by Torres-Reyna (2007).

The Fisher-type unit root test in Appendix C.1 shows that *govhealth* has a unit root in life expectancy regression. Therefore, two additional models, namely the fixed-effects model with *d.govhealth* (the first difference of *govhealth*) ($FE^{(2)}$) and the random-effects model with *d.govhealth* ($RE^{(2)}$), have been used and calculated from. The Hausman test indicates that life expectancy regression prefers the FE, $RE^{(2)}$, and 2SLS FE models; while both mortality regressions prefer the FE model[19].

Government spending on health is statistically significant in all two-stage least-squares models, but not for all FE and RE models. The coefficient of government spending on health is positive for life expectancy regression. A one percentage

[17] The Breusch-Pagan LM test for cross-sectional correlation in fixed-effects model can be obtained by using the command xttest2 in STATA program.

[18] The modified wald statistic for groupwise heteroskedasticity in the fixed-effects model can be estimated by using the command xttest3 in STATA program.

[19] "N/A" implies that the model fitted on these data fails to meet the asymptotic assumptions of the Hausman test since chi2<0

Table 6: The results of life expectancy regressions

Life Expectancy	FE	RE	FE$^{(2)}$	RE$^{(2)}$	2SLS FE	2SLS RE
govhealth	0.23	0.22			0.53***	0.47***
	(1.45)	(1.45)			(5.45)	(5.09)
$\Delta govhealth$			-0.05	-.07		
			(-1.01)	(-1.49)		
gdpcap	0.18***	0.18***	0.19***	0.19***	0.20***	0.19***
	(5.78)	(6.01)	(5.53)	(5.82)	(23.25)	(22.88)
sani	0.32***	0.29***	0.34***	0.30***	0.32***	0.28***
	(4.93)	(5.66)	(6.02)	(6.30)	(21.03)	(21.29)
phealthgdp	0.46**	0.45**	0.52**	0.49**	0.25***	0.27***
	(2.20)	(2.36)	(2.19)	(2.22)	(2.39)	(2.82)
Constant	38.56***	42.13***	38.05***	42.03***	37.99***	42.63***
	(6.67)	(10.20)	(7.76)	(10.96)	(26.85)	(35.23)
R-squared	0.74	0.74	0.72	0.72	0.77	0.76
No. of observations	860	860	783	783	847	847
F-Statistic/Wald chi^2	33.25***	173.23***	30.67***	150.74***	104.82***	1791.32***
Hausman test (chi^2)	63.18***	63.18***	4.72	4.72	128.63***	128.63***

$t-statistics$ (FE model), and z (RE model) are shown in parentheses.

F-Statistic is shown for fixed-effects model.

Wald chi^2 is shown for random-effects model.

The instruments of 2SLS FE and 2SLS RE are total government expenditure, government expenditure on defense, government expenditure on education, government expenditure on general public services- all variables are percent to GDP.

$*$ Indicates significance at the 10% level.

$**$ Indicates significance at the 5% level.

$***$ Indicates significance at the 1% level.

Table 7: The results of infant mortality regressions

Infant mortality	FE	RE	2SLS FE	2SLS RE
govhealth	-0.34**	-0.20	-1.04***	-0.99***
	(-2.06)	(-0.84)	(-3.10)	(-3.11)
gdpcap	-0.23**	-0.20**	-0.21***	-0.15***
	(-2.16)	(-2.43)	(-5.86)	(-4.25)
sani	-1.39***	-0.86***	-1.44***	-0.78***
	(-8.58)	(-6.95)	(-21.35)	(-15.97)
phealthgdp	-0.31	-0.19	0.04	0.09
	(-0.44)	(-0.35)	(0.10)	(0.25)
Constant	146.14***	96.58***	151.81***	89.85***
	(9.70)	(9.55)	(23.70)	(20.67)
R-squared	0.71	0.71	0.79	0.80
Number of observations	333	333	327	327
F-Statistic/Wald chi^2	33.02***	130.02***	35.47***	472.06***
Hausman test (chi^2)	169.82***	169.82***	N/A	N/A

$t-statistics$ (FE model), and z (RE model) are shown in parentheses.

F-Statistic is shown for fixed-effects model.

Wald chi^2 is shown for random-effects model.

The instruments of 2SLS FE and 2SLS RE are total government expenditure, government expenditure on defense, government expenditure on education, government expenditure on general public services- all variables are percent to GDP.

$*$ Indicates significance at the 10% level.

$**$ Indicates significance at the 5% level.

$***$ Indicates significance at the 1% level.

Table 8: The results of under-five mortality regressions

Under-five mortality	FE	RE	2SLS FE	2SLS RE
govhealth	-0.54*	-0.24*	-1.58***	-1.31***
	(-1.72)	(-0.67)	(-3.33)	(-2.97)
gdpcap	-0.25*	-0.21**	-0.22***	-0.14***
	(-1.97)	(-2.20)	(-4.35)	(-2.89)
sani	-2.00***	-1.15***	-2.07***	-1.04***
	(-7.43)	(-6.57)	(-21.66)	(-15.44)
phealthgdp	-0.40	-0.24	0.13	0.12
	(-0.43)	(-0.33)	(0.23)	(0.24)
Constant	205.41***	124.96***	214.07***	116.45***
	(8.17)	(8.69)	(23.58)	(19.70)
R-squared	0.70	0.70	0.79	0.79
Number of observations	333	333	327	327
F-Statistic/Wald chi^2	21.56***	104.39***	30.51***	416.72***
Hausman test (chi^2)	202.08***	202.08***	N/A	N/A

$t - statistics$ (FE model), and z (RE model) are shown in parentheses.

F-Statistic is shown for fixed-effects model.

Wald chi^2 is shown for random-effects model.

The instruments of 2SLS FE and 2SLS RE are total government expenditure government expenditure on defense, government expenditure on education, government expenditure on general public services- all variables are percent to GDP.

$*$ Indicates significance at the 10% level.

$**$ Indicates significance at the 5% level.

$***$ Indicates significance at the 1% level.

increase in government spending on health to GDP leads to approximately a half year increase in life expectancy across the countries analyzed. The results of the mortality regressions show a negative relation between government spending on health and both mortality rates that is consistent with Gupta et al. (2002) and Baldacci et al. (2003)'s findings. A one percentage increase in government spending on health to GDP statistically lowers the infant mortality rate and the under-five mortality rate by 1 to 1.1 and 1.3 to 1.6, respectively. This contrast with the finding from Filmer & Pritchett (1999) that government spending on health is not a powerful determinant of mortality.

Per capita income is significant for all regressions. The result shows that a higher per capita income is associated with a longer life expectancy and lowers both mortality rates across the countries analyzed, which is consistent with Gupta et al. (2002)'s findings. A one thousand 2011US$/person increase in per capita income improves the population's health through raising the life expectancy between 0.18 and 0.20 year, lowering the infant mortality rate between 0.15 and 0.23 (per thousand live births) and decreasing the under-five mortality rate between 0.14 and 0.25 (per thousand live births). Moreover, improved sanitation facilities are significant at the 1% level for all regressions. Improved sanitation facilities are considered to be strong predictors of the population's health status. This result is in line with earlier literature from Huttly (1990) and Kim & Moody (1992) that find a positive relation between an increase in access to sanitation and an improvement of health status. However, interestingly, this is contrary to a study from Gupta et al. (2002) that investigates the relation of access to sanitation with the mortality rate. Most of their regressions show an insignificant relationship between access to sanitation and mortality rate. Private spending on health is significant for the life expectancy regression but not for both mortality regressions. These results may imply that most amounts spent by private entities on health are allocated for improving longevity but not for reducing child mortality. The private health spending coefficient in the 2SLS model is half of the coefficient corresponding with government spending on health (in the range 0.25-0.27). A one percentage increase in private spending on health to GDP contributes to approximately a quarter year increase in life expectancy cross-country. Knowledge of the relationship between private spending on health and health status is important for budgetary planning by governments. Private spending on health can effectively substitute a government's spending on health in improving longevity. Therefore, the government can allocate extra government spending to other productive areas such as education, which can increase human capital and promote economic growth in the long term.

The world's government spending on health, as well as by selected countries and private entities, from 1995-2014 is shown in Figure 11. It is apparent from this figure that the relationship between government and private spending on health is mixed, as it is both substituting and complementary. The world's government spending on health and the world's private spending on health are complementary, since both amounts have increased over the last 20 years period. The share of the world's government spending on health to total health spending increased from 59 percent in 1995 to 60.3 percent in 2014. This shows additional government efforts to improve the global health. In contrast, the share of the world's private health spending to total health spending falls during that period. In some developed countries, for example, the United states and Japan, the government's spending on health and private spending on health are complementary. However, the roles of the government and private entities in these countries' healthcare systems are totally different. In the United states, private spending on health is larger than the government's expenditures on health. Healthcare costs in the United States are the highest in the world, measured by per capita and as percentages to GDP. According to the Centers for Medicare and Medicaid Services (CMS)[20], the United States' total health

[20]CMS provides historical data of the national health expenditure accounts (NHEA) of the United States. NHEA presents annual U.S. expenditures for health care goods and services, public health activities, government administration, the health insurance, and health care investment.

spending is $9,990 per person or 17.8 percent of GDP in 2015. Anderson, Reinhardt, Hussey & Petrosyan (2003) suggests that the U.S. government's spending on health is not significantly different from OECD countries, but the country's private spending on health is very high compared to this group. They conclude that a higher price of healthcare goods and services in the U.S. contributes to the highest amount of total healthcare spending in the world.

The largest part of the U.S.'s healthcare spending goes to hospital care and physician and clinical services, which accounted for 32 and 20 percent shares in 2015, respectively. The U.S.'s private spending on health is mainly composed of private health insurance and out-of-pocket health spending. On the contrary, Japan's private spending on health is relatively low, compared to its government spending on health. Japan has a universal health care insurance system, which prioritizes a relative equality of access. The government sets the level of patients' participation in medical fees by considering their ages and their families' incomes. For example, patients make a co-payment of 30% of medical fees for curative service, 20% of medical fees for pre-school children and those aged 70-74 years, and 10% of medical fees for those over 75 years (WHO 2012). Some developed countries have a substitution between government spending on health and private spending on health, such as the Netherlands. The Dutch government's spending on health has constantly increased over the last decade, while the Netherlands' private spending on health has fallen from 2.9 percent of GDP in 2005 to 1.4 percent of GDP in 2006. In Europe, the Netherlands' healthcare is ranked in first place by the Euro Health Consumer Index (EHCI)[21]. In 2006, the Netherlands introduced a new healthcare insurance system based on risk equalization through a risk equalization pool. Its insurance premiums are not related to health status or age. The entire population can purchase compulsory insurance at a reasonable price without risk assessing by the insurer.

Although government and private spending on health in most countries are

[21] EHCI is a healthcare index that is calculated based on waiting times, outcomes, and generosity. It was introduced in 2005.

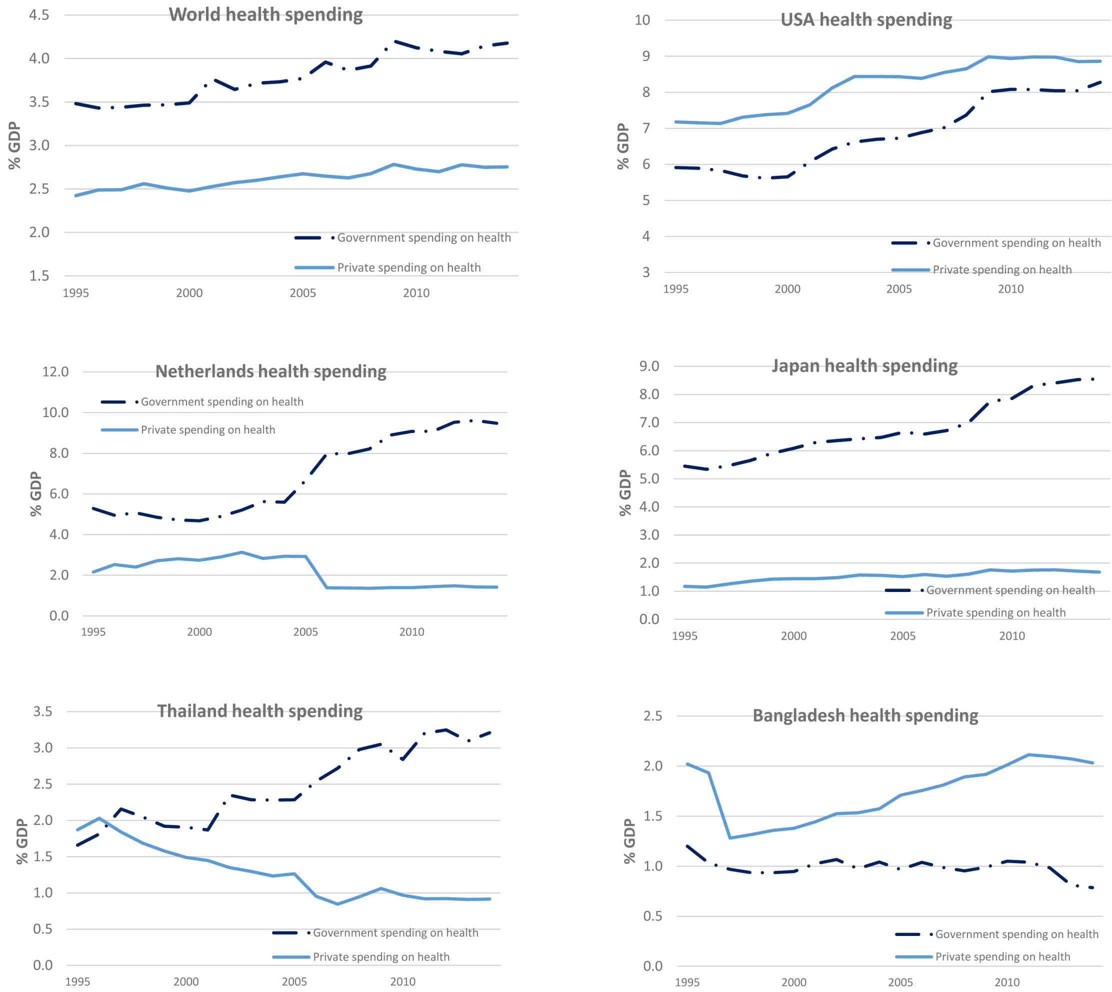
complement, several developing countries, such as Thailand and Bangladesh, have a substitution. Thailand's private spending on health continuously falls; whereas its government spending on health constantly rises (see Figure 11). The important advance in Thailand's healthcare is the introduction of a universal coverage scheme, namely the 30 Baht project, in 2001. All Thais who join this program are allowed to access health services by paying a small co-payment. This program significantly improves the health of middle to low income households that are not covered by the civil service welfare system and the social security program. These two former programs were designed for civil servants and private employees. After implementing the universal coverage scheme, Thailand's government spending on health substantial increased in 2002; while its private spending on health has gradually fallen. In spite of improvements in national health, the substitution between government and private spending on health of Thailand raises a concern of long-term fiscal debt. For a small-open economy, a higher fiscal debt directly affects the financial sector and trade sector via exchange rate adjustments.

The healthcare of Bangladesh contrasts with Thailand's. Its private spending on health has increased since 1997, but its government spending on health has slowly fallen. This process transfers the responsibility for healthcare from the government to the private sector, and it may allow more government spending for other productive sectors, such as education. The World Bank data show that Bangladesh's government spending on education has increased from 1.95 percent of GDP in 1997 to 2.18 percent of GDP in 2012.

4.4.2 The production function model

The production function models are investigated by using three data sets: global data, developed countries' data, and developing countries' data. The empirical results can be compared and examined for the role of health on economic growth in different environments. The regression's estimation employs a fixed-effect (FE) model and a random effect (RE) model. The FE model and RE model employ time-fixed effect to test whether the dummies for all years are

Figure 11: Government spending on health and private spending on health by the world and selected countries during 1995 - 2014



Source: World Health Organization. The global health expenditure data base

Table 9: The correlation of GDP and independent variables in production function mode in 1950-2014

Variable	*gdp*	*capital*	*labour*	*life*
gdp	1.00			
capital	0.92	1.0		
labour	0.36	0.28	1.00	
life	0.81	0.76	0.35	1.00

equal to zero or not. The coefficients of the time dummy are not presented due to a large number of coefficients. Table 9 presents the correlation of GDP and independent variables in the production function model, which are capital, labour and life expectancy. All variable have a positive correlation. The dependent variable, *gdp*, has a high correlation with *capital* and *life*. Among independent variables, only *capital* and *life* are highly correlated. All variables are diagnosed for unit root. The results of the Fisher-type unit root test are present in Appendix C.2. The unit root test results show that all variables do not have unit roots.

Moreover, all production function regressions are diagnosed for cross-sectional dependence and heteroskedasticity. The cross-sectional dependence can emerge from spatial effect, spillover effect, or unobserved common factors. The cross-sectional dependence problem cause a considerable distortion in estimators (Baltagi & Hashem Pesaran 2007). The cross-sectional dependence is tested by using the Pasaran CD test, since the Breusch-Pagan LM test of independence is not available for this model [22]. The null hypothesis of the Pasaran CD test of independence is independence among residuals across entities. The result of Pasaran CD test shows that there are cross-sectional dependences in the global model, developed countries and developing countries. Cross-sectional dependence can be caused by common shocks (such as recession) or spillover effects. Since the FE model and RE model assume cross-sectional independence, the results may show imprecise estimators. Hence, the mean group estimator approach is introduced in order to deal with this problem. The foundation procedures for the

[22] The Pasaran CD test for cross-sectional dependence in fixed-effects model can be obtained by using the command "xtcsd, pesaran abs" in STATA program.

mean group estimator approach are adding cross-sectional averages of both dependent variables and regressors to the regression, evaluating the regression of all specific groups and averaging the coefficients of all specific groups (Eberhardt et al. 2012). There are several types of mean group estimators in the literature. This paper chooses the augmented mean group estimator (AMG), including group-specific trend-terms, which is developed by Eberhardt & Teal (2010). AMG is commonly employed for estimating a production function[23]. It can capture a common dynamic process or an evolution of an unobservable TFP over time (See Eberhardt & Teal (2010) for details).

The heteroskedasticity test is conducted for all FE models. The modified Wald statistic for groupwise heteroskedasticity is calculated. The results show a presence of heteroskedasticity in all fixed-effect models. Therefore, the regression is re-estimated by using a "robust" command in order to obtain heteroskedasticity-robust standard errors. The robust standard errors relax the main assumption of OLS that the erroneous term are both independent and identically distributed.

The production function with life expectancy models are reported in Table 10. The explanatory variables can explain 62-64% of cross-country variations in the output of global models and developing country models and 31% of cross-country variation in the output of developed country models. The F-Statistic of all regression, which shows overall significance of the model, is significant at the 1% level[24]. This value implies that the chance for all regression parameters to equal zero is less than 1%. The Hausman test indicates that the production function with health status prefers the RE model for global, developed and developing models. Both the capital and labour coefficients are significant at the 1% level for all models and data sets. The capital income share in the global and developing countries' models is larger than the capital income share in the developed countries models (in the range of 0.51-0.73 and 0.46-0.53 respectively). In contrast, the share

[23] The augmented mean group estimator can be estimated by using the command "xtmg" in STATA program.

[24] Some regressions do not show the F-Statstic (N/A), because the computation software (STATA) is concerned with the misleading data. There is nothing necessarily wrong wihth the model.

of labour income in the global and developing countries' models is smaller than the share of labour income in the developed countries' models (in the range of 0.28-0.47 and 0.60-0.63 respectively). The global and developing countries' models show a decreasing return to scale property since the sum of the factors of the input coefficients is less than one; while, developed countries have an increasing return to scale.

The life expectancy is positively significant in the global and developing countries' models in the FE and RE approaches. The life expectancy coefficients of these models are close to 0.01, indicating that a one-year increase in life expectancy leads to a one percent increase in output. The result confirms that improving life expectancy in developing countries and the world contributes to a higher human capital in the form of health, leading to economic growth. The positive effect of life expectancy on output finding is consistent with the studies by Barro et al. (1996), Bloom & Williamson (1998), Bloom & Canning (2000) and Bloom et al. (2004). Their life expectancy coefficient is in the range of 0.04-0.06. These studies indicate that an improvement in health leads to an increase in human capital, which results in a higher labour productivity. Apart from improving in human capital, longer life expectancy affect saving decision. People who have longer life expectancy tend to save more in order to consume in the future, lead to a capital accumulation and enhancing economic growth (Zhang et al. 2003, Aísa et al. 2004, Lorentzen et al. 2008). Moreover, Acemoglu & Johnson (2007) finds that a longer life expectancy creates a higher population, resulting in more labour for goods production because the birth rate does not decrease enough to offset the longer life expectancy.

Conversely, the developed countries' life expectancy coefficient is not significant. The finding shows that improving life expectancy in a developed country may not contribute to economic growth. A possible reason is that the health status in a developed country is substantially higher than in a developing country, which is shown by the longer average life expectancy of people living in a developed country. The average life expectancy for the populations of developed countries is 79.9 years in 2014, comparing to 68.9 years for the populations of developing countries. Therefore, increasing human capital in the form of health of a developed country requires more resource than for a developing country and can take resources from more productive sectors, ultimately slowing down the economy.

While the results from the FE and RE models are in line with the literature on life expectancy, the result of the AMG models show the insignificance of the life expectancy coefficient in the global, developed countries', and developing countries' models. The AMG is used to deal with the cross-sectional dependence which usually arises in macroeconomics data with long duration series (over 20-30 years). This suggests that the result of the FE and RE models may present bias estimators, and the result should be interpreted with caution.

Table 10: The production function with life expectancy in the difference forms

ΔGDP	Global			Developed Countries			Developing Countries		
	FE	RE	AMG	FE	RE	AMG	FE	RE	AMG
$\Delta Capital$	0.54***	0.58***	0.65***	0.53***	0.50***	0.46***	0.51***	0.57***	0.73***
	(9.82)	(14.69)	(4.46)	(3.55)	(3.64)	(1.91)	(8.28)	(13.15)	(4.18)
$\Delta Labour$	0.33***	0.35***	0.47***	0.61***	0.60***	0.63***	0.28***	0.30***	0.330***
	(5.20)	(5.61)	(3.81)	(4.87)	(4.99)	(6.56)	(4.23)	(4.64)	(2.20)
$\Delta Life\ expectancy$	0.010***	0.009***	-0.01	0.009	0.008	-0.01	0.011***	0.010***	-0.02
	(3.87)	(3.66)	(-0.71)	(1.53)	(1.45)	(0.85)	(3.55)	(3.52)	(-0.55)
$Constant$	0.005	0.005	0.007	0.01	0.01	0.03**	0.002	0.002	-0.005
	(0.76)	(0.76)	(0.48)	(1.34)	(1.62)	(1.83)	(0.31)	(0.24)	(-0.29)
R-squared	0.62	0.62	N/A	0.31	0.31	N/A	0.64	0.64	N/A
Number of observations	5666	5666	5666	1400	1400	1400	4266	4266	4266
F-Statistic/Wald chi^2	15.39***	1056.97***	29.90***	N/A	N/A	59.52***	43.44***	1171.75***	19.29***
Hausman test (chi^2)	9.91	9.91		4.39	4.39		9.52	9.52	

$t - statistics$ (FE model), and z (RE and AMG model) are shown in parentheses

F-Statistic is shown for fixed-effects model, Wald chi^2 is shown for random-effects model

$*$ Indicates significance at the 10% level.

$**$ Indicates significance at the 5% level.

$***$ Indicates significance at the 1% level.

The production function's regressions, with non-medical determinants of health like tobacco consumption, total fat supply, alcohol consumption and sugar supply, are reported in Table 11. Due to the limitation of including non-medical variables, only OECD country data is available. The non-medical determinants of health model can explain 60-77% of cross-country variations in the output of OECD countries. All non-medical determinants of health regressions have higher R-squared results than life expectancy regressions (1). This suggests that non-medical determinants can represent cross-country variations in the output of OECD countries better than life expectancy. The F-Statistic of all regressions, which shows overall significance of the model, is significant at the 1% level [25]. The Hausman test indicates that all production functions with non-medical determinants prefer the RE model. Capital and labour coefficients are significant for all models. However, life expectancy coefficient is not statistically significant in regression (1), which is similar to the developed country regression in Table 10. The regression (2) shows a small, positive and significant coefficient of tobacco consumption at 10% level, which contrasts with common expectations. Tobacco use causes several diseases and significantly reduces the life expectancy of smokers (Olshansky et al. 2005). Valkonen & Van Poppel (1997) studies the effects of smoking on life expectancy in Europe countries, such as Denmark, Finland, Norway, Sweden and The Netherlands. The paper found that the estimated decrease of life expectancy from age 35 attributable to smoking was between 1.2-3.7 years from 1985 to 1989. The loss of life expectancy among males is significantly higher than among females. Hence, an increase in tobacco consumption clearly decrease the nation's human capital in the form of health.

So, what causes a positive effect from tobacco use on the economy? According to Bloom et al. (2004), the tobacco industry claims that tobacco is important for economic activities and nation fiscal health, thereby disregarding physical health problems resulting from tobacco use. Sales of tobacco products

[25] Some regressions do not show the F-Statstic (N/A), because the computation software (STATA) is concerned with the misleading data. There is nothing necessarily wrong with the model.

generate tax revenue and jobs related to tobacco manufacturing in farming, production, wholesale, transportation and retail. The United States Department of Agriculture (USDA) reported that U.S. consumer expenditures on tobacco in 1997 were worth $52.6 billion. Manufacturing received 43% of consumer expenditures on tobacco or $26.1 billion; whereas, farmers received a smaller share of this spending, only 6% of consumer expenditures on tobacco or $2.9 billion. However, the amount of U.S. tobacco farmers was relatively large, and roughly 90,000 farms grew tobacco leaf in 1998. The U.S. tobacco consumption generated $13.5 billion in excise tax for the Federal, State and local branches of government in 1997 (H. Frederick Gale, Foreman & Capehart 2000). Hence, higher demand for tobacco may lead to an economic expansion in The United States and tobacco-dependent countries.

Similarly, alcohol is positively significant at the 5% level. The coefficient of alcohol consumption is 0.006, which implies that a one litre per capita increase in alcohol consumption leads to a 0.6% increase in economic growth. This positive effect does not increase, higher human capital in the form of health, because alcohol consumption raises not only a risk of alcohol-related diseases but also numbers of accidents and violent incidents. Blanchard & Perotti (1999) study the impact of alcohol on life expectancy and describe alcohol-related mortality by cause of death in Finland. The paper shows that loss of life expectancy from age 15 years attributable to alcohol-related mortality is 2 years for men and 0.4 years for women. In addition, this paper also reviews the effect of alcohol consumption on life expectancy (see details in Appendix C.5). The finding shows that alcohol consumption and life expectancy are significantly negatively correlated. One liter per capita increases in alcohol consumption over a year lead to a shortening of 0.12 to 0.13 years in life expectancy across the OECD countries.

How does alcohol bring economic benefit to society? Economic benefits from alcohol can be directly measured through examining alcohol sales generated that are transferred to the government as excise tax revenue, as well as the number of jobs related to alcohol consumption. According to HM Revenue and Customs, the alcohol duty receipt has almost tripled over the last three decades, and it is worth £11 billion in 2016 (1.9% of total HMRC receipts and 0.6% of the U.K.'s GDP). The U.K.'s average taxes on wine and spirits are 56% and 77%, respectively(WSTA 2016). The alcohol duty receipt can be used to finance general government expenditures and specific sectors that are undermined by alcohol consumption, such as healthcare. The Wine and Spirit Trade Association (WSTA) claimed that alcohol manufacturing and retail sales employed more than 588,000 people in 2016. Therefore, an increase in alcohol consumption can create higher jobs and labour income, leading to economic growth. The results indicate that alcohol's economic benefit is greater than its cost in OECD countries (disregarding the social cost).

Fat and sugar are not statistically significant in all models. The finding shows that the consumption of fat and sugar does not contribute to economic growth or contraction. However, fat and sugar consumption are the important health indicators. High fat and sugar consumption are associated with the development of chronic diseases such as type 2 diabetes and cardiovascular disease (Malik, Popkin, Bray, Després, Willett & Hu 2010, Franco, Steyerberg, Hu, Mackenbach & Nusselder 2007, Hu, Stampfer, Manson, Rimm, Colditz, Rosner, Hennekens & Willett 1997). Malik et al. (2010) study the risk of attaining metabolic syndrome and type 2 diabetes by consuming sugar-sweetened beverages (SSBs). They find that individuals who consume SSBs (1-2 servings per day) have a 26% higher risk of developing type 2 diabetes than those who consume SSBs less than 1 serving per month. This disease is clearly associated with lower life expectancy. According to Franco et al. (2007), people with diabetes have a higher risk of developing cardiovascular disease (CVD) and their life expectancy significantly decreases by 7.5 years on average for men and 8.2 years for women.

Table 11: The production function with non-medical determinants of health in the different form of OECD countries

ΔGDP	(1)		(2)		(3)		(4)		(5)	
	FE	RE	FE	RE	FE	RE	FE	RE	FE	RE
$\Delta Capital$	0.66***	0.59***	1.03***	1.03***	0.93***	1.12***	0.79***	0.96***	0.93***	1.12***
	(5.00)	(4.56)	(3.6)	(6.14)	(4.01)	(9.34)	(3.26)	(6.61)	(4.09)	(9.65)
$\Delta Labour$	0.82***	0.81***	0.46***	0.45***	0.72***	0.65***	0.66***	0.60***	0.73***	0.65***
	(6.6)	(6.84)	(4.61)	(4.14)	(4.87)	(5.05)	(5.98)	(5.93)	(4.92)	(5.06)
$\Delta Life\ expectancy$	0.0030	0.0018								
	(0.50)	(0.37)								
$\Delta Tobacco$			$1.21*10^{-5}$	$1.51*10^{-5}$*						
			(1.44)	(1.73)						
ΔFat					$-3.87*10^{-5}$	$3.18*10^{-5}$				
					(-0.11)	(0.09)				
$\Delta Alcohol$							0.0057*	0.0061*		
							(1.86)	(1.87)		
$\Delta Sugar$									$2.36*10^{-4}$	$3.27*10^{-4}$
									(1.05)	(1.42)

Continued on next page

Table 11: The production function with non-medical determinants of health in the different form of OECD countries (continued)

ΔGDP	(1)		(2)		(3)		(4)		(5)	
	FE	RE	FE	RE	FE	RE	FE	RE	FE	RE
$Constant$	0.005	0.007***	-0.008	-0.007	-0.012	-0.017***	-0.009	-0.013***	-0.012	-0.017***
	(0.48)	(2.69)	(-0.95)	(0.23)	(-1.74)	(-3.33)	(1.26)	(-2.33)	(-1.75)	(-3.35)
R-squared	0.52	0.45	0.77	0.73	0.63	0.66	0.57	0.60	0.64	0.66
Number of observations	1396	1396	274	274	376	376	448	448	376	376
F-Statistic/Wald chi^2	N/A	162.15***	67.59***	625.96***	N/A	N/A	31.01***	484.06***	N/A	N/A
Hausman test (chi^2)	8.66	8.66	10.27	10.27	5.00	5.00	3.38	3.38	7.09	7.09

$t-statistics$ (FE model), and z (RE) are shown in parentheses.

F-Statistic is shown for fixed-effects model. Wald chi^2 is shown for random-effects model.

$*$ Indicates significance at the 10% level.

$**$ Indicates significance at the 5% level.

$***$ Indicates significance at the 1% level.

4.5 CONCLUSION

The chapter studies the role of public health spending on economic growth by analysing improvement in national health, which is represented by life expectancy and the mortality rate. The study is composed of two models, namely the health model and the production function with human capital model. The model data is panel data, which is the most up-to-date with observations from over 200 countries (including developed countries and developing countries). The health model is estimated by using the fixed-effects model, the random effect model, and the two-stage least-squares approach, which is applied for dealing with the reserve causality problem. The instruments of the two-stage least-squares approach are government spending on defense, government spending on education, government spending on public service and total government spending. Moreover, this paper examines the private sector's role in health, which is not considered in the previous literature on health due to a lack of data (Gupta et al. 2002). Other independent variables are GDP per capita and improvement in sanitation facilities. The result show that the effect of government spending on health is positively significant in all two-stage least-squares models. A one percentage of GDP increase in government spending on health leads to approximately a half year increase in life expectancy across the countries analyzed. The result of the mortality regressions show a negative relation between government spending on health and both mortality rates. This is consistent with Gupta et al. (2002) and Baldacci et al. (2003)'s findings. A one percentage of GDP increase in government spending on health to statistically lowers the infant mortality rate and the under-five mortality rate by 1 to 1.1 and 1.3 to 1.6, respectively. This contrasts with Filmer & Pritchett (1999) 's finding that government spending on health is not a powerful determinant of mortality. Interestingly, private spending on health has a significant positive effect on life expectancy, but it does not have a significant effect on either mortality rate. This finding implies that most amounts spent by private entities on health is allocated for improving longevity but not for reducing child mortality. The private health spending coefficient of 2SLS model is half of the coefficient of government spending on health, as it is in the range of 0.25-0.27. This result is useful for government budgetary planning. Private spending on health can effectively substitute a government's spending on health on improving longevity. Therefore, governments can allocate extra spending to other productive areas, such as education, which can increase human capital and promote economic growth in the long term.

The production function with human capital is estimated by using the fixed-effects model, the random effects model, and the mean group estimator, which is used to deal with a cross-sectional dependence problem . The national health status is represented by life expectancy. In order to compare the effect of different countries' incomes on health and economic growth, the models are estimated by using three data sets, which are global data, developed countries' data and developing countries' data. The results show that life expectancy is positively significant for global and developing countries' models by using the fixed-effects and random effects approaches. The life expectancy coefficients of these models are close to 0.01, which implies that a one year increase in life expectancy leads to a one percent increase in output. The finding is consistent with the studies by Barro et al. (1996), Bloom & Williamson (1998), Bloom & Canning (2000) and Bloom et al. (2004). Their life expectancy coefficients are in the range of 0.04-0.06. However, an increase in life expectancy in a developed country may not contribute to economic growth, since developed countries requires more resource to improve health status than in developing countries. In contrast, the mean group estimator shows the insignificance of the life expectancy coefficient in both developed countries' and developing countries' models. This suggests that the result of the fixed-effects and random effect models should be interpreted with caution.

Moreover, non-medical determinants of health, such as tobacco consumption, alcohol consumption, sugar supply, and total fat supply, are used as a proxy for health indicators in developed countries. Since most populations in developed countries have a high life expectancies, using life expectancy as a health indicator may not reflect the national health and the lifestyle of the population (Larson & Mercer 2004). The data for this analysis is obtained from OECD countries. The findings suggest that only tobacco and alcohol consumption have significantly positive relations (at 10% level) with economic growth, which contrasts with the expectation. Both tobacco and alcohol consumption shorten life expectancy, (Olshansky et al. 2005), (Valkonen & Van Poppel 1997), and (Bloom et al. 2004), so they should decrease human capital in the form of health in production function as well. The positive effect of higher tobacco and alcohol consumption on economic growth can arise from an increase in economic activities and improvement in the nation's fiscal health. A higher demand for tobacco and alcohol products generates more tax revenue, which supports fiscal health and creates jobs related to manufacturing in farming, production, wholesale, transportation and retail. This result implies that the tobacco and alcohol business is significantly important for the economy of OECD countries. When promoting a health campaign, such as a smoke-free program, the government can balance the trade-off between the benefit of a healthier population and the loss of tobacco-related economic activity.

Part 5

CONCLUSION

Fiscal policy is an important governmental tool for stabilizing and maintaining economic growth, especially during an economic crisis. The impacts of fiscal policy on economies are extensively investigated in numerous closed economy studies, such as Fernández-Villaverde (2010), Eggertsson (2011), and Zubairy (2014). However, the estimation of a fiscal multiplier in closed economy models may be sufficiently different from the estimation of one in a small-open economy, because trading in the goods and services sector can be important, and trade can potentially impact the exchange rate's adjustment and interest rate's response to fiscal policies. The purpose of this thesis is examining the effectiveness of expansionary fiscal policy shocks, such as an increase in government spending or a decrease in sales tax, payroll tax, and capital tax shocks, on macroeconomic variables in a small-open economy. The study employs a medium-scale DSGE model, calibrated to Thailand's parameters. The model's foundation is adopted from The Bank of Thailand's Structural Model (DSGE model), which is introduced by Tanboon (2008). This thesis extends the DSGE model and introduces a rich fiscal block for analyzing the effect of fiscal policy.

The most important finding is that an increase in government expenditures has a significantly positive impact on the domestic firms' output, whereas exporting firms respond by lowering their production. This is because wage and capital rent are raised, which leads to higher costs for the export sector. Hence, the total effect of an increase in government spending is smaller in a small-open economy as compared to a closed economy. In addition, the reduction of the tax rate has a fairly positive effect on domestic output. However, depending on the tax base, it can have a positive or negative effect on exporting firms. This can possibly be explained by the difference in the market structure of the domestic and exporting firms. It is assumed that the export sector is perfectly competitive, while the domestic firms price their goods with a positive mark-up. Moreover, the results show that the impact multiplier of government spending on the national output is 0.25, and the impact multipliers of sales tax, payroll tax, and capital tax are 0.08, 0.37 and 0.09, respectively. In long-term, the impact of government spending is smaller than the impact of the tax cut. Lastly, comparing on three taxes, lowering the payroll tax can be the most effective means in the long-term.

The second paper studies the optimal taxes in a small-open economy with an imperfectly competitive market and habit preferences. Under imperfectly competitive market, firms can influence the price setting, rather than be price takers. They can set a positive price mark-up over marginal costs. Since this condition can alter the firms' optimization behaviour, it changes the optimal capital income tax rate. Moreover, habit formation preferences are important in analyzing consumers' behaviour (Ravn et al. 2006, Ljungqvist & Uhlig 2000). The households with habit formation tend to smooth their consumption over the time and gradually adjust their consumption when confronted with an income shock (Dynan 2000). The habit preference can change the households' optimization problem and the dynamics of the demand facing the firms, which in turn changes firms' investment strategies and alter the optimal tax policy. This paper uses both numerical estimates and analytical investigation to study optimal capital income and labour income tax in a small-open economy. The numerical approach solves the Ramsey problem. The economic model follows the DSGE model in the first paper and is parameterized to Thailand's data. The numerical result shows that the optimal capital income tax appears to be negative, which is consistent with Judd (1997) 's results. In order to understand the effect of model's distortions, such as a monopolistic distortion, on the numerical result, the analytical investigation is employed. The model is simplified by using a zero investment adjustment cost and flexible wages and prices. The analytical investigation highlights three important findings. Firstly, the optimal capital income tax in a small-open economy with a perfectly competitive market is not different from the optimal capital income tax in closed economy, and it equals to zero as in Chamley (1981), Judd (1985), Chamley (1986), Lucas (1990) and Chari et al. (1991). Secondly, the optimal capital income tax in a small-open economy with an imperfectly competitive market is negative and negatively related to price mark-up. This analytical result ensures the finding regarding optimal capital income tax in numerical estimates. Thirdly, the most interesting result, deep habit preferences create a volatile and counter-cyclical mark-up. Hence, capital income tax is not smooth and volatile over the horizon as a response to the price mark-up's adjustment. The optimal capital income tax rate should be increased during an economic boom period and lowered during recessions.

The second paper contributes to the literature in the following way. This study extends the Judd (1997) results for the optimal capital income tax and estimates optimal tax rates in a small-open economy with an imperfectly competitive market and habit persistence The result suggests that governments should subsidize capital income taxes to offset gaps between the price and the marginal cost. Hence, the capital income tax is negatively related to the mark-up. The labour income tax is set to maintain the implementability of the government budget.

The third paper examines the impact of the government spending on health on economic growth by analyzing improvement in the national health condition. The government has an important role in improving national health through providing, for example, inclusive access to health care and nutrition services, reducing health gaps between different population groups and ensuring sustainable public health financing. However, the literature on the effectiveness of government spending on national health finds ambiguous results. The third paper has two objectives. The first one investigates the effect of the government's spending on health on the improvement of national health indicators, such as life expectancy, infant mortality and under-five mortality. The health model is estimated by using the fixed-effects model, the random effect model, and the two-stage least-squares approach. The global panel data, observed over 200 countries, is used for the study. In addition, the private health spending, which has not been considered in the literature on health due to a lack of data (Gupta et al. 2002), is included in the health model. The results reveal that a government spending on health has a significantly positive effect on health status by improving life expectancy at birth, infant mortality, and the under-five mortality rate. Interestingly, private spending on health has a significant positive effect on life expectancy, but it does not have the significant effect on mortality rates. This gives rise to the implication of government budget allocation on health. Private spending on health can effectively substitute government spending on health for improving longevity.

The second objective of the third paper is examining the importance of human capital in the form of health for productivity and economic growth. Three panel estimations are implemented: the fixed-effect model, the random-effect model, and the mean group estimator, which is used to deal with a cross-sectional dependence problem. The models are estimated with three data-sets: global data, developed countries' data, and developing countries' data. Moreover, non-medical determinants of health, such as tobacco consumption, alcohol consumption, sugar supply, and total fat supply, are used as proxies for health indicators in developed countries. The results show that an increase in life expectancy has a positive effect on output in developing countries. The model predicts that a one-year increase in life expectancy can raise output by one percent. However, an increase in life expectancy does not have a significant effect in developed countries. Since most developed countries have significantly longer life expectancies and lower mortality rates than developing countries, more resources are required to improve health in a developed country than in a developing country. Additionally, the result of non-medical determinants of health indicates that tobacco and alcohol consumption have a significantly (at 10% level) positive effect on economic growth in OECD countries. This may be surprising, but tobacco and alcohol consumption may have two offsetting effects on economic growth. On the one hand, tobacco and alcohol consumption certainly lower human capital in the form of health, because they shorten the consumer's life expectancy (Olshansky et al. 2005, Valkonen & Van Poppel 1997, Bloom et al. 2004). On the other hand, higher tobacco and alcohol consumption lead to higher demand, which may increase economic activities and economic growth, create jobs related to manufacturing (in the farming, industrial production, wholesale, transportation and retail sectors, for example) and generate additional tax revenue. Most importantly, a higher tax revenue can be used to support the fiscal health.

References

Acemoglu, D. & Johnson, S. (2007), 'Disease and development: the effect of life expectancy on economic growth', *Journal of political Economy* **115**(6), 925–985.

Adolfson, M., Laséen, S., Lindé, J. & Villani, M. (2007), 'Bayesian estimation of an open economy dsge model with incomplete pass-through', *Journal of International Economics* **72**(2), 481–511.

Aghion, P., Howitt, P. & Murtin, F. (2010), The relationship between health and growth: when lucas meets nelson-phelps, Technical report, National Bureau of Economic Research.

Ahuja, A., Peungchanchaikul, C. & Piyagarn, N. (2004), On monetary and fiscal policy mix over thailand business cycles, Technical report, Economic Research Department, Bank of Thailand.

Aisa, R. & Pueyo, F. (2006), 'Government health spending and growth in a model of endogenous longevity', *Economics letters* **90**(2), 249–253.

Aísa, R., Pueyo, F. et al. (2004), 'Endogenous longevity, health and economic growth: a slow growth for a longer life', *Economics Bulletin* **9**(3), 1–10.

Aiyagari, S. R. (1995), 'Optimal capital income taxation with incomplete markets, borrowing constraints, and constant discounting', *Journal of political Economy* pp. 1158–1175.

Aiyagari, S. R., Marcet, A., Sargent, T. J. & Seppälä, J. (2002), 'Optimal taxation without state-contingent debt', *Journal of Political Economy* **110**(6), 1220–1254.

Almeida, M. (2012), The transmission mechanism of fiscal policy in an open economy under the var framework. University of Surrey.

Alvarez, L. J., Dhyne, E., Hoeberichts, M., Kwapil, C., Bihan, H., Lünnemann, P., Martins, F., Sabbatini, R., Stahl, H., Vermeulen, P. et al. (2006), 'Sticky prices in the euro area: A summary of new micro-evidence', *Journal of the European Economic association* **4**(2-3), 575–584.

An, C.-B. & Jeon, S.-H. (2006), 'Demographic change and economic growth: An inverted-u shape relationship', *Economics Letters* **92**(3), 447–454.

Anderson, G. F., Reinhardt, U. E., Hussey, P. S. & Petrosyan, V. (2003), 'ItâĂŹs the prices, stupid: why the united states is so different from other countries', *Health Affairs* **22**(3), 89–105.

Atkinson, A. B. & Stiglitz, J. E. (1976), 'The design of tax structure: direct versus indirect taxation', *Journal of public Economics* **6**(1-2), 55–75.

Atta-Mensah, J. & Dib, A. (2008), 'Bank lending, credit shocks, and the transmission of canadian monetary policy', *International Review of Economics & Finance* **17**(1), 159–176.

Baldacci, E., Clements, B., Gupta, S. & Cui, Q. (2008), 'Social spending, human capital, and growth in developing countries', *World development* **36**(8), 1317–1341.

Baldacci, E., Guin-Siu, M. T. & Mello, L. D. (2003), 'More on the effectiveness of public spending on health care and education: a covariance structure model', *Journal of International Development* **15**(6), 709–725.

Baltagi, B. H. & Hashem Pesaran, M. (2007), 'Heterogeneity and cross section dependence in panel data models: theory and applications introduction', *Journal of Applied Econometrics* **22**(2), 229–232.

Barro, R. J. (1974), 'Are government bonds net wealth?', *The Journal of Political Economy* pp. 1095–1117.

Barro, R. J. & Lee, J.-W. (1994), Sources of economic growth, *in* 'Carnegie-Rochester conference series on public policy', Vol. 40, Elsevier, pp. 1–46.

Barro, R. et al. (1996), 'Health and economic growth', *World Health Organization* .

Becker, G. (1993), *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education (3d edition)*, The University of Chicago Press, Chicago.

Becker, G. S., Philipson, T. J. & Soares, R. R. (2005), 'The quantity and quality of life and the evolution of world inequality', *The American Economic Review* **95**(1), 277–291.

Bhattarai, K. & Trzeciakiewicz, D. (2012), 'Macroeconomic impacts of fiscal policy shocks in uk: A dsge analysis', *Unpublished manuscript, Business School, University of Hull* .

Blanchard, O. & Perotti, R. (1999), An empirical characterization of the dynamic effects of changes in government spending and taxes on output, Technical report, National bureau of economic research.

Bloom, D. E. & Canning, D. (2000), 'The health and wealth of nations', *Science* **287**(5456), 1207–1209.

Bloom, D. E., Canning, D. & Sevilla, J. (2004), 'The effect of health on economic growth: a production function approach', *World development* **32**(1), 1–13.

Bloom, D. E. & Williamson, J. G. (1998), 'Demographic transitions and economic miracles in emerging asia', *The World Bank Economic Review* **12**(3), 419–455.

Bouakez, H., Chihi, F. & Normandin, M. (2010), 'Measuring the effects of fiscal policy', *Cahier de recherche/Working Paper* **10**, 16.

Caldara, D. & Kamps, C. (2008), 'What are the effects of fiscal policy shocks? a var-based comparative analysis'.

Canova, F. & Sala, L. (2009), 'Back to square one: identification issues in dsge models', *Journal of Monetary Economics* **56**(4), 431–449.

Chamley, C. (1981), 'The welfare cost of capital income taxation in a growing economy', *Journal of Political Economy* **89**(3), 468–496.

Chamley, C. (1986), 'Optimal taxation of capital income in general equilibrium with infinite lives', *Econometrica: Journal of the Econometric Society* pp. 607–622.

Chari, V. V., Christiano, L. J. & Kehoe, P. J. (1991), 'Optimal fiscal and monetary policy: Some recent results', *Journal of Money, Credit and Banking* **23**(3), 519–539.

Chari, V. V. & Kehoe, P. J. (1999), 'Optimal fiscal and monetary policy', *Handbook of macroeconomics* **1**, 1671–1745.

Chetty, R., Guren, A., Manoli, D. & Weber, A. (2011), 'Are micro and macro labor supply elasticities consistent? a review of evidence on the intensive and extensive margins', *The American Economic Review* **101**(3), 471–475.

Chintagunta, P., Kyriazidou, E. & Perktold, J. (2001), 'Panel data analysis of household brand choices', *Journal of Econometrics* **103**(1-2), 111–153.

Choi, I. (2001), 'Unit root tests for panel data', *Journal of International Money and Finance* **20**(2), 249–272.

Christiano, L. J., Eichenbaum, M. & Evans, C. L. (1999), 'Monetary policy shocks: What have we learned and to what end?', *Handbook of macroeconomics* **1**, 65–148.

Christiano, L. J., Eichenbaum, M. & Evans, C. L. (2005), 'Nominal rigidities and the dynamic effects of a shock to monetary policy', *Journal of political Economy* **113**(1), 1–45.

Conesa, J. C., Kitao, S. & Krueger, D. (2009), 'Taxing capital? not a bad idea after all!', *The American economic review* **99**(1), 25–48.

Correia, I. H. (1996), 'Dynamic optimal taxation in small open economies', *Journal of Economic Dynamics and Control* **20**(4), 691–708.

Crimmins, E. M., Hayward, M. D. & Saito, Y. (1994), 'Changing mortality and morbidity rates and the health status and life expectancy of the older population', *Demography* **31**(1), 159–175.

Devarajan, S., Swaroop, V. & Zou, H.-f. (1996), 'The composition of public expenditure and economic growth', *Journal of monetary economics* **37**(2), 313–344.

Diamond, P. A. & Mirrlees, J. A. (1971), 'Optimal taxation and public production i: Production efficiency', *The American Economic Review* **61**(1), 8–27.

Domeij, D. (2005), 'Optimal capital taxation and labor market search', *Review of Economic Dynamics* **8**(3), 623–650.

Dynan, K. E. (2000), 'Habit formation in consumer preferences: Evidence from panel data', *American Economic Review* pp. 391–406.

Eberhardt, M. & Teal, F. (2010), 'Productivity analysis in global manufacturing production.'.

Eberhardt, M. et al. (2012), 'Estimating panel time-series models with heterogeneous slopes', *Stata Journal* **12**(1), 61.

Eggertsson, G. B. (2011), What fiscal policy is effective at zero interest rates?, *in* 'NBER Macroeconomics Annual 2010, Volume 25', University of Chicago Press, pp. 59–112.

Faia, E., Lechthaler, W. & Merkl, C. (2010), 'Fiscal multipliers and the labour market in the open economy', *IZA Discussion Paper* (4849).

Fernández-Villaverde, J. (2010), 'Fiscal policy in a model with financial frictions', *The American Economic Review* pp. 35–40.

Filmer, D. & Pritchett, L. (1999), 'The impact of public spending on health: does money matter?', *Social science & medicine* **49**(10), 1309–1323.

Fleming, J. M. (1962), 'Domestic financial policies under fixed and under floating exchange rates (politiques finacierieures interieures avec un systeme de taux de change fixe et avec un systeme de taux de change fluctuant)(politica financiera interna bajo sistemas de tipos de cambio fijos o de tipos de cambio fluctuantes)', *Staff Papers-International Monetary Fund* pp. 369–380.

Forni, L., Monteforte, L. & Sessa, L. (2009), 'The general equilibrium effects of fiscal policy: Estimates for the euro area', *Journal of Public Economics* **93**(3), 559–585.

Franco, O. H., Steyerberg, E. W., Hu, F. B., Mackenbach, J. & Nusselder, W. (2007), 'Associations of diabetes mellitus with total life expectancy and life expectancy with and without cardiovascular disease', *Archives of internal medicine* **167**(11), 1145–1151.

Friedman, M. (2009), *Capitalism and freedom*, University of Chicago press.

Fuhrer, J. C. (2000), 'Habit formation in consumption and its implications for monetary-policy models', *American Economic Review* pp. 367–390.

Furceri, D. & Mourougane, A. (2010), 'The effects of fiscal policy on output', *OECD Economics Department Working Papers* **-**(770), 36.

Gärtner, M. (2009), *Macroeconomics*, Essex, Pearson Education Limited.

Gbesemete, K. P. & Gerdtham, U.-G. (1992), 'Determinants of health care expenditure in africa: a cross-sectional study', *World development* **20**(2), 303–308.

Gordon, R. H. (1992), 'Can capital income taxes survive in open economies?', *The Journal of Finance* **47**(3), 1159–1180.

Gottschalk, J. (2001), 'An introduction into the svar methodology: Identification', *Interpretation and Limitations of SVAR models, Kiel Institute of World Economics Working Paper* **1072**.

Guerriero, M. (2012), 'The labour share of income around the world. evidence from a panel dataset', *Development Economics and Public Policy Working Paper* **32**, 2012.

Guo, J.-T. & Lansing, K. J. (1999), 'Optimal taxation of capital income with imperfectly competitive product markets', *Journal of Economic Dynamics and Control* **23**(7), 967–995.

Guo, J.-T., Lansing, K. J. et al. (1995), Optimal taxation of capital income in a growth model with monopoly profits, Technical report, Citeseer.

Gupta, S., Verhoeven, M. & Tiongson, E. R. (2002), 'The effectiveness of government spending on education and health care in developing and transition economies', *European Journal of Political Economy* **18**(4), 717–737.

H. Frederick Gale, J., Foreman, L. & Capehart, T. (2000), 'Tobacco and the economy: Farms, jobs, and communities', *Agricultural Economic Report* (AER-789).

Hu, F. B., Stampfer, M. J., Manson, J. E., Rimm, E., Colditz, G. A., Rosner, B. A., Hennekens, C. H. & Willett, W. C. (1997), 'Dietary fat intake and the risk of coronary heart disease in women', *New England Journal of Medicine* **337**(21), 1491–1499.

Hubbard, R. G., Judd, K. L., Hall, R. E. & Summers, L. (1986), 'Liquidity constraints, fiscal policy, and consumption', *Brookings Papers on Economic Activity* **1986**(1), 1–59.

Hur, S.-K. (2007), Measuring the effectiveness of fiscal policy in korea, *in* 'Fiscal Policy and Management in East Asia, NBER-EASE, Volume 16', University Of Chicago Press, pp. 63–93.

Huttly, S. R. (1990), 'The impact of inadequate sanitary conditions on health in developing countries.', *World health statistics quarterly. Rapport trimestriel de statistiques sanitaires mondiales* **43**(3), 118–126.

ILO (2011), 'A review of global fiscal stimulus', *International Institute for Labour Studies. EC-IILS Joint Discussion Paper Series No. 5* .

Ilzetzki, E., Mendoza, E. G. & Végh, C. A. (2013), 'How big (small?) are fiscal multipliers?', *Journal of monetary economics* **60**(2), 239–254.

Judd, K. L. (1985), 'Redistributive taxation in a simple perfect foresight model', *Journal of public Economics* **28**(1), 59–83.

Judd, K. L. (1997), The optimal tax rate for capital income is negative, Technical report, National Bureau of Economic Research.

Judd, K. L. (2002), 'Capital-income taxation with imperfect competition', *The American Economic Review* **92**(2), 417–421.

Keynes, J. M. (1936), 'The general theory of employment, interest and money (london, 1936)', *KeynesThe General Theory of Employment, Interest and Money1936* .

Kim, K. & Moody, P. M. (1992), 'More resources better health? a cross-national perspective', *Social science & medicine* **34**(8), 837–842.

Koehne, S. & Kuhn, M. (2013), 'Optimal capital taxation for time-nonseparable preferences', *Available at SSRN 2235171* .

Kollmann, R., Roeger, W. et al. (2012), 'Fiscal policy in a financial crisis: Standard policy versus bank rescue measures', *The American Economic Review* **102**(3), 77–81.

Kydland, F. E. & Prescott, E. C. (1982), 'Time to build and aggregate fluctuations', *Econometrica: Journal of the Econometric Society* pp. 1345–1370.

Larson, C. & Mercer, A. (2004), 'Global health indicators: an overview', *Canadian Medical Association Journal* **171**(10), 1199–1200.

Levin, A., Lin, C.-F. & Chu, C.-S. J. (2002), 'Unit root tests in panel data: asymptotic and finite-sample properties', *Journal of econometrics* **108**(1), 1–24.

Levy, D., Bergen, M., Dutta, S. & Venable, R. (1997), 'The magnitude of menu costs: direct evidence from large us supermarket chains', *The Quarterly Journal of Economics* **112**(3), 791–824.

Ljungqvist, L. & Uhlig, H. (2000), 'Tax policy and aggregate demand management under catching up with the joneses', *American Economic Review* pp. 356–366.

Looney Robert E, F. P. C. (1996), 'Defense expenditures and budgetary patterns in selected middle eastern and mediterranean countries: An assessment', *Public Budgeting and Financial Management* .

Lorentzen, P., McMillan, J. & Wacziarg, R. (2008), 'Death and development', *Journal of Economic Growth* **13**(2), 81–124.

Lucas, R. E. (1990), 'Supply-side economics: An analytical review', *Oxford economic papers* **42**(2), 293–316.

Malik, V. S., Popkin, B. M., Bray, G. A., Després, J.-P., Willett, W. C. & Hu, F. B. (2010), 'Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes', *Diabetes care* **33**(11), 2477–2483.

Mankiw, N. G. (2009), *Macroeconomics 7th ed*, Worth Publishers.

Mountford, A. & Uhlig, H. (2009), 'What are the effects of fiscal policy shocks?', *Journal of applied econometrics* **24**(6), 960–992.

Mundell, R. A. (1963), 'Capital mobility and stabilization policy under fixed and flexible exchange rates', *Canadian Journal of Economics and Political*

Science/Revue canadienne de economiques et science politique **29**(04), 475–485.

Murray, C. J. & Chen, L. C. (1992), 'Understanding morbidity change', *The Population and Development Review* pp. 481–503.

Nations, U. (2004), 'World population to 2300.'.

Oeppen, J. & Vaupel, J. W. (2002), 'Broken limits to life expectancy', *Science* **296**(5570), 1029–1031.

Olshansky, S. J., Passaro, D. J., Hershow, R. C., Layden, J., Carnes, B. A., Brody, J., Hayflick, L., Butler, R. N., Allison, D. B. & Ludwig, D. S. (2005), 'A potential decline in life expectancy in the united states in the 21st century', *New England Journal of Medicine* **352**(11), 1138–1145.

Oster, E., Shoulson, I. & Dorsey, E. (2013), 'Limited life expectancy, human capital and health investments', *The American Economic Review* **103**(5), 1977–2002.

Perotti, R. (2005), 'Estimating the effects of fiscal policy in oecd countries'.

Pigou, A. (1920), *The Economics of Welfare*, Macmillan, London.

Psacharopoulos, G. & Nguyen, X. N. (1997), *The role of government and the private sector in fighting poverty*, Vol. 346, World Bank Publications.

Ramsey, F. P. (1927), 'A contribution to the theory of taxation', *The Economic Journal* **37**(145), 47–61.

Ratto, M., Roeger, W. & in't Veld, J. (2009), 'Quest iii: An estimated open-economy dsge model of the euro area with fiscal and monetary policy', *economic Modelling* **26**(1), 222–233.

Ravn, M., Schmitt-Grohé, S. & Uribe, M. (2006), 'Deep habits', *The Review of Economic Studies* **73**(1), 195–218.

Razin, A. & Sadka, E. (1991), Vanishing tax on capital income in the open economy, Technical report, National Bureau of Economic Research.

Razin, A. & Sadka, E. (1995), 'The status of capital income taxation in the open economy', *FinanzArchiv/Public Finance Analysis* pp. 21–32.

Reichling, F. & Whalen, C. (2012), 'Review of estimates of the frisch elasticity of labor supply'.

Ricardo, D., Gonner, E. C. K. et al. (1891), 'Principles of political economy and taxation'.

Romer, C. D. & Romer, D. H. (2007), The macroeconomic effects of tax changes: estimates based on a new measure of fiscal shocks, Technical report, National Bureau of Economic Research.

Romer, D. (2006), *Advanced Macroeconomics (3rd edition)*, McGraw-Hill/Irwin.

Rotemberg, J. J. (1982), 'Sticky prices in the united states', *Journal of Political Economy* **90**(6), 1187–1211.

Rotemberg, J. J. & Woodford, M. (1997), 'An optimization-based econometric framework for the evaluation of monetary policy', *NBER macroeconomics annual* **12**, 297–346.

Sandmo, A. (1976), 'Optimal taxation: An introduction to the literature', *Journal of public economics* **6**(1), 37–54.

Schmitt-Grohé, S. & Uribe, M. (2004), 'Optimal fiscal and monetary policy under sticky prices', *Journal of economic Theory* **114**(2), 198–230.

Schmitt-Grohé, S. & Uribe, M. (2006), Optimal fiscal and monetary policy in a medium-scale macroeconomic model, *in* 'NBER Macroeconomics Annual 2005, Volume 20', MIT Press, pp. 383–462.

Slemrod, J. (1989), Optimal taxation and optimal tax systems, Technical report, National Bureau of Economic Research.

Tanboon, S. (2008), The bank of thailand structural model for policy analysis, Technical report, The Bank of Thailand.

Tenhofen, J. & Wolff, G. B. (2007), Does anticipation of government spending matter? evidence from an expectation augmented var, Technical report, Deutsche Bundes Bank.

Tobin, J. (1969), 'A general equilibrium approach to monetary theory', *Journal of money, credit and banking* **1**(1), 15–29.

Torres-Reyna, O. (2007), 'Panel data analysis fixed and random effects using stata (v. 4.2)', *Data & Statistical Services, Priceton University* .

Valkonen, T. & Van Poppel, F. (1997), 'The contribution of smoking to sex differences in life expectancy: four nordic countries and the netherlands 1970–1989', *The European Journal of Public Health* **7**(3), 302–310.

Weil, D. N. et al. (2013), 'Health and economic growth'.

Well, D. N. (2007), 'Accounting for the effect of health on economic growth', *The quarterly journal of economics* **122**(3), 1265–1306.

WHO (2012), Health service delivery profile, japan 2012, Technical report, WHO Western Pacific Region.

WSTA, T. W. . S. T. A. (2016), 'Wsta market overview', *The Wine & Spirit Trade Association* .

Zhang, J., Zhang, J. & Lee, R. (2003), 'Rising longevity, education, savings, and growth', *Journal of Development Economics* **70**(1), 83–101.

Zubairy, S. (2014), 'On fiscal multipliers: Estimates from a medium scale dsge model', *International Economic Review* **55**(1), 169–195.

Part 6

APPENDIX

A APPENDIX: Fiscal Policy on Small-Open Economy

A.1 The households' and firms' intertemporal problems

Intertemporal problem that households' face is

$$\begin{aligned}\mathcal{L} &= E_0\sum_{t=0}^{\infty}\beta^t\Bigg\{(1-\chi)\log\tilde{C}_t-\varphi^L\frac{L_t^{1+\eta}}{1+\eta}+\lambda_t\left[(1+R_{t-1})\,D_{t-1}+(1-\tau_t^w)W_tL_t+\left[1-(1-\delta)\,\tau_t^k\right]R_t^KK_t\right.\\&\left.+\sum_{j=D,X}\Phi_t^j-(1+\tau_t^s)(1-\chi)P_t^D\tilde{C}_t-(1+\tau_t^s)\chi P_t^Dh_t-P_t^DI_t-D_t\right]\\&+\lambda_tQ_t^K\left[(1-\delta)\,K_t+F(I_t,I_{t-1})-K_{t+1}\right]\Bigg\}\end{aligned}$$

The households budget constraint is assumed as follows:

$$\begin{aligned}&\left[1+R_{t-1}\right]D_{t-1}+(1-\tau_t^w)W_tL_t+(1-\tau_t^k)R_t^KK_t+\sum_j\Phi_j\\&=(1+\tau_t^s)(1-\chi)P_t^D\tilde{C}_t+(1+\tau_t^s)\chi P_t^Dh_t+P_t^DI_t+D_t\end{aligned}$$

The consumption-decision is acquired from deriving the first-order condition by applying $\frac{\partial\mathcal{L}}{\partial\tilde{C}_t}=0$.

$$\begin{aligned}\frac{\partial L}{\partial\tilde{C}_t} &= \frac{\beta^t(1-\chi)}{\tilde{C}_t}-\lambda_t\beta^t(1+\tau_t^s)(1-\chi)P_t^D=0\\\lambda_t &= \frac{1}{(1+\tau_t^s)P_t^D\tilde{C}_t}\end{aligned}$$

The capital decision is acquired from deriving the first-order condition by applying $\frac{\partial\mathcal{L}}{\partial K_{t+1}}=0$.

$$
\begin{aligned}
\frac{\partial L}{\partial K_{t+1}} &= \beta^{t+1}\lambda_{t+1}\left[1-(1-\delta)\,\tau^{k}_{t+1})\right]R^{K}_{t+1}+\beta^{t+1}\lambda_{t+1}Q^{K}_{t+1}(1-\delta)-\beta^{t}\lambda_{t}Q^{K}_{t}=0\\
Q^{K}_{t} &= \beta E_{t}\frac{\lambda_{t+1}}{\lambda_{t}}\left[\left[1-(1-\delta)\,\tau^{k}_{t+1}\right]R^{K}_{t+1}+Q^{K}_{t+1}(1-\delta)\right]
\end{aligned}
$$

The investment decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}}{\partial I_t}=0$.

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial I_t} &= -\beta^{t}\lambda_{t}P^{D}_{t}+\beta^{t}\lambda_{t}Q^{K}_{t}\frac{\partial F(I_t,I_{t-1})}{\partial I_t}+\beta^{t+1}\lambda_{t+1}Q^{K}_{t+1}\frac{\partial F(I_{t+1},I_t)}{\partial I_t}=0\\
\frac{Q^{K}_{t}}{P^{D}_{t}} &= \frac{1}{F_1(I_t,I_{t-1})}\left[1-\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{Q^{K}_{t+1}}{P^{D}_{t}}F_2(I_{t+1},I_t)\right]\\
\frac{Q^{K}_{t}}{P^{D}_{t}} &= \frac{1}{1-\xi^{I}\frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}}-(1+\alpha)\right)-\frac{\xi^{I}}{2}\left(\frac{I_t}{I_{t-1}}-(1+\alpha)\right)^{2}}\\
&\quad\times\left[1-\xi^{I}\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{Q^{K}_{t+1}}{P^{D}_{t}}\left(\frac{I_{t+1}}{I_t}\right)^{2}\left(\frac{I_{t+1}}{I_t}-(1+\alpha)\right)\right]
\end{aligned}
$$

The labour supply decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}}{\partial L_t}=0$.

$$
\begin{aligned}
\frac{\partial L}{\partial L_t} &= -\beta^{t}\varphi^{L}L^{\eta}_{t}+(1-\tau^{w}_{t})\beta^{t}\lambda_t W_t=0\\
(1-\tau^{w}_{t})\lambda_t W_t &= \varphi^{L}L^{\eta}_{t}
\end{aligned}
$$

The saving and borrowing decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}}{\partial D_t}=0$.

$$
\begin{aligned}
\frac{\partial L}{\partial D_t} &= -\beta^{t}\lambda_t+\beta^{t+1}\lambda_{t+1}\left[1+R_t\right]=0\\
\lambda_t &= \beta\lambda_{t+1}\left[1+R_t\right]
\end{aligned}
$$

The production function of domestic firms.

$$
Y^{D}_{t}=(A_tL^{D}_{t})^{\gamma^{D}_{L}}(M^{D}_{t})^{\gamma^{D}_{M}}(K^{D}_{t})^{1-\gamma^{D}_{L}-\gamma^{D}_{M}}
$$

The domestic firms minimize their cost of production with subject to production function constraint. The Lagrangian function is

$$\mathcal{L}^D = \left(1 + R_t^L\right) W_t L_t^D + P_t^M M_t^D + R_t^K K_t^D + Q_t^D \left[Y_t^D - (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}\right]$$

The labour demand decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial L_t^D} = 0$.

$$\begin{aligned} \frac{\partial \mathcal{L}^D}{\partial L_t^D} &= -\left(1 + R_t^L\right) W_t + Q_t^D (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D} (A_t)^{\gamma_L^D} \gamma_L^D \left(L_t^D\right)^{\gamma_L^D - 1} = 0 \\ \left(1 + R_t^L\right) W_t L_t^D &= \gamma_L^D Q_t^D Y_t^D \end{aligned}$$

The raw imported material demand decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial M_t^D} = 0$.

$$\begin{aligned} \frac{\partial \mathcal{L}^D}{\partial M_t^D} &= -P_t^M + \gamma_M^D Q_t^D (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D - 1} (K_t^D)^{1-\gamma_L^D-\gamma_M^D} = 0 \\ P_t^M M_t^D &= \gamma_M^D Q_t^D Y_t^D \end{aligned}$$

The capital service decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial K_t^D} = 0$.

$$\begin{aligned} \frac{\partial \mathcal{L}^D}{\partial K_t^D} &= -R_t^K + \left(1 - \gamma_L^D - \gamma_M^D\right) Q_t^D (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{-\gamma_L^D-\gamma_M^D} = 0 \\ R_t^K K_t^D &= \left(1 - \gamma_L^D - \gamma_M^D\right) Q_t^D Y_t^D \end{aligned}$$

The price markup is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^D}{\partial \left(\frac{P_t^D}{P_t^D(i)}\right)} = 0$. Since

$$Y_t^D = Y_t^D(i) \left(\frac{P_t^D}{P_t^D(i)}\right)^{-\sigma_i}$$

$$\begin{aligned}\mathcal{L}^D &= \left[P_t^D Y_t^D - \left(1+R_t^L\right) W_t L_t^D - P_t^M M_t^D - R_t^K K_t^D\right] - Q_t^D \left[Y_t^D - (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}\right] \\ &= \left[P_t^D(i) Y_t^D(i) \left(\frac{P_t^D}{P_t^D(i)}\right)^{1-\sigma_i} - \left(1+R_t^L\right) W_t L_t^D - P_t^M M_t^D - R_t^K K_t^D\right] \\ &\quad -Q_t^D \left[Y_t^D(i) \left(\frac{P_t^D}{P_t^D(i)}\right)^{-\sigma_i} - (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}\right]\end{aligned}$$

$$\begin{aligned}\frac{\partial \mathcal{L}^D}{\partial \left(\frac{P_t^D}{P_t^D(i)}\right)} &= (1-\sigma_i) \left(\frac{P_t^D}{P_t^D(i)}\right)^{-\sigma_i} P_t^D(i) Y_t^D(i) + \sigma_i Q_t^D Y_t^D(i) \left(\frac{P_t^D}{P_t^D(i)}\right)^{-\sigma_i - 1} \\ Q_t^D &= \frac{P_t^D}{\mu};\ \text{where } \mu = \frac{\sigma_i}{(\sigma_i - 1)}\end{aligned}$$

Domestic firms try to minimization problem of price setting.

$$\min_{P_t^D} E_0 \sum_{t=0}^{\infty} \beta^t \left[\left(P_t^D - P_t^{D*}\right)^2 + \zeta^D \left(\triangle P_t^D - \triangle \bar{P}_{t-1}^D\right)^2\right]$$

The solution is

$$P_t^D = P_t^{D*} + \zeta^D \left[-\left(\triangle P_t^D - \triangle \bar{P}_{t-1}^D\right) + \beta \left(\triangle P_{t+1}^D - \triangle \bar{P}_t^D\right)\right]$$

The production function of foreign firms is calculated through

$$Y_t^X = (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X}$$

Export firms minimize their cost of production with subject to a production function constraint. The Lagrangian function is

$$\mathcal{L}^X = W_t L_t^X + P_t^M M_t^X + R_t^K K_t^X + Q_t^X \left[Y_t^X - (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X}\right]$$

The labour demand decision for export firms is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^X}{\partial L_t^X} = 0$.

$$\frac{\partial \mathcal{L}^X}{\partial L_t^X} = -W_t + Q_t^X (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X} (A_t)^{\gamma_L^X} \gamma_L^X \left(L_t^X\right)^{\gamma_L^X-1} = 0$$

$$W_t L_t^X = \gamma_L^X Q_t^X Y_t^X$$

The raw imported material demand decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^X}{\partial M_t^X} = 0$.

$$\frac{\partial \mathcal{L}^X}{\partial M_t^X} = -P_t^M - \gamma_M^X Q_t^X (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X-1} (K_t^X)^{1-\gamma_L^X-\gamma_M^X} = 0$$

$$P_t^M M_t^X = \gamma_M^X Q_t^X Y_t^X$$

The capital service decision is acquired from deriving the first-order condition by applying $\frac{\partial \mathcal{L}^X}{\partial K_t^X} = 0$.

$$\frac{\partial \mathcal{L}^X}{\partial K_t^X} = -R_t^X - \left(1 - \gamma_L^X - \gamma_M^X\right) Q_t^X (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{-\gamma_L^X-\gamma_M^X} = 0$$

$$R_t^K K_t^X = \left(1 - \gamma_L^X - \gamma_M^X\right) Q_t^X Y_t^X$$

A.2 Log-Linearized Equations

This section illustrates how Log-Linearlized Equations are employed. A Log-Linearlized estimation is a simple approximation technique for studying a range of economic problems. There are a number of steps for estimating Log-Linearlized Equations. Firstly, a percentage deviation from a steady state of variable x is defined as follows:

$$\widehat{x_t} = \frac{x_t - \overline{x}}{\overline{x}}$$

$\widehat{x_t}$ is the percentage deviation of x_t from steady state $\overline{x}$. $\overline{x}$ or x (both without subscript t) is a steady state value of x_t. Secondly, the Taylor's theorem is applied for evaluating a dynamic equation. Let us consider a univariate function, $f(x)$. The basic version of **Taylor's theorem** can be presented by

$$f(x) = f(\overline{x})+\frac{f^{'}(\overline{x})}{1!}(x_t-\overline{x})+\frac{f^{''}(\overline{x})}{2!}(x_t-\overline{x})^2+...+\frac{f^{(k)}(\overline{x})}{k!}(x_t-\overline{x})^k+h_k(x)(x_t-\overline{x})^k.$$

$f^{'}(\overline{x})$ is the first derivative of f with respect to x, calculated at the value of $\overline{x}$. $f^{''}(\overline{x})$ is the second derivative of f with respect to x, calculated at the value of $\overline{x}$. The continuum of the derivative term continues until k terms, which is also called the k order of Taylor's theorem. $h_k(x)$ is the remainder of Taylor's theorem. In this present research, the first-order of Taylor's approximation is used since the most equation is continuous. The first-order of Taylor approximation can be shortened as follows:

$$f(x,y) \approx f(\overline{x},\overline{y}) + f_x(\overline{x},\overline{y})\overline{x}\widehat{x_t} + f_y(\overline{x},\overline{y})\overline{y}\widehat{y_t}$$

The first order of Taylor approximation of each economic sector are shown as follows:

A.2.1 Households Sector

The household sector's behavior equations are summarized in Table 12.

Table 12: The list of household sector behaviour equations

	Non-linear equations	Linearized equations	Descriptions
1	$\tilde{C}_t = \frac{C_t - \chi C_{t-1}}{1-\chi}$	$(1-\chi)\widehat{\tilde{C}_t} = \widehat{C}_t - \chi\widehat{C_{t-1}}$	Habit formation
2	$K_{t+1} = (1-\delta) K_t + \left[1 - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t$	$\widehat{K_{t+1}} = \delta \widehat{I}_t + (1-\delta)\widehat{K}_t$	Capital accumulation
3	$q_t^K = \beta E_t \frac{(1+\tau_t^s)\tilde{C}_t}{(1+\tau_{t+1}^s)\tilde{C}_{t+1}} \left[\left[1-(1-\delta)\tau_t^k\right] r_{t+1}^K + (1-\delta) q_{t+1}^K\right]$	$\widehat{q_t^k} = E_t\left[\widehat{\tilde{C}_t} - \widehat{\tilde{C}_{t+1}} + \frac{\tau^s}{1+\tau^s}\left(\widehat{\tau_t^s} - \widehat{\tau_{t+1}^s}\right)\right]$ $+E_t\left[\left[1-\beta(1-\delta)\right]\widehat{r_t^k} + \beta(1-\delta)\widehat{q_{t+1}^k}\right.$ $\left.-\frac{[1-\beta(1-\delta)]\overline{\tau^k}}{1-(1-\delta)\overline{\tau^k}}\widehat{\tau_{t+1}^k}\right]$	Euler equation for capital
4	$q_t^K\left[1 - \xi^I \frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}} - 1\right) - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right]$ $= 1 - \xi^I \beta E_t \frac{(1+\tau_t^s)\tilde{C}_t}{(1+\tau_{t+1}^s)\tilde{C}_{t+1}\pi_{t+1}} q_{t+1}^K \left(\frac{I_{t+1}}{I_t}\right)^2\left(\frac{I_{t+1}}{I_t} - 1\right)$	$\widehat{q_t^K} = \xi^I\left(\widehat{I}_t - \widehat{I}_{t-1} + \beta E_t\left[\widehat{I}_t - \widehat{I}_{t+1}\right]\right)$	Price for capital
5	$w_t^* = \mu^w \varphi^L \frac{(1+\tau_t^s)}{(1-\tau_t^w)} L_t^\eta \tilde{C}_t$	$\widehat{w}_t = \widehat{\tilde{C}_t} + \eta\widehat{L}_t + \frac{\tau^s}{(1+\tau^s)}\widehat{\tau_t^s} + \frac{\overline{\tau^w}}{(1-\overline{\tau^w})}\widehat{\tau_t^w}$	Flexible labour supply
6	$w_t = w_t^* + w_t\zeta^W\left[-\left(\pi_t^D \frac{w_t}{w_{t-1}} - \pi_{t-1}^D \frac{w_{t-1}}{w_{t-2}}\right)\right.$ $\left.+\beta E_t\left(\pi_{t+1}^D \frac{w_{t+1}}{w_t} - \pi_t^D \frac{w_t}{w_{t-1}}\right)\right]$	$\widehat{w}_t = \widehat{w}_t^* - \zeta^W\left[\widehat{\pi}_t^D - \widehat{\pi}_{t-1}^D + \widehat{w}_t - 2\widehat{w}_{t-1} + \widehat{w}_{t-2}\right.$ $\left.-\beta E_t\left(\widehat{\pi}_{t+1}^D - \widehat{\pi}_t^D + \widehat{w}_{t+1} - 2\widehat{w}_t + \widehat{w}_{t-1}\right)\right]$	Wage setting
7	$1 = E_t\beta\frac{(1+\tau_t^s)\tilde{C}_t}{(1+\tau_{t+1}^s)\tilde{C}_{t+1}\pi_{t+1}}\left[1+R_t\right]$	$\widehat{\tilde{C}_t} = \widehat{\tilde{C}_{t+1}} + \widehat{\pi_{t+1}} + \frac{\tau^s}{1+\tau^s}\left[\widehat{\tau_{t+1}^s} - \widehat{\tau_t^s}\right] - \frac{R}{1+R}\widehat{R_t}$	Euler equation
8	$(1+\tau_t^s)C_t + I_t + d_t = \left[1+R_{t-1}\right]\frac{d_{t-1}}{\pi_t}$ $+(1-\tau_t^w)w_t L_t + \left[1-(1-\delta)\tau_t^k\right] r_t^K K_t + \left(\widetilde{\Phi}_t^D + \widetilde{\Phi}_t^X\right)$	$C\tau^s\widehat{\tau_t^s} + (1+\tau^s)C\widehat{C}_t + I\widehat{I}_t + d\widehat{d}_t = \frac{d}{\pi}R\widehat{R_{t-1}}$ $+\frac{d}{\pi}\left[1+R\right]\left(\widehat{d_{t-1}} - \widehat{\pi}_t\right)$ $-wL(1-\tau^w)\left[\frac{\tau^w}{1-\tau^w}\widehat{\tau_t^w} - \widehat{w}_t - \widehat{L}_t\right]$ $-(1-\delta)\tau^k r_t^K K_t\left[\widehat{\tau_t^k} - \left(\frac{1}{(1-\delta)\tau^k} - 1\right)\left[\widehat{r_t^K} + \widehat{K_t}\right]\right]$ $+(\overline{\widetilde{\Phi}^D}\widehat{\widetilde{\Phi}_t^D} + \overline{\widetilde{\Phi}_t^X}\widehat{\widetilde{\Phi}_t^X});$	Budget constraint

Where $q_t^K = \frac{Q_t}{P_t^D}$; $r_t^K = \frac{R_t^K}{P_t^D}$; $w_t = \frac{W_t}{P_t^D}$; $\pi_t = \frac{P_t^D}{P_{t-1}^D}$; $s_t = S_t \frac{P_t^{MF}}{P_t^D}$; $b_t = \frac{B_t}{P_t^D}$; and it is assumed that $\overline{\pi} = 1$; $\alpha = 0$;

A.2.2 Firms Sector

The firms sector's behavior equations are summarized in Table 13.

Table 13: The list of firms sector behaviour equations

	Non-linear equations	Linearized equations	Descriptions
1f	$Y_t^D = (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}$	$\widehat{Y_t^D} = \gamma_L^D \widehat{A_t} + \gamma_L^D \widehat{L_t^D} + \gamma_M^D \widehat{M_t^D} + (1-\gamma_L^D-\gamma_M^D)\widehat{K_t^D}$	Production function
2f	$\left(1+R_t^L\right) w_t L_t^D \mu^D = P_t^{D*} \gamma_L^D Y_t^D$	$\widehat{p_t^{D*}} + \widehat{Y_t^D} = \frac{R^L}{(1+R^L)} \widehat{R_t^L} + \widehat{w}_t + \widehat{L_t^D}$	Labour demand
3f	$p_t^M M_t^D \mu^D = \gamma_M^D p_t^{D*} Y_t^D$	$\widehat{p_t^{D*}} + \widehat{Y_t^D} = \widehat{p_t^M} + \widehat{M_t^D}$	Intermediary demand
4f	$r_t^K K_t^D \mu^D = \left(1-\gamma_L^D-\gamma_M^D\right) p_t^{D*} Y_t^D$	$\widehat{r_t^K} + \widehat{K_t^D} = \widehat{p_t^{D*}} + \widehat{Y_t^D}$	Demand for capita
5f	$p_t^{D*} = 1 - \zeta^W \left[-\left(\pi_t - \pi_{t-1}\right) + \beta\left(\pi_{t+1} - \pi_t\right)\right]$	$\widehat{p_t^{D*}} = \zeta^W \left[(\widehat{\pi}_t - \widehat{\pi_{t-1}}) - \beta(\widehat{\pi_{t+1}} - \widehat{\pi}_t)\right]$	Price stickiness
6f	$Y_t^X = (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X}$	$\widehat{Y_t^X} = \gamma_L^X \widehat{A_t} + \gamma_L^X \widehat{L_t^X} + \gamma_M^X \widehat{M_t^X} + \left(1-\gamma_L^X-\gamma_M^X\right) \widehat{K_t^X}$	Production function
7f	$w_t L_t^X = \gamma_L^X p_t^X Y_t^X$	$\widehat{w}_t + \widehat{L_t^X} = \widehat{p_t^X} + \widehat{Y_t^X}$	Demand for labour
8f	$p_t^M M_t^X = \gamma_M^X p_t^X Y_t^X$	$\widehat{p_t^M} + \widehat{M_t^X} = \widehat{p_t^X} + \widehat{Y_t^X}$	Intermediary demand
9f	$r_t^K K_t^X = \left(1-\gamma_L^X-\gamma_M^X\right) p_t^X Y_t^X$	$\widehat{r_t^K} + \widehat{K_t^X} = \widehat{p_t^X} + \widehat{Y_t^X}$	Demand for capital
10f	$1 + R_t^L = sp \left[\frac{Y_{t-1}^D}{Y_t^D}\right]^\tau (1+R_t)$	$\widehat{R_t^L} = \widehat{R_t} - \tau\left(\widehat{Y}_t^D - \widehat{Y}_{t-1}^D\right)$	Loan spread
11f	$\widetilde{\Phi_t^D} = Y_t^D - (1+R_t^L) w_t L_t^D - p_t^M M_t^D - r_t^K K_t^D$	$\overline{\widetilde{\Phi^D}}\widehat{\widetilde{\Phi_t^D}} = \overline{Y^D}\widehat{Y_t^D} - wL^D R^L \left[\widehat{R_t^L} + (\frac{1}{R^L}+1)\widehat{w}_t + (\frac{1}{R^L}+1)\widehat{L_t^D}\right]$ $-M^D\overline{p^M}\left[\widehat{p_t^M} + \widehat{M_t^D}\right] - K^D\overline{r^K}\left[\widehat{r_t^K} + \widehat{K_t^D}\right]$	Domestic firms profit
12f	$\widetilde{\Phi_t^X} = p_t^X Y_t^X - w_t L_t^X - p_t^M M_t^X - r_t^K K_t^X$	$\overline{\widetilde{\Phi^X}}\widehat{\widetilde{\Phi_t^X}} = \overline{p^X Y^X}\left[\widehat{Y_t^X} + \widehat{p_t^X}\right] - L^X\overline{w}\left[\widehat{w}_t + \widehat{L_t^X}\right]$ $-M^X\overline{p^M}\left[\widehat{p_t^M} + \widehat{M_t^X}\right] - K^X\overline{r^K}\left[\widehat{r_t^K} + \widehat{K_t^X}\right]$	Export firms profit

Table 14: The list of aggregation equations

	Non-linear equations	Linearized equations	Descriptions
1A	$Y_t^N = Y_t^D + Y_t^X$	$\widehat{Y_t^N} = \frac{Y^D}{Y^D+Y^X}\widehat{Y_t^D} + \frac{Y^X}{Y^D+Y^X}\widehat{Y_t^X}$	National output
2A	$K_t = K_t^D + K_t^X$	$\widehat{K_t} = \frac{K^D}{K^D+K^X}\widehat{K_t^D} + \frac{K^X}{K^D+K^X}\widehat{K_t^X}$	Capital
3A	$L_t = L_t^D + L_t^X$	$\widehat{L_t} = \frac{L^D}{L^D+L^X}\widehat{L_t^D} + \frac{L^X}{L^D+L^X}\widehat{L_t^X}$	Labour
4A	$M_t = M_t^D + M_t^X$	$\widehat{M_t} = \frac{M^D}{M^D+M^X}\widehat{M_t^D} + \frac{M^X}{M^D+M^X}\widehat{M_t^X}$	Intermediate good
5A	$Y_t^D = C_t + I_t + G_t$	$\widehat{Y_t^D} = \frac{C}{Y^D}\widehat{C}_t + \frac{I}{Y^D}\widehat{I}_t + \frac{G}{Y^D}\widehat{G}_t$	Market clearance

, where $p_t^M = \frac{P_t^M}{P_t^D}$; $p_t^{D*} = \frac{P_t^{D*}}{P_t^D}$; $p_t^X = \frac{P_t^X}{P_t^D}$; $\widetilde{\Phi_t^D} = \frac{\Phi_t^D}{p_t^D}$; $\widetilde{\Phi_t^X} = \frac{\Phi_t^X}{p_t^D}$

A.2.3 Aggregation

The aggregation equations are summarized in Table 14.

A.2.4 Fiscal Policy and Monetary Policy Sector

The fiscal policy and monetary policy equations are summarized in Table 15.

Table 15: The list of fiscal policy and monetary policy sector behaviour equations

	Non-linear equations	Linearized equations	Descriptions
1p	$P_t^D G_t = \rho^G \left(P_{t-1}^D G_{t-1}\right) + \left(1-\rho^G\right)\left(\sigma P_t^D Y_t^N\right)$	$\widehat{G_t} = \rho^G \left(\widehat{G}_{t-1} - \widehat{\pi}_t\right) + \left(1-\rho^G\right)\sigma\widehat{Y_t^N}$	Expenditure
2p	$R_t = \rho^R R_{t-1} + \left(1-\rho^R\right)\left[R^{ss} + \kappa\left(\pi_t - 1\right)\right]$	$\widehat{R_t} = \rho^R \widehat{R_{t-1}} + \left(1-\rho^R\right)\left[\widehat{R^{ss}} + \frac{\kappa}{\overline{R}}\widehat{\pi}_t\right]$	Taylor rule
3p	$b_t^G = (1+R_{t-1})\frac{b_{t-1}^G}{\pi_t} + G_t - \tau_t^s C_t$ $-\tau_t^w w_t L_t - (1-\delta)\,\tau_t^k r_t^K K_t$	$\widehat{b_t^G} = \frac{1}{(1+\alpha+\pi)\overline{\pi}}(1+R)\left[\frac{R}{(1+R)}\widehat{R_{t-1}} + \widehat{b_{t-1}^G} - \widehat{\pi}_t\right]$ $+\frac{G}{b^G}\widehat{G_t} - \frac{C\tau^s}{b^G}\left[\widehat{\tau_t^s} + \widehat{C_t}\right]$ $-\frac{wL\tau^w}{b^G}\left[\widehat{\tau_t^w} + \widehat{w}_t + \widehat{L_t}\right] - \frac{(1-\delta)r^K K\tau^k}{b^G}\left[\widehat{\tau_t^k} + \widehat{r_t^K} + \widehat{K_t}\right]$	Government debt dynamic
4p	$t_t^s = \tau_t^s C_t$	$\widehat{t_t^s} = \widehat{\tau_t^s} + \widehat{C_t}$	Sales tax revenue
5p	$t_t^w = \tau_t^w w_t L_t$	$\widehat{t_t^w} = \widehat{\tau_t^w} + \widehat{w}_t + \widehat{L_t}$	Labour income tax revenue
6p	$t_t^k = (1-\delta)\,\tau_t^k r_t^K K_t$	$\widehat{t_t^k} = \widehat{\tau_t^k} + \widehat{r_t^K} + \widehat{K_t}$	Capital income tax revenue
7p	$t_t^{total} = t_t^s + t_t^w + t_t^k$	$\widehat{t_t^{total}} = \frac{t^s}{t^{total}}\widehat{t_t^s} + \frac{t^w}{t^{total}}\widehat{t_t^w} + \frac{t^k}{t^{total}}\widehat{t_t^k}$	Total tax revenue

Where $t_t^w = \frac{T_t^w}{P_t^D}; t_t^s = \frac{T_t^s}{P_t^D}; t_t^k = \frac{T_t^k}{P_t^D};$

A.2.5 International externalities

The international externalities equations are summarized in Table 16.

Table 16: The list of internetional externalities equations

	Non-linear equations	Linearized equations	Descriptions
1x	$(1+R_t) = (1+R_t^*)\, E_t\,(dS_{t+1}) \left(\frac{b_t}{4Y_t^N}\frac{1}{\psi}\right)^{\zeta^B}$	$\overline{R}\widehat{R_t} = \overline{R^*}\widehat{R_t^*} + \widehat{S_{t+1}} - \widehat{S}_t + \zeta^B \frac{\bar{b}}{4\bar{Y}^N}\left[\widehat{b}_t - \widehat{Y_t^N}\right]$	Risk premium
2x	$S_t = s_t \frac{P_t^D}{P_t^{Mf}}$	$\widehat{S}_t - \widehat{P}_t^D = \widehat{s}_t - \widehat{P}_t^{Mf};$	Real exchange rate
3x	$b_t = (1+R_{t-1})\frac{b_{t-1}}{\pi_t} - (p_t^X X_t - p_t^M M_t)$	$\widehat{b}_t = (1+R)\left(\widehat{b_{t-1}} - \widehat{\pi}_t\right) + R\widehat{R_{t-1}}$ $-\frac{Xp^X}{b}\left[\widehat{p_t^X} + \widehat{X_t}\right] + \frac{Mp^M}{b}\left[\widehat{p_t^M} + \widehat{M_t}\right]$	Foreign debt
4x	$p_t^X = \frac{S_t P_t^{Xf}}{P_t^D}$	$\widehat{p_t^X} = \widehat{P_t^{Xf}} + \widehat{S}_t - \widehat{P_t^D}$	Export price
5x	$p_t^M = \frac{S_t P_t^{Mf}}{P_t^D}$	$\widehat{p_t^M} = \widehat{P_t^{Mf}} + \widehat{S}_t - \widehat{P_t^D};\ \widehat{p_t^M} = \widehat{s}_t$	Import price
6x	$T_t = \frac{p_t^X}{p_t^M} = \frac{P_t^{Xf}}{P_t^{Mf}}$	$T_t = \widehat{P_t^{Xf}} - \widehat{P_t^{Mf}}$	Terms of trade
7x	$tb_t = p_t^X X_t - p_t^M M_t$	$\widehat{tb} = \frac{p^X X}{tb}\left(\widehat{p_t^X} + \widehat{X_t}\right) - \frac{p^M M}{tb}\left(\widehat{p_t^M} + \widehat{M_t}\right)$	Trade balance

B APPENDIX : Optimal Taxes in a Small-Open Economy

B.1 The small-open economy model for optimal taxation

B.1.1 Households sector

A small-open economy is populated with a number of infinitely lived households. Households are identical and homogeneous . At period t, they consume the amount C_t of goods. The household utility function, $U(.)$, is in the Von Neumann-Morgenstern preferences form. $U(.)$ is uniformly identical over a households' lifetime and is an infinitely consumption series. It is a strictly increasing and concave function. The most important characteristic of a household's preference is its persistence as a habit. Koehne & Kuhn (2013) claims that the habit's persistence can affect the calculation of the optimal taxation by wealth effect, the complementary effect and the future incentive effect. Habit-adjusted consumption, $\tilde{C}_t$ is assumed as equation (2). The continuum of the expected lifetime of the households' utility is the same as in the first section's equation (1). The households' utility function is subject to households' budgeting constraints as follows:

$$C_t + I_t + d_t = \frac{(1 + R_{t-1})}{\pi_t} d_{t-1} + (1 - \tau_t^w) w_t L_t + \left[1 - (1 - \delta)\, \tau_t^k\right] r_t^K K_t + \sum_{j=D,X} \widetilde{\Phi}_t^j \tag{157}$$

The households' budget constraints are presented in real terms by normalizing with P_t^D. The households' expenditures, the left-hand side of budget constraints equation, are composed of three parts: consumption (C_t), investment (I_t), and deposit (D_t). On the right-hand side of the budget constraints, four sources of households' incomes derive from previous periods' savings, and they include the interest rate, the labour supply return, the capital return, and the profit from the firms' operations'. R_t, w_t, r_t^K denotes a nominal interest rate for the deposit, which is similar to the policy interest rate, real wage rate, and the real price of capital, respectively. Households' incomes are taxed at a payroll tax rate (τ_t^w) and a capital tax rate (τ_t^k). δ is a rate of depreciation, and K_t is capital at the current period. Households who are owners of firms receive the operation profit $\widetilde{\Phi}_t^j$, where $\widetilde{\Phi}_t^D$ is the domestic firms' profits, and $\widetilde{\Phi}_t^X$ is the export firms' profits. A capital accumulation and an investment adjustment's costs are presented in equation (5) and (6).

For the households' intertemporal problem, the Lagrangian formulation is presented as follows:

$$\begin{aligned}\mathcal{L} \;=\; & E_0 \sum_{t=0}^{\infty} \beta^t \Bigg\{ (1-\chi) \log \tilde{C}_t - \varphi^L \frac{L_t^{1+\eta}}{1+\eta} + \lambda_t \left[(1+R_{t-1}) D_{t-1} + (1-\tau_t^w) w_t L_t + \left[1-(1-\delta)\tau_t^k\right] r_t^K K_t \right. \\ & \left. + \sum_{j=D,X} \widetilde{\Phi}_t^j - (1-\chi)\tilde{C}_t - \chi h_t - I_t - D_t \right] + \lambda_t q_t^K \left[(1-\delta) K_t + F(I_t, I_{t-1}) - K_{t+1} \right] \Bigg\} \qquad (158)\end{aligned}$$

, where h_t represents habits and is taken by the households as an exogenous variable, while q_t^K is a shadow price of capital. The households' decision is the maximizing of a habit's persistence utility subject to budget constraints and capital accumulation. In order to determine the households' decision, the first-order condition with respect to macroeconomic variables is derived. The details of the first-order condition are as follows:

The first-order condition with respect to $\tilde{C}_t$, $\frac{\partial \mathcal{L}}{\partial \tilde{C}_t} = 0$

$$\lambda_t = \frac{1}{\tilde{C}_t} \qquad (159)$$

The first-order condition with respect to K_{t+1}, $\frac{\partial \mathcal{L}}{\partial K_{t+1}} = 0$

$$q_t^K = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[\left[1-(1-\delta)\tau_{t+1}^k\right] r_{t+1}^K + q_{t+1}^K (1-\delta) \right] \qquad (160)$$

The first-order condition with respect to I_t, $\frac{\partial \mathcal{L}}{\partial I_t} = 0$

$$
\begin{aligned}
q_t^K &= \frac{1}{1 - \xi^I \frac{I_t}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} - (1+\alpha) \right) - \frac{\xi^I}{2} \left(\frac{I_t}{I_{t-1}} - (1+\alpha) \right)^2} \\
&\quad \times \left[1 - \xi^I \beta E_t \frac{\lambda_{t+1}}{\lambda_t} q_{t+1}^K \left(\frac{I_{t+1}}{I_t} \right)^2 \left(\frac{I_{t+1}}{I_t} - (1+\alpha) \right) \right] \qquad (161)
\end{aligned}
$$

The first-order condition with respect to L_t, $\frac{\partial \mathcal{L}}{\partial L_t} = 0$

$$(1 - \tau_t^w)\lambda_t w_t = \varphi^L L_t^\eta \qquad (162)$$

The first-order condition with respect to D_t, $\frac{\partial \mathcal{L}}{\partial D_t} = 0$

$$\lambda_t = \beta \lambda_{t+1}(1 + R_t) \qquad (163)$$

For the price of labour, wage is rigid. The real wage setting for a real wage rigidity is assumed as follows:

$$w_t = w_t^* + \zeta^W \left[- \left(\triangle w_t - \triangle \overline{w}_{t-1} \right) + \beta \left(\triangle w_{t+1} - \triangle \overline{w}_t \right) \right] \qquad (164)$$

, where $w_t^* = \mu^w w_t$ would be the wage if there are no wage rigidities, ζ^W is a wage's stickiness, and $\triangle \overline{w}_{t-1}$ aggregates wage inflation in previous period. $\mu^w > 1$ is wage mark up. The wage depends on two terms. Firstly, it directly relies on the optimal wage in a wage-flexible environment. Secondly, the wage depends on rigidity term, which is a different between wage inflation, $\triangle w_t$, and wage inflation of previous period,$\triangle \overline{w}_{t-1}$.

The capital market is open, and foreign investors can finance the domestic economy. b_t^* is foreign debt in a foreign currency. The spread between the domestic interest rate, R_t, and the foreign interest rate, R_t^*, depends on an expected change in the nominal exchange rate, $E_t \left(\frac{s_{t+1}}{s_t} \right)$, and an additional risk premium proportional to a foreign debt to national income ratio:

$$\frac{(1+R_t)}{(1+R_t^*)} = E_t\left(\frac{s_{t+1}}{s_t}\right)\left(\frac{b_t}{2\psi Y_t^N}\right)^{\zeta^B} \upsilon_t \tag{165}$$

, where s_t is a real exchange rate, and ξ^B is an elasticity of interest rate premium on foreign debt holdings. Y_t^N is a national output, and b_t is a foreign bond in domestic currency. υ_t denotes a transition cost, since there is a spread between the domestic interest rate and the foreign interest rate. The term in brackets shows the risk premium, which the ratio of local debt to nominal GDP is $\frac{b_t}{Y_t^N}$, and ψ is the average foreign debt to GDP the ratio. The risk premium reflects the sustainability of the foreign debt.

, where s_t is a real exchange rate, ξ^B is an elasticity of interest rate premium on foreign debt holdings. Y_t^N is a national output, b_t is a foreign bond in domestic currency. υ_t denotes a transaction costs.

B.1.2 Firms sector

The most important function of the firms is to produce goods for the economy. In this model, there are two type of firms, namely domestic firms and export firms. Their names define the destination market of the goods, as domestic firms only produce goods for the domestic market, and export firms only produce goods for trading abroad. The specific characteristics of each firm are explained as follows:

Domestic Firms Domestic firms have a Cobb-Douglas production function that is similar to the production function in the first part, namely equation (21).

A domestic firm's real total cost is

$$tc_t^D = \left(1+R_t^L\right) w_t L_t^D + p_t^M M_t^D + r_t^K K_t^D \tag{166}$$

, where tc_t^D is the domestic firm's real total cost, which is derived from costs of labour, intermediate goods and capital service. A cost of labour is the sum of a wage payment and an interest rate payment at a labour loan interest rate, R_t^L, since the main assumption is that only domestic firms borrow money from the bank. p_t^M is a raw imported material price.

A real profit of the domestic firm, $\widetilde{\Phi}_t^D$, is a real total domestic firm's revenue less a real total cost of production. The expression of the domestic firms' real profit is

$$\widetilde{\Phi}_t^D = \left[Y_t^D - (1 + R_t^L) w_t L_t^D - p_t^M M_t^D - r_t^K K_t^D\right] \tag{167}$$

The objective of a domestic firm is maximizing profit subject to a production function constraint. The domestic firms' decisions are composed of the amount of labour input, L_t^D, a capital service input, K_t^D, and an intermediate goods input, M_t^D. The Lagrangian function is

$$\mathcal{L}^D = \left[Y_t^D - \left(1 + R_t^L\right) w_t L_t^D - p_t^M M_t^D - r_t^K K_t^D\right] - q_t^D \left[Y_t^D - (A_t L_t^D)^{\gamma_L^D} (M_t^D)^{\gamma_M^D} (K_t^D)^{1-\gamma_L^D-\gamma_M^D}\right] \tag{168}$$

In order to determine the firm's decision, the first-order condition with respect to macroeconomic variables is derived. The details of the first-order condition are as follows:

The first-order condition with respect to L_t^D, $\frac{\partial \mathcal{L}^D}{\partial L_t^D} = 0$

$$\left(1 + R_t^L\right) w_t L_t^D = \gamma_L^D q_t^D Y_t^D \tag{169}$$

The first-order condition with respect to M_t^D,$\frac{\partial \mathcal{L}^D}{\partial M_t^D} = 0$

$$p_t^M M_t^D = \gamma_M^D q_t^D Y_t^D \tag{170}$$

The first-order condition with respect to K_t^D, $\frac{\partial \mathcal{L}^D}{\partial K_t^D} = 0$

$$r_t^K K_t^D = \left(1 - \gamma_L^D - \gamma_M^D\right) q_t^D Y_t^D \tag{171}$$

Domestic firms can set the price of goods, since they have a monopolistic power by differentiating their products. However, there is a rigidity in the domestic firms' price. The price adjustment is sticky when responding to the shock. The domestic firms' price setting, a given domestic price, and a domestic price markup are similar to the situation described in equation (30), (31), (28), respectively.

Export Firms Export firms also have a Cobb-Douglas production function, which is similar to the production function described in equation (32).

The export firms' total cost, tc_t^X, contrasts with the domestic firms' total cost. This thesis assumes that export firms have large capital investments, so they do not borrow money for labour payments from banks. Thus, there is no labour cost loan term in the export firms' real total cost function. A real cost of the export firm's production, tc_t^X, is assumed as follows:

$$tc_t^X = w_t L_t^X + p_t^M M_t^X + r_t^K K_t^X \tag{172}$$

Furthermore, a real export firm's profit, $\widetilde{\Phi}_t^X$, is a total export firm's revenue less a total cost of production, and it is assumed as follows:

$$\widetilde{\Phi}_t^X = p_t^X Y_t^X - w_t L_t^X - p_t^M M_t^X - r_t^K K_t^X \tag{173}$$

, where p_t^X is the price of the export firms' goods in terms of the local currency, which is equal to the global price. The export firms' profit is presented in real terms through normalizing with P_t^D.

The objective of export firms is maximizing profit subject to a production function constraint. The export firms' decisions are composed of the amount of a labour input, L_t^X, a capital service input, K_t^X, and an intermediate goods input, M_t^X. The Lagrangian function is

$$\mathcal{L}^X = \left[p_t^X Y_t^X - w_t L_t^X - p_t^M M_t^X - r_t^K K_t^X\right] - q_t^X \left[Y_t^X - (A_t L_t^X)^{\gamma_L^X} (M_t^X)^{\gamma_M^X} (K_t^X)^{1-\gamma_L^X-\gamma_M^X}\right] \tag{174}$$

The first-order condition with respect to L_t^X, $\frac{\partial \mathcal{L}^X}{\partial L_t^X} = 0$

$$w_t L_t^X = \gamma_L^X q_t^X Y_t^X \tag{175}$$

The first-order condition with respect to M_t^X, $\frac{\partial \mathcal{L}^X}{\partial M_t^X} = 0$

$$p_t^M M_t^X = \gamma_M^X q_t^X Y_t^X \tag{176}$$

The first-order condition with respect to K_t^X, $\frac{\partial \mathcal{L}^X}{\partial K_t^X} = 0$

$$r_t^K K_t^X = \left(1 - \gamma_L^X - \gamma_M^X\right) q_t^X Y_t^X \tag{177}$$

The price setting of the export firms is different from the price setting of the domestic firms. Since export firms' goods are sold in a perfectly competitive market, the export firms receive a global price for their price setting. At an equilibrium, the export firms price is

$$q_t^X = p_t^X \tag{178}$$

, where q_t^X is the export firms' shadow price.

p_t^X is the product of the real exchange rate, s_t, and the price of export goods in a foreign currency, p_t^{Xf}. The price of the export firms is assumed as follows:

$$p_t^X = s_t p_t^{Xf} \tag{179}$$

Similarly, p_t^M denotes a domestic import price, which is the product of the foreign import price, P_t^{MF}, and the nominal exchange rate, S_t. The import firms' price is assumed as follows:

$$p_t^M = S_t P_t^{MF} = s_t \tag{180}$$

The national output or Gross Domestic Product (GDP), Y_t^N, is the sum of the domestic firms' and export firms' outputs. The national output is

$$Y_t^N = Y_t^D + Y_t^X \tag{181}$$

B.1.3 Banks Sector

The lending spread varies over time. During an economic expansion, the lending spread decreases. In contrast, it increases during recessions. The labour loan interest rate and the deposits lent out to the firm ratio are similar equations (44) and (45). The households face an incomplete asset market, since they cannot hedge against undesirable outcomes in the future. The incomplete asset market is an important assumption in several studies on optimal taxation, such as Aiyagari (1995), Aiyagari, Marcet, Sargent & Seppälä (2002) and Schmitt-Grohé & Uribe (2004). The households can only allocate their incomes to deposits and earn deposit interest rates.

B.1.4 Government sector

This part explains the role of government in a small-open economy, including a fiscal rule, a government expenditure, taxation, and a government budget constraint. The main roles of government are consuming and providing sustainable economic growth. To maintain these objectives, governments use a simple fiscal rule for planning spending. A fiscal rule can be assumed as follows:

$$G_t = \rho^G \frac{G_{t-1}}{\pi_t^D} + \left(1 - \rho^G\right) \sigma Y_t^N \tag{182}$$

, where G_t is real government spending. Government spending is adjusted according to the level of the previous period's government spending and the national output. ρ^G is the persistence of government spending. σ is a ratio of government spending to output. Government spending is set to σ percentage of national output for supporting sustainable economic growth. This study uses the government budget constraint developed in Zubairy (2014)'s study. Her DSGE model includes a comprehensive fiscal policy block. There are two types of taxes, namely a payroll tax and a capital tax. The government's budget constraint is

$$b_t^G = (1 + R_{t-1})b_{t-1}^G + G_t - \tau_t^w w_t L_t - (1 - \delta)\,\tau_t^k r_t^K K_t \tag{183}$$

, where b_t^G is a real government bond. Governments issue bonds for financing spending. Private agents (households, domestic firms and foreign firms) can buy bonds. In the government's budget constraint, a bond has two main components. Firstly, it depends on the last period's government bond, particularly its interest rate payment. Secondly, a bond depends on the government's primary deficit, which is a difference between the latter's spending and total revenue. The government's total revenue consists of payroll tax revenue and capital income tax revenue.

In the credit market, a debt balance equation is assumed as follows:

$$b_t^G + w_t L_t^D = d_t + b_t \tag{184}$$

The above equation simply presents the total loan that is required in the economy. The sum of the government bond and domestic firms' borrowing, which is on the left hand side of the debt balance equation, is equal to the total available credit in the economy, which is composed of the households' saving and foreign borrowing.

B.1.5 Central Bank Sector

The central bank's objective is maintaining the economy's price stability. In order to reach this objective, the central bank introduces monetary policies by announcing the policy interest rate as a benchmark for banks. The central bank adjusts the policy interest rate as a response to inflation and output. The principle of the Taylor rule is used as a monetary policy in the present model. The Taylor rule is similar to equation (52).

B.1.6 Market Clearing Condition

The market clearing condition requires a equality of the supply and demand of output. The price of goods also adjusts until reaching a market clearing price at the market clearing condition. The adjustment of price and quantity of output freely moves toward that condition. The market clearing condition for domestic output, foreign output, labour, import, capital and banks is similar to equation (53), (54), (55), (56), (57) and (58), respectively.

B.1.7 Steady State Condition

The steady state condition is the condition where all variables do not change. For example, the quantity is at the same level or grows at the steady growth rate. In order to prevent an explosion or a collapse of macroeconomic variables, a growth rate of these variables is set as a constant (Tanboon 2008). In the present model, the growth rate of all variables is zero. The change in the price level or inflation is also set to zero ($\pi_t = 1$). The step of the steady state estimation of the small-economy model is similar to the procedure in the first part. The steady state labour tax and capital income tax, τ^w and τ^k, are obtained from Thailand's labour tax and capital income in 2017. The details of steady state equations are presented in Appendix B.2.

B.1.8 Model Parameters Calibration

The present model uses the same calibration parameter as provided in the first part. The parameters are calibrated for representing Thailand's economy. Data are obtained from several sources, such as the bank of Thailand's structural model for policy analysis (Tanboon 2008), the bank of Thailand's macroeconometric model, the Office of the National Economic and Social Development Board's website[26], the Fiscal Policy Office, the Ministry of Finance, and the revenue department . The details of the calibration parameters are presented in Table 17 and 17. A description of all parameter has been provided in the first section of this paper.

Table 17: The model parameters

Symbol	Parameter	Value
β	Discount Factor	0.9926
χ	Consumption Habit Persistence Factor	0.85
φ^L	Scaling Parameter of Labour Disutility Function	1
η	Inverse of Frisch Elasticity	3.0303
ξ^I	The Elasticity of Investment Adjustment Cost	0.9
α	Productivity Growth Rate	0
δ	Depreciation Rate	0.0072
μ^W	Wage Markup	1.05
ξ^W	The Elasticity of Wage Adjustment Cost	9
R^*	Foreign Interest Rate	0.0036
ξ^B	The Elasticity of Interest Rate Premium on Foreign Debt Holdings	0.35
ψ	The Foreign Debt-to-GDP Ratio at Steady-State	0.299
υ	The Gap between Domestic and Foreign Interest Rate	0.0025
γ_L^D	Labour Income Share of Domestic Firms	0.76
γ_M^D	Imported Input Income Share of Domestic Firms	0.12
ξ^D	The Elasticity of Price Rigidities	9
μ^D	Domestic Price Markup	1.02
γ_L^X	Labour Income Share of Foreign Firms	0.72
γ_M^X	Imported Input Income Share of Foreign Firms	0.14
τ	The Degree of Bank Willingness to Lend subject to the Relative GDP Growth rate	0.6
ρ^G	The Degree of Government Expenditure Persistency	0.85
σ	The Specific Ratio of Government Expenditure to GDP	0.149
ρ^R	The Degree of Interest Rate Policy Persistency	0.9
κ	The Sensitivity of Interest Rate Policy to Inflation	20
P^D	Domestic Price of Consumption and Investment Goods	1.0
P^{XF}	Foreign Export Price	1.0
P^{MF}	Foreign Import Price	1.0

B.2 The steady-state condition of the optimal taxes in a small-open economy

The details of all steady-state equation are as follows:

[26] http://www.nesdb.go.th/

Table 17: The model parameters (continued)

Symbol	Parameter	Value
τ^w	Payroll Tax	0.131
τ^k	Return on Capital Tax	0.1

Table 18: The steady-state condition of the optimal taxes in a small-open economy

	Steady-state equations
1ss	$\tilde{C} = C$
2ss	$K = \frac{F(I,I)}{\alpha+\delta}$
3ss	$F(I_t, I_{t-1}) = I$
4ss	$\lambda = \frac{1}{\tilde{C}}$
5ss	$q^K = \frac{\left[1-(1-\delta)\tau^k\right]\beta}{(1-\beta(1-\delta))} r^K$
6ss	$q^K = 1$
7ss	$w = \frac{\varphi^L \tilde{C} L^\eta}{(1-\tau^w)}$
8ss	$w = w^*$
9ss	$1 + R = \frac{\pi}{\beta}$
10ss	$\frac{(1+R)}{1+R^*} = \left(\frac{\pi}{\pi^*}\right) \zeta^B \left(\frac{b}{2\psi Y^N}\right)^{\zeta^B} \upsilon$
11ss	$b^G + wL^D = d + b$
12ss	$Y^D = (AL^D)^{\gamma_L^D} (M^D)^{\gamma_M^D} (K^D)^{1-\gamma_L^D-\gamma_M^D}$
13ss	$\left(1 + R^L\right) wL^D = \gamma_L^D \frac{1}{\mu^D} Y^D$
14ss	$Sp^{MF} M^D = \gamma_M^D \frac{1}{\mu^D} Y^D$
15ss	$r^K K^D = \left(1 - \gamma_L^D - \gamma_M^D\right) \frac{1}{\mu^D} Y^D$
16ss	$P^D = P^{D*}$
17ss	$1 = \mu^D q^D$
18ss	$Y^X = (AL^X)^{\gamma_L^X} (M^X)^{\gamma_M^X} (K^X)^{1-\gamma_L^X-\gamma_M^X}$
19ss	$wL^X = \gamma_L^X p^X Y^X$
20ss	$Sp^{MF} M^X = \gamma_M^X p^X Y^X$
21ss	$r^K K^X = \left(1 - \gamma_L^X - \gamma_M^X\right) p^X Y^X$
22ss	$Q^X = P^X$
23ss	$P^X = SP^{Xf}$
24ss	$Y^N = Y^D + Y^X$
25ss	$LN = \Lambda D$
26ss	$\Lambda = 1$
27ss	$R^L = R$
28ss	$G_t = \rho^G \left(\frac{G_{t-1}}{\pi_t^D}\right) + \left(1 - \rho^G\right) \left(\sigma y_t^N\right)$

Continued on the next page

Table 18: The steady-state condition of the optimal taxes in a small-open economy (continued)

	Steady-state equations
29ss	$R = R^{ss}$
30ss	$L = L^D + L^X$
31ss	$M = M^D + M^X$
32ss	$K = K^D + K^X$
33ss	$Y^D = C + I + G$
34ss	$Y^X = X$
35ss	$B = SB^*$
36ss	$P^M = SP^{MF}$
37ss	$d = \frac{1}{\left(1-\frac{1}{\beta}\right)}\left[(1-\tau^w)wL + \left[1-(1-\delta)\tau^k\right]r^K K + \left(\widetilde{\Phi}^D + \widetilde{\Phi}^X\right) - C - I\right]$
38ss	$b^G = \frac{1}{\left(1-\frac{1}{\beta}\right)}\left[G - \tau^w wL - (1-\delta)\tau^k r^K K\right]$
39ss	$\widetilde{\Phi}^D = Y^D - (1+R_t^L)wL^D - p^M M^D - r^K K^D$
40ss	$\widetilde{\Phi}^X = p^X Y^X - wL^X - p^M M^X - r^K K^X$

B.3 The first-order condition of the Ramsey problem

This step involves finding the first-order conditions of the Lagrangian problem ($\mathcal{L}$) with respect to considered variables, which are C, d_t, I_t, π_t, w_t, L_t^D, L_t^X, r^K, q_t^D, q_t^K, b_t, b_t^G, K_t^D, K_t^X, R^L, s_t, Y_t^D, Y_t^X, M_t^D, M_t^X, G_t, $(1+R_t)$, τ_t^k, τ_t^w. The detail of all 24 first-order conditions of the Lagrangian problem are shown as follows:

The first-order condition with respect to C_t[27]

$$\begin{aligned}\frac{d\mathcal{L}}{dC_t} &= \frac{(1-\chi)}{C_t - \chi C_{t-1}} - \Lambda_{1t}(1+\tau_t^s) + \Lambda_{5t}(1+\tau_t^s)\mu^w\varphi^L\left(L_t^D + L_t^X\right)^\eta \\ &\quad + \Lambda_{6t}\left[(1+\tau_{t+1}^s)\pi_{t+1}\chi + \beta(1+\tau_t^s)\left[1+R_t\right]\right] + \Lambda_{19t} - \Lambda_{20t}\tau_t^s \\ &\quad - \beta\frac{\chi(1-\chi)}{C_{t+1} - \chi C_t} - \beta\Lambda_{5t+1}(1+\tau_{t+1}^s)\chi\mu^w\varphi^L\left(L_{t+1}^D + L_{t+1}^X\right)^\eta \\ &\quad - \beta\Lambda_{6t+1}(1+\tau_{t+1}^s)\chi\left[1+R_{t+1}\right] - \beta^{-1}\Lambda_{6t-1}(1+\tau_t^s)\pi_t \end{aligned} \tag{185}$$

The first-order condition with respect to d_t

$$\frac{d\mathcal{L}}{dd_t} = -\Lambda_{1t} + \beta\Lambda_{1t+1}\left(\frac{(1+R_t)}{\pi_{t+1}}\right) - \Lambda_{8t} \tag{186}$$

[27] Differentiate Logarithm : if y = ln x then $\frac{dy}{dx} = \frac{1}{x}$. if y = ln f(x) then $\frac{dy}{dx} = \frac{f'(x)}{f(x)}$.

The first-order condition with respect to I_t

$$\begin{aligned}
\frac{d\mathcal{L}}{dI_t} &= \Lambda_{1t}(-1) + \Lambda_{2t}\left[1 - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \frac{I_t}{I_{t-1}} - \xi^I\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] \\
&+\beta\Lambda_{2t+1}\left(\xi^I\left(\frac{I_{t+1}}{I_t} - 1\right)\left(-\frac{I_{t+1}^2}{I_t^2}\right)\right) \\
&+\Lambda_{4t}\left(\frac{\xi^I}{I_{t-1}}\left[2\frac{I_t}{I_{t-1}} - 1 + \left(\frac{I_t}{I_{t-1}} - 1\right)\right] q_t^K\left(1+R_t\right) + \xi^I\frac{I_{t+1}}{I_t^2}\left[3\left(\frac{I_{t+1}}{I_t}\right)^2 - 2\left(\frac{I_{t+1}}{I_t}\right)\right] E_t q_{t+1}^K \pi_{t+1}\right) \\
&-\beta\Lambda_{4t+1}\xi^I\frac{I_{t+1}}{I_t^2}\left[2\frac{I_{t+1}}{I_t} - 1 + \left(\frac{I_{t+1}}{I_t} - 1\right)\right] q_{t+1}^K\left(1+R_{t+1}\right) \\
&-\beta^{-1}\Lambda_{4t-1}\xi^I E_{t-1} q_t^K \pi_t\left(3\frac{I_t^2}{I_{t-1}^3} - 2\frac{I_t}{I_{t-1}^2}\right) + \Lambda_{19t} \qquad (187)
\end{aligned}$$

The first-order condition with respect to π_t

$$\begin{aligned}
\frac{d\mathcal{L}}{d\pi_t} &= \Lambda_{1t}\left(-\frac{[1+R_{t-1}]}{\pi_t^2}d_{t-1}\right) + \beta^{-1}\Lambda_{3t-1}\left(\left[\left(1-(1-\delta)\tau_t^k\right)r_t^K + q_t^K(1-\delta)\right]\right) \\
&+\beta^{-1}\Lambda_{4t-1}\left(-\xi^I E_{t-1} q_t^K\left(\frac{I_t}{I_{t-1}}\right)^2\left(\frac{I_t}{I_{t-1}} - 1\right)\right) \\
&+\Lambda_{5t}\left(\left(-\frac{w_t}{w_{t-1}}\right)(1-\tau_t^w)\zeta^W[1+\beta]\right) \\
&+\beta^1\Lambda_{5t+1}\left((1-\tau_{t+1}^w)\zeta^W\frac{w_t}{w_{t-1}}\right) + \beta^{-1}\Lambda_{5t-1}\left((1-\tau_{t-1}^w)\zeta^W\beta\frac{w_t}{w_{t-1}}\right) \\
&+\beta^{-1}\Lambda_{6t-1}\left[-(1+\tau_t^s)\left(C_t - \chi C_{t-1}\right)\right] \\
&+\beta^{-1}\Lambda_{7t-1}\left[\left(1+R_{t-1}^*\right)E_{t-1}\left(\frac{s_t}{s_{t-1}}\frac{1}{\pi_t^*}\right)\times\left(\frac{b_{t-1}}{2\psi\left(Y_{t-1}^D + Y_{t-1}^X\right)}\right)^{\zeta^B}\upsilon_{t-1}\right] \\
&-\Lambda_{12t}\zeta^D[1+\beta] + \beta\Lambda_{12t+1}\zeta^D + \Lambda_{12t-1}\zeta^D - \Lambda_{17t}\rho^G\left(\frac{G_{t-1}}{\pi_t^2}\right) \\
&+\Lambda_{18t}\left([1+R_t]\kappa\left(1-\rho^R\right)\pi_t^{-1}\right) + \Lambda_{20t}\left(-(1+R_{t-1})\frac{b_{t-1}^G}{\pi_t^2}\right) \qquad (188)
\end{aligned}$$

The first-order condition with respect to w_t

$$\begin{aligned}
\frac{d\mathcal{L}}{dw_t} &= \Lambda_{1t}\left[(1-\tau_t^w)(L_t^D+L_t^X)-(1+R_t^L)L_t^D-L_t^X\right] \\
&+\Lambda_{5t}(1-\tau_t^w)\left(-1+\zeta^W\left[-(1+\beta)\frac{\pi_t}{w_{t-1}}-\beta\frac{w_{t+1}}{w_t^2}\pi_{t+1}\right]\right) \\
&+\beta\Lambda_{5t+1}\left((1-\tau_{t+1}^w)\zeta^W\left[\frac{w_{t+1}}{w_t^2}\pi_{t+1}(1+\beta)+\frac{1}{w_{t-1}}\pi_t\right]\right) \\
&+\beta^2\Lambda_{5t+2}\left(-(1-\tau_{t+2}^w)\zeta^W\left[\frac{w_{t+1}}{w_t^2}\pi_{t+1}\right]\right) \\
&+\Lambda_{5t-1}\left((1-\tau_{t-1}^w)\zeta^W\frac{1}{w_{t-1}}\pi_t\right) \\
&+\Lambda_{8t}L_t^D \\
&+\Lambda_{9t}\left(-\left(1+R_t^L\right)L_t^D\right)+\Lambda_{13t}\left(-L_t^X\right)+\Lambda_{20t}\left(-\tau_t^w(L_t^D+L_t^X)\right)
\end{aligned} \tag{189}$$

The first-order condition with respect to L_t^D

$$\begin{aligned}
\frac{d\mathcal{L}}{dL_t^D} &= -\varphi^L(L_t^D+L_t^X)^\eta-\Lambda_{1t}\left[\tau_t^w+R_t^L\right]w_t \\
&+\Lambda_{5t}(1+\tau_t^s)\left(C_t-\chi C_{t-1}\right)\mu^w\varphi^L\eta\left(L_t^D+L_t^X\right)^{\eta-1} \\
&+\Lambda_{8t}w_t \\
&-\Lambda_{9t}\left(1+R_t^L\right)w_t \\
&-\Lambda_{20t}\tau_t^w w_t+\Lambda_{22t}\gamma_L^D Y_t^D/L_t^D
\end{aligned} \tag{190}$$

The first-order condition with respect to L_t^X

$$\begin{aligned}
\frac{d\mathcal{L}}{dL_t^X} &= -\varphi^L(L_t^D+L_t^X)^\eta-\Lambda_{1t}w_t\tau_t^w+\Lambda_{5t}(1+\tau_t^s)\left(C_t-\chi C_{t-1}\right)\mu^w\varphi^L\eta\left(L_t^D+L_t^X\right)^{\eta-1} \\
&-\Lambda_{13t}w_t-\Lambda_{20t}\tau_t^w w_t+\Lambda_{21t}\gamma_L^X\frac{Y_t^X}{L_t^X}
\end{aligned} \tag{191}$$

The first-order condition with respect to r_t^K

$$\begin{aligned}
\frac{d\mathcal{L}}{dr_t^K} &= -\Lambda_{1t}(K_t^D+K_t^X)(1-\delta)\tau^k+\beta^{-1}\Lambda_{3t-1}\left(1-(1-\delta)\tau_{t-1}^k\right)\pi_t \\
&-\Lambda_{11t}K_t^D-\Lambda_{15t}K_t^X-\Lambda_{20t}(1-\delta)\tau_t^k(K_t^D+K_t^X)
\end{aligned} \tag{192}$$

The first-order condition with respect to q_t^D

$$\frac{d\mathcal{L}}{dq_t^D} = \Lambda_{12t}\mu^D \tag{193}$$

The first-order condition with respect to q_t^K

$$\begin{aligned}\frac{d\mathcal{L}}{dq_t^K} &= -\Lambda_{3t}\left[1+R_t\right]+\beta^{-1}\Lambda_{3t-1}\pi_t\left(1-\delta\right) \\ &\quad -\Lambda_{4t}\left[1-\xi^I\frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}}-1\right)-\frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right](1+R_t) \\ &\quad -\beta^{-1}\Lambda_{4t-1}\xi^I\pi_t\left(\frac{I_t}{I_{t-1}}\right)^2\left(\frac{I_t}{I_{t-1}}-1\right)\end{aligned} \tag{194}$$

The first-order condition with respect to b_t

$$\begin{aligned}\frac{d\mathcal{L}}{db_t} &= \beta^t\Lambda_{7t}\left[\left(1+R_t^*\right)E_t\zeta^B\left(\frac{s_{t+1}}{s_t}\frac{\pi_{t+1}}{\pi_{t+1}^*}\right)\left(\frac{1}{\left(\left(Y_t^D+Y_t^X\right)2\psi\right)}\right)^{\zeta^B}\left(b_t\right)^{\zeta^B-1}\upsilon_t\right] \\ &\quad -\beta^t\Lambda_{8t} \\ &= \Lambda_{7t}\left(1+R_t\right)\zeta^B\frac{1}{b_t}-\Lambda_{8t}\end{aligned} \tag{195}$$

The first-order condition with respect to b_t^G

$$\frac{d\mathcal{L}}{db_t^G} = \Lambda_{8t}-\Lambda_{20t}+\beta\Lambda_{20t+1}(1+R_t)\frac{1}{\pi_{t+1}} \tag{196}$$

The first-order condition with respect to K_t^D

$$\begin{aligned}\frac{d\mathcal{L}}{dK_t^D} &= -\Lambda_{1t}r_t^K\left(1-\delta\right)\tau_t^k)+\Lambda_{2t}\left(1-\delta\right)-\beta^{-1}\Lambda_{2t-1} \\ &\quad -\Lambda_{11t}r_t^K-\Lambda_{20t}\left(1-\delta\right)\tau_t^kr_t^K \\ &\quad +\Lambda_{22t}\left(1-\gamma_L^D-\gamma_M^D\right)\frac{Y_t^D}{K_t^D}\end{aligned} \tag{197}$$

The first-order condition with respect to K_t^X

$$\begin{aligned}
\frac{d\mathcal{L}}{dK_t^X} &= -\Lambda_{1t} r_t^K (1-\delta)\,\tau_t^k) + \Lambda_{2t}(1-\delta) - \beta^{-1}\Lambda_{2t-1} \\
&\quad -\Lambda_{15t} r_t^K - \Lambda_{20t}(1-\delta)\,\tau_t^k r_t^K \\
&\quad +\Lambda_{21t}\left(1-\gamma_L^X-\gamma_M^X\right)\frac{Y_t^X}{K_t^X} \qquad (198)
\end{aligned}$$

The first-order condition with respect to R_t^L

$$\frac{d\mathcal{L}}{dR_t^L} = -\Lambda_{1t} w_t L_t^D - \Lambda_{9t} w_t L_t^D - \Lambda_{16t}\left(\frac{Y_t^D}{Y_{t-1}^D}\right)^{\tau} \qquad (199)$$

The first-order condition with respect to s_t

$$\begin{aligned}
\frac{d\mathcal{L}}{ds_t} &= \Lambda_{1t}\left[Y_t^X - \frac{P_t^{MF}}{P_t^{XF}}\left(M_t^D+M_t^X\right)+\right] \\
&\quad -\Lambda_{7t}\left[(1+R_t)/s_t\right] + \beta^{-1}\Lambda_{7t-1}\left[(1+R_{t-1})/s_t\right] \\
&\quad -\Lambda_{10t}\left(\frac{P_t^{MF}}{P_t^{XF}} M_t^D\right) + \Lambda_{13t}\left(\gamma_L^X Y_t^X\right) \\
&\quad +\Lambda_{15t}\left(1-\gamma_L^X-\gamma_M^X\right) Y_t^X \qquad (200)
\end{aligned}$$

The first-order condition with respect to Y_t^D

$$\begin{aligned}
\frac{d\mathcal{L}}{dY_t^D} &= \Lambda_{1t} + \Lambda_{7t}\left[(1+R_t)\left(-\zeta^B\right)\left(Y_t^D+Y_t^X\right)^{-1}\right] \\
&\quad +\Lambda_{9t}\gamma_L^D\frac{1}{\mu^D} + \Lambda_{10t}\gamma_M^D\frac{1}{\mu^D} + \Lambda_{11t}\left(1-\gamma_L^D-\gamma_M^D\right)\frac{1}{\mu^D} \\
&\quad -\Lambda_{16t}\frac{\tau(1+R_t^L)(\frac{Y_t^D}{Y_{t-1}^D})^{\tau-1}}{Y_{t-1}^D} - \tau\beta\Lambda_{16t+1}(-1-R_t^L)\frac{Y_t^D(\frac{Y_t^D}{Y_{t-1}^D})^{\tau-1}}{(Y_{t-1}^D)^2} + \Lambda_{17t}\left(1-\rho^G\right)\sigma \\
&\quad -\Lambda_{19t} - \Lambda_{22t} \qquad (201)
\end{aligned}$$

The first-order condition with respect to Y_t^X

$$\begin{aligned}
\frac{d\mathcal{L}}{dY_t^X} &= \Lambda_{1t}s_t + \Lambda_{7t}\left[(1+R_t)\left(-\zeta^B\right)\left(Y_t^D+Y_t^X\right)^{-1}\right] \\
&\quad +\Lambda_{13t}\gamma_L^X s_t + \Lambda_{14t}\left(-\gamma_M^X\right) + \Lambda_{15t}\left(1-\gamma_L^X-\gamma_M^X\right)s_t \\
&\quad +\Lambda_{17t}\left(\left(1-\rho^G\right)\sigma\right) - \Lambda_{21t} \qquad (202)
\end{aligned}$$

The first-order condition with respect to M_t^D

$$\frac{d\mathcal{L}}{dM_t^D} = \Lambda_{1t}\left[-s_t\frac{P_t^{MF}}{P_t^{XF}}\right] + \Lambda_{10t}\left(-s_t\frac{P_t^{MF}}{P_t^{XF}}\right) + \Lambda_{22t}\gamma_M^D\frac{Y_t^D}{M_t^D} \tag{203}$$

The first-order condition with respect to M_t^X

$$\frac{d\mathcal{L}}{dM_t^X} = \frac{P_t^{MF}}{P_t^{XF}}\left(-\Lambda_{1t}s_t - \Lambda_{14t}\right) + \Lambda_{21t}\gamma_M^X\frac{Y_t^X}{M_t^X} \tag{204}$$

The first-order condition with respect to G_t

$$\frac{d\mathcal{L}}{dG_t} = -\Lambda_{17t} + \beta\Lambda_{17t+1}\rho^G\frac{G_t}{\pi_{t+1}} + \Lambda_{19t} + \Lambda_{20t} \tag{205}$$

The first-order condition with respect to $(1+R_t)$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial(1+R_t)} &= \beta\Lambda_{1t+1}\frac{d_t}{\pi_{t+1}} - \Lambda_{3t}q_t^K \\ &+\Lambda_{4t}\left(1-\left[1-\xi^I\frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}}-1\right)-\frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right]q_t^K\right) \\ &+\Lambda_{6t}\beta(1+\tau_t^s)\left(C_t-\chi C_{t-1}\right) - \Lambda_{7t} + \Lambda_{16t} \\ &-\Lambda_{18t} + \beta\Lambda_{18t+1}\frac{[1+R_{t+1}]}{1+R_t}\rho^R + \beta\Lambda_{20t+1}\frac{b_t^G}{\pi_{t+1}^D}\end{aligned} \tag{206}$$

The first-order condition with respect to τ_t^k

$$\begin{aligned}\frac{d\mathcal{L}}{d\tau_t^k} &= -\Lambda_{1t}\left(1-\delta\right)r_t^K(K_t^D+K_t^X) - \Lambda_{3t}\left(1-\delta\right)r_{t+1}^K\pi_{t+1} \\ &-\Lambda_{20t}\left(1-\delta\right)r_t^K(K_t^D+K_t^X)\end{aligned} \tag{207}$$

The first-order condition with respect to τ_t^w

$$\begin{aligned}\frac{d\mathcal{L}}{d\tau_t^w} &= -\Lambda_{1t}w_t(L_t^D+L_t^X) \\ &+\Lambda_{5t}\left(w_t+\zeta^W\left(\frac{w_t}{w_{t-1}}\pi_t-\frac{w_{t-1}}{w_{t-2}}\pi_{t-1}\right)-\zeta^W\beta\left(\frac{w_{t+1}}{w_t}\pi_{t+1}-\frac{w_t}{w_{t-1}}\pi_t\right)\right) \\ &-\Lambda_{20t}w_t(L_t^D+L_t^X)\end{aligned} \tag{208}$$

All of the above first-order condition equations are used for deriving a steady-state condition in the next step.

B.4 Steady state equations of the first-order condition of the Ramsey problem

The steady-state equations of the first-order condition with respect to C_t

$$\begin{aligned} 0 &= \frac{1}{C}(1-\beta\chi) - \Lambda_1 + \Lambda_5 \mu^w \varphi^L \left(L^D + L^X\right)^\eta (1-\beta\chi) \\ &\quad + \Lambda_6 \left[\pi\chi + \beta\left[1+R\right] - \beta\chi\left[1+R\right] - \frac{\pi}{\beta}\right] + \Lambda_{19} \end{aligned} \tag{209}$$

The steady-state equations of the first-order condition with respect to d_t

$$\Lambda_8 = 0 \tag{210}$$

The steady-state equations of the first-order condition with respect to I_t

$$0 = -\Lambda_1 + \Lambda_2 + \Lambda_{19} + (1-\beta)\Lambda_4 \frac{\xi^I}{I} q^K \left((1+R) - \frac{\pi}{\beta}\right) \tag{211}$$

The steady-state equations of the first-order condition with respect to π_t

$$\begin{aligned} 0 &= \Lambda_1 \left(-\frac{\left[1+R\right]}{\pi^2} d\right) + \beta^{-1}\Lambda_3 \left(\left(1-(1-\delta)\tau^k\right) r^K + q^K (1-\delta)\right) \\ &\quad + \beta^{-1}\Lambda_6 \left[-(1-\chi)\right] C \\ &\quad + \beta^{-1}\Lambda_7 \left[(1+R^*)\left(\frac{1}{\pi_t^*}\right)\left(\frac{b}{2\psi\left(Y^D+Y^X\right)}\right)^{\zeta^B}\right] \\ &\quad + \Lambda_{17}\left(-\rho^G \frac{G}{\pi^2}\right) + \Lambda_{18}\left(\left[1+R\right]\kappa\left(1-\rho^R\right)\pi^{-1}\right) + \Lambda_{20}\left(-(1+R)\frac{b^G}{\pi^2}\right) \end{aligned} \tag{212}$$

The steady-state equations of the first-order condition with respect to w_t

$$\begin{aligned} 0 &= \Lambda_1 \left[(1-\tau^w)(L^D+L^X) - (1+R^L)L^D - L^X\right] - \Lambda_5(1-\tau^w) + \Lambda_8 L^D \\ &\quad +\Lambda_9 \left(-\left(1+R^L\right)L^D\right) + \Lambda_{13}\left(-L^X\right) + \Lambda_{20}\left(-\tau^w(L^D+L^X)\right) \end{aligned} \tag{213}$$

The steady-state equations of the first-order condition with respect to L_t^D

$$\begin{aligned} 0 &= -\varphi^L(L^D+L^X)^\eta - \Lambda_1\left[\tau^w + R^L\right]w \\ &\quad +\Lambda_5\left(1-\chi\right)C\mu^w\varphi^L\eta\left(L_t^D+L_t^X\right)^{\eta-1} + \Lambda_{8t}w_t \\ &\quad -\Lambda_9\left(1+R^L\right)w - \Lambda_{20}\tau^w w + \Lambda_{22}\gamma_L^D\frac{Y^D}{L^D} \end{aligned} \tag{214}$$

The steady-state equations of the first-order condition with respect to L_t^X

$$\begin{aligned} 0 &= -\varphi^L(L^D+L^X)^\eta - \Lambda_1 w\tau^w + \Lambda_5\left(1-\chi\right)C\mu^w\varphi^L\eta\left(L^D+L^X\right)^{\eta-1} \\ &\quad -\Lambda_{13}w - \Lambda_{20}\tau^w w + \Lambda_{21}\gamma_L^X\frac{Y^X}{L^X} \end{aligned} \tag{215}$$

The steady-state equations of the first-order condition with respect to r_t^K

$$\begin{aligned} 0 &= -\Lambda_1(K^D+K^X)\left(1-\delta\right)\tau^k + \beta^{-1}\Lambda_3\left(1-\left(1-\delta\right)\tau^k\right)\pi \\ &\quad -\Lambda_{11}K^D - \Lambda_{15}K^X - \Lambda_{20}\left(1-\delta\right)\tau^k(K^D+K^X) \end{aligned} \tag{216}$$

The steady-state equations of the first-order condition with respect to q_t^D

$$\Lambda_{12} = 0 \tag{217}$$

The steady-state equations of the first-order condition with respect to q_t^K

$$0 = -\Lambda_3\beta\left[1+R\right] + \Lambda_3\pi\left(1-\delta\right) - \Lambda_4\beta\left(1+R\right) \tag{218}$$

The steady-state equations of the first-order condition with respect to b_t

$$0 = \Lambda_7 \left(1 + R\right) \zeta^B \frac{1}{b} - \Lambda_8 \tag{219}$$

The steady-state equations of the first-order condition with respect to b_t^G

$$0 = \Lambda_8 + \Lambda_{20} \left(-1 + \frac{\beta(1+R)}{\pi} \right) \tag{220}$$

The steady-state equations of the first-order condition with respect to K_t^D

$$\begin{aligned} 0 &= -\Lambda_1 r^K \left(1-\delta\right) \tau^k + \Lambda_2 \left(\left(1-\delta\right) - \beta^{-1} \right) - \Lambda_{11} r^K - \Lambda_{20} \left(1-\delta\right) \tau^k r^K \\ & \quad + \Lambda_{22} \left(1 - \gamma_L^D - \gamma_M^D\right) \frac{Y^D}{K^D} \end{aligned} \tag{221}$$

The steady-state equations of the first-order condition with respect to K_t^X

$$\begin{aligned} 0 &= -\Lambda_1 r^K \left(1-\delta\right) \tau^k + \Lambda_2 \left(\left(1-\delta\right) - \beta^{-1} \right) - \Lambda_{15} r^K - \Lambda_{20} \left(1-\delta\right) \tau^k r^K \\ & \quad + \Lambda_{21} \left(1 - \gamma_L^X - \gamma_M^X\right) \frac{Y^X}{K^X} \end{aligned} \tag{222}$$

The steady-state equations of the first-order condition with respect to R^L

$$0 = -\Lambda_1 w L^D - \Lambda_9 w L^D - \Lambda_{16} \left(\frac{Y_t^D}{Y_{t-1}^D} \right)^{\tau} \tag{223}$$

The steady-state equations of the first-order condition with respect to s_t

$$\begin{aligned} 0 &= \Lambda_1 \left[Y^X - \frac{P^{MF}}{P^{XF}} \left(M^D + M^X\right) \right] + \Lambda_7 \left(1 + R\right) \frac{(1-\beta)}{s\beta} \\ & \quad - \Lambda_{10} \left(\frac{P^{MF}}{P^{XF}} M^D \right) + \Lambda_{13} \left(\gamma_L^X Y^X \right) + \Lambda_{15} \left(1 - \gamma_L^X - \gamma_M^X\right) Y^X \end{aligned} \tag{224}$$

The steady-state equations of the first-order condition with respect to Y_t^D

$$\begin{aligned} 0 &= \Lambda_1 - \Lambda_7 \frac{\left(1 + R_t\right) \zeta^B}{\left(Y^D + Y^X\right)} + \Lambda_9 \gamma_L^D \frac{1}{\mu^D} + \Lambda_{10t} \gamma_M^D \frac{1}{\mu^D} + \Lambda_{11} \left(1 - \gamma_L^D - \gamma_M^D\right) \frac{1}{\mu^D} \\ & \quad - \Lambda_{16} \tau (1 + R^L) \left(Y^D\right)^{-1} (1-\beta) + \Lambda_{17} \left(1 - \rho^G\right) \sigma - \Lambda_{19} - \Lambda_{22} \end{aligned} \tag{225}$$

The steady-state equations of the first-order condition with respect to Y_t^X

$$\begin{aligned} 0 &= \Lambda_1 s + \Lambda_7 \left[(1+R)\left(-\zeta^B\right)\left(Y^D + Y^X\right)^{-1}\right] + \Lambda_{13}\gamma_L^X s \\ &\quad + \Lambda_{14}\left(-\gamma_M^X\right) + \Lambda_{15}\left(1-\gamma_L^X-\gamma_M^X\right)s + \Lambda_{17}\left(1-\rho^G\right)\sigma - \Lambda_{21} \end{aligned} \quad (226)$$

The steady-state equations of the first-order condition with respect to M_t^D

$$0 = \left(s\frac{P^{MF}}{P^{XF}}\right)(-\Lambda_1 - \Lambda_{10}) + \Lambda_{22}\gamma_M^D \frac{Y^D}{M^D} \quad (227)$$

The steady-state equations of the first-order condition with respect to M_t^X

$$0 = \frac{P^{MF}}{P^{XF}}(-\Lambda_1 s - \Lambda_{14}) + \Lambda_{21}\gamma_M^X \frac{Y^X}{M^X} \quad (228)$$

The steady-state equations of the first-order condition with respect to G_t

$$0 = \Lambda_{17}\left(\beta\rho^G \frac{1}{\pi} - 1\right) + \Lambda_{19} + \Lambda_{20} \quad (229)$$

The steady-state equations of the first-order condition with respect to τ_t^k

$$0 = -\Lambda_1(K^D + K^X) - \Lambda_3\pi - \Lambda_{20}(K^D + K^X) \quad (230)$$

The steady-state equations of the first-order condition with respect to τ_t^w

$$0 = -\Lambda_1(L^D + L^X) + \Lambda_5 - \Lambda_{20}(L^D + L^X) \quad (231)$$

The steady-state equations of the first-order condition with respect to $(1+R_t)$

$$0 = \Lambda_1 \frac{d_t}{1+R} - \Lambda_3 + \Lambda_6\beta C(1-\chi) + \Lambda_{16t} - \Lambda_{18}\left(1-\beta\rho^R\right) + \Lambda_{20}\frac{b^G}{1+R} \quad (232)$$

Equation (210), (217), and (219) show that $\Lambda_7 = \Lambda_8 = \Lambda_{12} = 0$. The above steady state equations are in the form of a non-linear equations system that is composed of 24 unknown variables $(\Lambda_1, \Lambda_{2,...}, \Lambda_{22}, \tau_t^k, \tau_{t+1}^w)$ and 24 equations. Thus, mathematically, all unknown variables of the non-linear equations system can be solved.

B.5 Implementability constraint of the closed economy model

The government budget constraint

$$d_t = r_t d_{t-1} + G_t - \tau_t^w w_t L_t - (1-\delta)\,\tau_t^k r_t^K K_t \tag{233}$$

Rewritten in discounted form as below

$$\begin{aligned}\sum_{t=0}^{\infty}\beta^t d_t \frac{1}{C_t} &= \sum_{t=0}^{\infty}\beta^t \frac{1}{C_t} r_t d_{t-1} + \sum_{t=0}^{\infty}\beta^t \frac{1}{C_t} G_t - \sum_{t=0}^{\infty}\beta^t \tau_t^w \frac{1}{C_t} w_t L_t \\ &\quad -\sum_{t=0}^{\infty}\beta^t \frac{1}{C_t}(1-\delta)\,\tau_t^k r_t^K K_t\end{aligned} \tag{234}$$

From

$$\begin{aligned}\frac{1}{C_t} &= \beta E_t \frac{1}{C_{t+1}}\left[\left[1-(1-\delta)\,\tau_{t+1}^k\right] r_{t+1}^K + (1-\delta)\right] \\ \beta E_t \frac{1}{C_{t+1}}(1-\delta)\,\tau_{t+1}^k r_{t+1}^K K_{t+1} &= \beta E_t \frac{1}{C_{t+1}}\left(1-\delta+r_{t+1}^K\right) K_{t+1} - \frac{1}{C_t} K_{t+1}\end{aligned} \tag{235}$$

Substituted

$$\sum_{t=0}^{\infty}\beta^t \frac{1}{C_t}(1-\delta)\,\tau_t^k r_t^K K_t = \frac{1}{C_0}(1-\delta)\,\tau_0^k r_0^K K_0 + \sum_{t=0}^{\infty}\beta E_t \frac{1}{C_{t+1}}(1-\delta)\,\tau_{t+1}^k r_{t+1}^K K_{t+1}$$

to the government budget constraint.

$$\begin{aligned}\sum_{t=0}^{\infty}\beta^t d_t \frac{1}{C_t} &= \sum_{t=0}^{\infty}\beta^t \frac{1}{C_t} r_t d_{t-1} + \sum_{t=0}^{\infty}\beta^t \frac{1}{C_t} G_t - \sum_{t=0}^{\infty}\beta^t \tau_t^w \frac{1}{C_t} w_t L_t \\ &\quad + \frac{1}{C_0}(1-\delta)\,\tau_0^k r_0^K K_0 - \sum_{t=0}^{\infty}\beta^{t+1} E_t \frac{1}{C_{t+1}}\left(1-\delta+r_{t+1}^K\right) K_{t+1} + \sum_{t=0}^{\infty}\beta^t \frac{1}{C_t} K_{t+1}\end{aligned} \tag{236}$$

From the Euler equation

$$\frac{1}{C_t} = \beta r_{t+1} \frac{1}{C_{t+1}} \tag{237}$$

The first term on the right hand side of the government budget constraint is

$$\begin{aligned} \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} r_t d_{t-1} &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \beta \frac{1}{C_{t+1}} r_{t+1} d_t \\ &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} d_t \end{aligned} \tag{238}$$

Substituted to the government budget constraint

$$\begin{aligned} \sum_{t=0}^{\infty} \beta^t d_t \frac{1}{C_t} &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} d_t + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} G_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \tau_t^w w_t L_t \\ & \frac{1}{C_0} (1-\delta) \tau_0^k r_0^K K_0 - \sum_{t=0}^{\infty} \beta^{t+1} E_t \frac{1}{C_{t+1}} \left(1 - \delta + r_{t+1}^K\right) K_{t+1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} K_{t+1} \end{aligned} \tag{239}$$

From labour supply

$$\begin{aligned} (1-\tau_t^w) w_t &= \varphi^L L_t^\eta C_t \\ \tau_t^w w_t &= w_t - \varphi^L L_t^\eta C_t \end{aligned} \tag{240}$$

Substituted to the government budget constraint

$$\begin{aligned} 0 &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} G_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(w_t - \varphi^L L_t^\eta C_t\right) L_t \\ & + \frac{1}{C_0} (1-\delta) \tau_0^k r_0^K K_0 - \sum_{t=0}^{\infty} \beta^{t+1} E_t \frac{1}{C_{t+1}} \left(1 - \delta + r_{t+1}^K\right) K_{t+1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} K_{t+1} \end{aligned} \tag{241}$$

From the resource constraint and capital accumulation

$$Y_t^D = C_t + I_t + G_t \tag{242}$$

$$K_{t+1} - (1-\delta) K_t = I_t, \tag{243}$$

Substituted to the government budget constraint

$$
\begin{aligned}
0 &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(Y_t^D - C_t - \left(K_{t+1} - (1-\delta) K_t \right) \right) \\
&\quad - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(w_t L_t - \varphi^L L_t^{\eta} C_t L_t \right) + \frac{1}{C_0} (1-\delta) \tau_0^k r_0^K K_0 \\
&\quad - \sum_{t=0}^{\infty} \beta^{t+1} E_t \frac{1}{C_{t+1}} \left(1 - \delta + r_{t+1}^K \right) K_{t+1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} K_{t+1}
\end{aligned} \tag{244}
$$

From firms' decision

$$
\mu^D w_t L_t^D = \gamma_L^D Y_t^D \tag{245}
$$

$$
\mu^D r_t^K K_t^D = \left(1 - \gamma_L^D \right) Y_t^D \tag{246}
$$

Substituted to the government budget constraint

$$
\begin{aligned}
0 &= \frac{1}{C_0} r_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(\mu \left(w_t L_t + r_t^K K_t \right) - C_t - \left(K_{t+1} - (1-\delta) K_t \right) \right) \\
&\quad - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(w_t L_t - \varphi^L L_t^{\eta} C_t L_t \right) + \frac{1}{C_0} (1-\delta) \tau_0^k r_0^K K_0 \\
&\quad - \sum_{t=0}^{\infty} \beta^{t+1} E_t \frac{1}{C_{t+1}} \left(1 - \delta + r_{t+1}^K \right) K_{t+1} + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} K_{t+1}
\end{aligned}
$$

$$
\begin{aligned}
0 &= \frac{1}{C_0} r_0 d_{-1} - \frac{1}{C_0} (1-\mu) \left(r_0^K K_0 \right) + \frac{1}{C_0} \left((1-\delta) + (1-\delta) \tau_0^k r_0^K + r_0^K \right) K_0 \\
&\quad + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \varphi^L L_t^{\eta+1} C_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t \\
&\quad + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (\mu - 1) (w_t L_t) + \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} (\mu - 1) \left(r_{t+1}^K K_{t+1} \right)
\end{aligned} \tag{247}
$$

Defined A_0

$$
A_0 = \frac{1}{C_0} r_0 d_{-1} + \frac{1}{C_0} \left((1-\delta) + (1-\delta) \tau_0^k r_0^K + \mu \left(r_0^K \right) \right) K_0 > 0 \tag{248}
$$

Thus, the implementability constraint is

$$\begin{aligned} -A_0 &= \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \varphi^L L_t^{\eta+1} C_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (\mu - 1)(w_t L_t) \\ &+ \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} (\mu - 1) \left(r_{t+1}^K K_{t+1} \right) \end{aligned} \tag{249}$$

Note:$-A_0 < 0$

Defined r_t

$$r_t = \frac{(1 + R_{t-1})}{\pi_t} > 1 \tag{250}$$

Thus, the government budget constraint at $t+1$ can be rewrite as below

$$d_t = \frac{d_{t+1}}{r_{t+1}} + \frac{\tau_{t+1}^w w_{t+1} L_{t+1} + (1 - \delta) \tau_{t+1}^k r_{t+1}^K K_{t+1} - G_{t+1}}{r_{t+1}}$$

The household budget constraint can be rewrite as below

$$(1+\tau_t^s) C_t + I_t + d_t \leq r_t d_{t-1} + (1 - \tau_t^w) w_t L_t + \left[1 - (1 - \delta) \tau_t^k\right] r_t^k K_t + Y_t^D \left(1 - \frac{1}{\mu^D}\right) \tag{251}$$

Rewritten it as debt = the net present values of future surpluses, and real return

Introduced a cumulative discounting

$$\Omega_{t,t+s} = \prod_{k=1,s-1} r_{t+k} \tag{252}$$

No Ponzi condition

$$\lim_{s \to \infty} \frac{b_{t+s}^G}{\Omega_{t,t+s}} = 0 \tag{253}$$

Integrating forward, the implementability constraint is

$$d_t = \sum_{s=0,\infty} \frac{\tau_{t+s}^w w_{t+s} L_{t+s} + (1 - \delta) \tau_{t+s}^k r_{t+s}^K K_{t+s} - G_{t+s}}{\Omega_{t,t+s}} \tag{254}$$

B.6 Lagrangian form of the Ramsey problem and the first-order condition of the closed economy model

The Lagrangian form of the Ramsey problem ($\mathcal{L}^c$) is presented as follows:

$$\begin{aligned}
\mathcal{L}^c \;=\; & E_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - \varphi^L \frac{L^{1+\eta}}{1+\eta} \right] \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{2t} \left(\frac{1}{C_t} - \beta E_t \frac{1}{C_{t+1}} \left[\left[1 - (1-\delta)\, \tau_{t+1}^k \right] r_{t+1}^K + (1-\delta) \right] \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{3t} \left((1-\tau_t^w) w_t - \mu^w \varphi^L L_t^\eta C_t \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{4t} \left(\frac{1}{C_t} - \beta r_{t+1} \frac{1}{C_{t+1}} \right) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{5t} \left(Y_t - (A_t L_t)^{\gamma_L} (K_t)^{1-\gamma_L} \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{6t} \left(\mu^D w_t L_t^D - \gamma_L^D Y_t^D \right) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{7t} \left(\mu^D r_t^K K_t^D - \left(1 - \gamma_L^D\right) Y_t^D \right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{8t} \left(Y_t - C_t - K_{t+1} + (1-\delta) K_t - G_t \right) \\
& + \Gamma \left[\sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \varphi^L L_t^{\eta+1} C_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(\mu^D - 1 \right) (w_t L_t) \right. \\
& \left. + \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} \left(\mu^D - 1 \right) \left(r_{t+1}^K K_{t+1} \right) \right] \qquad (255)
\end{aligned}$$

This step involve finding the first-order conditions of the Lagrangian problem ($\mathcal{L}^c$) with respect to considered variables, which are C_t, L_t, K_{t+1}, Y_t, r_{t+1}, r_t^k, τ_{t+1}^k, τ_t^w, w_t.

The first-order condition with respect to τ_{t+1}^k and τ_t^w show that $\lambda_{2t} = 0, \lambda_{3t} = 0$

Thus, the Ramsey problem is reduced to

$$\begin{aligned}
\mathcal{L}^c &= E_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - \varphi^L \frac{L^{1+\eta}}{1+\eta} \right] \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{4t} \left(\frac{1}{C_t} - \beta r_{t+1} \frac{1}{C_{t+1}} \right) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{5t} \left(Y_t - (A_t L_t)^{\gamma_L} (K_t)^{1-\gamma_L} \right) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{6t} \left(\mu^D w_t L_t^D - \gamma_L^D Y_t^D \right) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{7t} \left(\mu^D r_t^K K_t^D - \left(1 - \gamma_L^D\right) Y_t^D \right) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{8t} \left(Y_t - C_t - K_{t+1} + (1-\delta) K_t - G_t \right) \\
&+ \Gamma \left[\sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \varphi^L L_t^{\eta+1} C_t - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t + \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(\mu^D - 1 \right) (w_t L_t) \right. \\
&\left. + \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} \left(\mu^D - 1 \right) \left(r_{t+1}^K K_{t+1} \right) \right]
\end{aligned} \tag{256}$$

Note: In contrast to λ_t, the Γ is not depended on time.

So, optimality condition implies that

$$\Gamma < 0$$

The detail of all first-order conditions of the Ramsey problem with respect to C_t, L_t, K_{t+1}, Y_t, r_{t+1}, r_t^k, w_t are shown as follows:

The first-order condition with respect to r_{t+1}

$$\frac{d\mathcal{L}^c}{dr_{t+1}} = -\lambda_{4t} \beta \frac{1}{C_{t+1}} = 0 \tag{257}$$

$$\lambda_{4t} = 0 \tag{258}$$

The first-order condition with respect to K_{t+1}

$$\begin{aligned}
\frac{d\mathcal{L}^c}{dK_{t+1}} &= -\lambda_{5t+1} \beta (A_{t+1} L_{t+1})^{\gamma_L} (1-\gamma_L) (K_{t+1})^{-\gamma_L} + \lambda_{7t+1} \beta \mu^D r_{t+1}^K - \lambda_{8t} \\
&\quad + \lambda_{8t+1} \beta (1-\delta) + \Gamma \left(\beta \frac{1}{C_{t+1}} \left(\mu^D - 1 \right) r_{t+1}^K \right) \\
&= 0
\end{aligned} \tag{259}$$

The first-order condition with respect to L_t

$$\frac{d\mathcal{L}^c}{dL_t}\frac{C_t}{w_t} = -(1-\tau_t^w) - \lambda_{5t}\mu^D C_t + \lambda_{6t}\mu^D C_t + \Gamma\left[(\eta+1)(1-\tau_t^w) + \left(\mu^D - 1\right)\right] = 0 \tag{260}$$

The first-order condition with respect to w_t

$$\frac{d\mathcal{L}^c}{dw_t}\frac{1}{L_t} = \lambda_{6t}\mu^D + \Gamma\left(\mu^D - 1\right)\frac{1}{C_t} = 0 \tag{261}$$

The first-order condition with respect to r_t^k

$$\frac{d\mathcal{L}^c}{dr_t^k}\frac{1}{K_t} = \lambda_{7t}\mu^D + \Gamma\left(\mu^D - 1\right)\frac{1}{C_t} = 0 \tag{262}$$

The first-order condition with respect to C_t

$$\frac{d\mathcal{L}^c}{dC_t}C_t = 1 - \lambda_{8t}C_t - \Gamma\frac{Y_t}{C_t}\frac{\left(\mu^D - 1\right)}{\mu^D} = 0 \tag{263}$$

The first-order condition with respect to Y_t

$$\frac{d\mathcal{L}^c}{dY_t} = \lambda_{5t} - \lambda_{6t}\gamma_L^D - \lambda_{7t}\left(1-\gamma_L^D\right) + \lambda_{8t} = 0 \tag{264}$$

The first-order condition show that the λ_t are as follows:

$$\lambda_{6t} = \lambda_{7t} = -\Gamma\frac{\left(\mu^D - 1\right)}{\mu^D}\left(\frac{1}{C_t}\right) \tag{265}$$

$$\lambda_{8t} = \frac{1}{C_t}\left(1 - \Gamma\frac{Y_t}{C_t}\frac{\left(\mu^D - 1\right)}{\mu^D}\right) \tag{266}$$

$$\lambda_{5t} = \frac{1}{C_t}\left(\Gamma\frac{\left(\mu^D - 1\right)}{\mu^D}\left(\frac{Y_t}{C_t} - 1\right) - 1\right) \tag{267}$$

Substituted λ_{5t+1}, λ_{7t}, λ_{8t}, λ_{8t+1} to equation (259) and (260)

$$\frac{dJ}{dK_{t+1}}C_t = \left(1+\Gamma\frac{\left(\mu^D-1\right)}{\mu^D}\left(1-\frac{Y_{t+1}}{C_{t+1}}\right)\right)\beta\mu^D r^K_{t+1}\frac{C_t}{C_{t+1}} - \left(1-\Gamma\frac{Y_t}{C_t}\frac{\left(\mu^D-1\right)}{\mu^D}\right) + \beta\left(1-\delta\right)\left(1-\Gamma\frac{Y_{t+1}}{C_{t+1}}\frac{\left(\mu^D-1\right)}{\mu^D}\right)\frac{C_t}{C_{t+1}} \tag{268}$$

$$\frac{dJ}{dL_t}\frac{C_t}{w_t} = -(1-\tau^w_t)+\mu^D-\Gamma\left(\frac{Y_t}{C_t}-1\right)\left(\mu^D-1\right)+\Gamma\left((\eta+1)(1-\tau^w_t)\right) \tag{269}$$

At steady-state

$$0=\beta\left[\mu^D r^K_{t+1}+(1-\delta)\right]-1+\Gamma\frac{\left(\mu^D-1\right)}{\mu^D}\left[\beta\left(\mu^D r^K_{t+1}-\frac{Y}{C}\left(\mu^D r^K_{t+1}+(1-\delta)\right)\right)+\frac{Y}{C}\right] \tag{270}$$

$$0=-(1-\tau^w_t)+\mu^D+\Gamma(\eta+1)(1-\tau^w_t)-\Gamma\left(\frac{Y}{C}-1\right)\left(\mu^D-1\right) \tag{271}$$

B.7 The simple closed economy model with an imperfectly competitive market and deep habit preferences

B.7.1 Household optimization

Households maximize their utility subject to the budget constraint and capital accumulation dynamics. The households' Lagrangian function,$\mathcal{L}^H$, can be written as

$$\begin{aligned}
\mathcal{L}^H &= E_0 \sum_{t=0}^{\infty} \beta^t \{ [U(X_t) - V(L_t)] \\
&\quad + \rho_t \left(R_{t-1} B_{t-1} + (1-\tau_t^w) W_t L_t + s_{t-1}(q_t + d_t) + \left[1 - \tau_t^k (1-\delta)\right] R_t^k K_{t-1} \right. \\
&\quad \left. - C_t - I_t - B_t - s_t q_t \right) - \lambda_t [X_t - (\theta C_t - \chi C_{t-1})] \\
&\quad + \rho_t Q_t^K \left[(1-\delta) K_{t-1} + I_t - K_t \right] \} \qquad (272)
\end{aligned}$$

, where Q_t^K is the shadow price of capital. The households' decision is derived from the first-order condition with respect to $X_t, C_t, L_t, I_t, B_t, s_t, K_{t+1}$;

$$\begin{aligned}
\frac{\partial \mathcal{L}^H}{\partial X_t} &= U'(X_t) - \lambda_t = 0; \\
\frac{\partial \mathcal{L}^H}{\partial L_t} &= -V'(L_t) + \rho_t (1-\tau_t^w) W_t = 0; \qquad (273) \\
\frac{\partial \mathcal{L}^H}{\partial B_t} &= \beta \rho_{t+1} R_t - \rho_t = 0; \qquad (274) \\
\frac{\partial \mathcal{L}^H}{\partial K_t} &= \beta \rho_{t+1} R_{t+1}^K \left[1 - \tau_{t+1}^k (1-\delta)\right] + \beta \rho_{t+1} (1-\delta) Q_{t+1}^K - \rho_t Q_t^K; \qquad (275) \\
\frac{\partial \mathcal{L}^H}{\partial I_t} &= -\rho_t + \rho_t Q_t^K = 0; \qquad (276) \\
\frac{\partial \mathcal{L}^H}{\partial C_t} &= -\rho_t + \theta \lambda_t - \beta \lambda_{t+1} \chi, \qquad (277) \\
\frac{\partial \mathcal{L}^H}{\partial s_t} &= -\rho_t q_t - \beta \rho_{t+1} (q_{t+1} + d_{t+1}), \qquad (278)
\end{aligned}$$

which imply $Q_t^K = 1$

B.7.2 Implementability constraint

The government's budget constraint can be obtained by combining firms' and households' budget constraints and the market clearance condition equation (116). Following Chari & Kehoe (1999), the period zero household budget constraint is replaced by the discounted sum of the financial constraints that the representative household will face in the future. Then, fiscal variables such as tax rates and government debt will be eliminated by using the households' first-order conditions. This process derives the generalized budget implementability constraint for an economy with deep habit formation. The implementability constraint relates to a household's initial assets to the discounted sum of marginal utilities. All households' intertemporal budget constraints become redundant as they will only solve for the future value of government debt.

Recall that the household budget constraint is

$$C_t + I_t + B_t + q_t = R_{t-1}B_{t-1} + (1-\tau_t^w)W_tL_t + \left[1-(1-\delta)\,\tau_t^k\right] R_t^K K_{t-1} + (q_t + d_t)$$

The above equation is discounted with a market discount and integrated forward.

$$\begin{aligned} & \sum_{t=0}^{\infty}\beta^t\rho_t C_t + \sum_{t=0}^{\infty}\beta^t\rho_t I_t + \sum_{t=0}^{\infty}\beta^t\rho_t B_t + \sum_{t=0}^{\infty}\beta^t\rho_t q_t \\ = \; & \sum_{t=0}^{\infty}\beta^t\rho_t R_{t-1}B_{t-1} + \sum_{t=0}^{\infty}\beta^t\rho_t(1-\tau_t^w)W_tL_t + \sum_{t=0}^{\infty}\beta^t\rho_t\left[1-(1-\delta)\,\tau_t^k\right] R_t^k K_{t-1} \\ & + \sum_{t=0}^{\infty}\beta^t\rho_t\,(q_t+d_t) \end{aligned}$$

Firstly, considering the Euler equation $\rho_t = E_t\beta R_t\rho_{t+1}$, which implies

$$\begin{aligned} E_0\sum_{t=0}^{\infty}\beta^t\rho_t B_t - E_0\sum_{t=0}^{\infty}\beta^t\rho_t R_{t-1}B_{t-1} &= E_0\sum_{t=0}^{\infty}\beta^t B_t\left(\rho_t - E_t\beta R_t\rho_{t+1}\right) - \rho_0 R_{-1}B_{-1} \\ &= -\rho_0 R_{-1}B_{-1} \end{aligned}$$

Secondly, using the Euler equation for shares, consider equation (105), which implies that

$$\sum_{t=0}^{\infty}\beta^t\rho_t\,(q_t+d_t) = \rho_0\,(q_0+d_0) + \sum_{t=0}^{\infty}\beta^{t+1}\rho_{t+1}\,(q_{t+1}+d_{t+1}) = \rho_0\,(q_0+d_0) + \sum_{t=0}^{\infty}\beta^t\rho_t q_t$$

Thirdly, using the households' FOC with respect to capital , consider equation

(102)

$$\begin{aligned}
&\sum_{t=0}^{\infty} \beta^t \rho_t \left[1 - (1-\delta)\tau_t^k\right] R_t^k K_t \\
= \quad & \rho_0 \left[1 - (1-\delta)\tau_0^k\right] R_0^k K_0 + \sum_{t=0}^{\infty} \beta^t \beta \rho_{t+1} \left[1 - (1-\delta)\tau_{t+1}^k\right] R_{t+1}^k K_{t+1} \\
= \quad & \rho_0 \left[1 - (1-\delta)\tau_0^k\right] R_0^k K_0 + \sum_{t=0}^{\infty} \beta^t \left[\rho_t - \beta(1-\delta)\rho_{t+1}\right] K_{t+1} \\
= \quad & \rho_0 \left[1 - (1-\delta)\tau_0^k\right] R_0^k K_0 + (1-\delta)\rho_0 K_0 + \sum_{t=0}^{\infty} \beta^t \rho_t \left[K_{t+1} - (1-\delta) K_t\right].
\end{aligned}$$

Finally, the study utilizes the capital accumulation equation, equation (5), and labour supply, equation (103), to obtain the final expression

$$\sum_{t=0}^{\infty} \beta^t \rho_t C_t - \sum_{t=0}^{\infty} \beta^t V'(L_t) L_t = \rho_0 A_0, \tag{279}$$

, where A_0 denotes the initial assets. $A_0 = \left[1 + \left(1 - \tau_0^k\right)(1-\delta) R_0^k\right] K_0 + R_{-1} B_{-1} + (q_0 + d_0)$

Finally, the expression for profit, $\Pi_t = (1 - mc_t) Y_t$ is combined with first-order conditions.

B.8 Proof of proposition 4

The Lagrangian form for the Ramsey problem is

$$\begin{aligned}
J &= E_0 \sum_{t=0}^{\infty} \beta^t \{U(X_t) - V(L_t)\} \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{1t} (Y_t - C_t - (K_{t+1} - (1-\delta) K_t) - G_t) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{2t} \left(\rho_t - \beta E_t \rho_{t+1} \left[\left[1 - \tau_t^k (1-\delta)\right] R_t^k + (1-\delta)\right]\right) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{3t} ((1-\tau_t^w)\rho_t w_t - V'(L_t)) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{4t} \left(\rho_t - \beta R_t \rho_{t+1}\right) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{5t} \left((A_t L_t)^{1-\gamma} (K_t)^{\gamma} - Y_t\right) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{6t} (w_t L_t - (1-\gamma) mc_t Y_t) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{7t} \left(R_t^K K_t - \gamma mc_t Y_t\right) \\
&+ E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{8t} (\rho_t - \theta U'(X_t) + \beta \chi U'(X_{t+1})) + E_0 \sum_{t=0}^{\infty} \beta^t \lambda_{9t} (-X_t + \theta C_t - \chi C_{t-1},) \\
&+ \Gamma E_0 \left[\rho_0 A_0 - \left(\sum_{t=0}^{\infty} \beta^t \rho_t C_t + \sum_{t=0}^{\infty} \beta^t V'(L_t) L_t\right)\right].
\end{aligned}$$

The first-order conditions of J with respect to $R_t, \tau_{t+1}^k, \tau_t^w, w_t, R_t^K$ suggest that $\lambda_{2t} = 0$, $\lambda_{3t} = 0$, $\lambda_{4t} = 0$, $\lambda_{6t} = 0$, $\lambda_{7t} = 0$.

The first-order conditions are

$$\beta^{-t} \frac{dJ}{dC_t} = -\lambda_{1t} + \lambda_{9t}\theta - \chi\beta\lambda_{9t+1} - \Gamma\rho_t = 0 \tag{280}$$

$$\beta^{-t} \frac{dJ}{dX_t} = U'(X_t) - \lambda_{8t}\theta U''(X_t) + \lambda_{8t-1}\chi U''(X_t) - \lambda_{9t} \tag{281}$$

$$\beta^{-t} \frac{dJ}{d\rho_t} = \lambda_{8t} - \Gamma C_t = 0 \tag{282}$$

$$\beta^{-t} \frac{dJ}{dY_t} = \lambda_{1t} - \lambda_{5t} = 0 \tag{283}$$

$$\beta^{-t} \frac{dJ}{dL_t} = -V'(L_t) + \lambda_{5t}\gamma \frac{Y_t}{L_t} - \Gamma\left[V'(L_t) + V''(L_t) L_t\right] \tag{284}$$

$$\beta^{-t}\frac{dJ}{dK_{t+1}} = -\lambda_{1t} + (1-\delta)\beta E_t\lambda_{1t+1} + E_t\lambda_{5t+1}\beta(1-\gamma)\frac{Y_{t+1}}{K_{t+1}} \tag{285}$$

The study substitutes for $\lambda_{5t+1} = \lambda_{1t+1}$; $\lambda_{8t} = \Gamma C_t$, which reduces equation (281) to $\lambda_{9t} = U'(X_t) - \Gamma U''(X_t)X_t$. The last equations (284) and (285) are combined with the firms' demand for capital (equation (108)) and labour demand (equation (107)).

$$\begin{aligned}
\lambda_{1t} &= \theta\left(U'(X_t) - \Gamma U''(X_t)X_t\right) - E_t\beta\chi\left(U'(X_{t+1}) - \Gamma U''(X_{t+1})X_{t+1}\right) - \Gamma\rho_t \\
&= 0; && (286)\\
V'(L_t) &= \lambda_{1t}\frac{w_t}{mc_t} - \Gamma\left[V'(L_t) + V''(L_t)L_t\right]; && (287)\\
\lambda_{1t} &= E_t\lambda_{1t+1}\beta\left((1-\delta) + \frac{1}{mc_{t+1}}R^K_{t+1}\right); && (288)
\end{aligned}$$

Recalling equation (101) and considering the CRRA form of utility function, let $U''(X_t)X_t = -\sigma U'(X_t)$; and $V''(L_t)L_t = vV'(L_t)$. Then, the equations (286), (287), and (288) can be written as

$$\begin{aligned}
\lambda_{1t} &= \rho_t\left(1 + (\sigma-1)\Gamma\right); && (289)\\
V'(L_t)\left[1 + (1+v)\Gamma\right] &= \rho_t\left(1 + (\sigma-1)\Gamma\right)\frac{1}{mc_t}w_t; && (290)\\
\rho_t &= \beta E_t\rho_{t+1}\left((1-\delta) + \frac{1}{mc_{t+1}}R^K_{t+1}\right); && (291)
\end{aligned}$$

The combination of equation (290) and (291) with equation (102) and (103) defines the optimal tax rate.

$$\begin{aligned}
\tau^k_{t+1} &= \left(1 - \frac{1}{mc_{t+1}}\right)\frac{1}{1-\delta}\\
(1-\tau^w_t) &= \frac{1-(1-\sigma)\Gamma}{1+(1+v)\Gamma}\frac{1}{mc_t}
\end{aligned}$$

, where Γ is the shadow price of the budget constraint. If lump-sum taxes are available, $\Gamma = 0$, the optimal policy is a subsidy to labour $(1-\tau_t^w) = \frac{1}{mc_t}$.

B.9 The small-open economy model

Using equation (142) and (143), the ratio of domestic output to export output is

$$\begin{aligned}\frac{Y_t^D}{p^X Y_t^X} &= \frac{(C_t+I_t+G_t)\left(p^D\right)^{-\frac{1}{1-\theta}}}{s^{\frac{-1}{1-\theta}} p^M \left(C+I_t+G_{t,}\right)\left(p_t^M\right)^{-\frac{1}{1-\theta}}} \\ \frac{Y_t^X}{Y_t^D} &= s^{\frac{-1}{1-\theta}} \frac{p^M}{p^X}\left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}} \qquad (292)\end{aligned}$$

Using equation (127) and (130), the ratio of domestic firms labour demand to export firms labour demand is

$$\frac{L_t^X}{L_t^D} = \frac{\mu^D}{\mu^X}\left(\frac{sp_t^M}{p^D}\right)^{-\frac{\theta}{1-\theta}} \frac{\gamma_L^X}{\gamma_L^D} = \Lambda_{LXD,t}\left(s\right) \qquad (293)$$

Using equation (128) and (131), the ratio of domestic firms capital demand to export firms capital demand is

$$\frac{K_t^X}{K_t^D} = \frac{\mu^D}{\mu^X}\frac{\left(1-\gamma_L^X\right)}{\left(1-\gamma_L^D\right)}\left(\frac{sp_t^M}{p^D}\right)^{-\frac{\theta}{1-\theta}} = \Lambda_{KXD,t}\left(s\right) \qquad (294)$$

Using equation (126), (129), and (292), the ratio of export price to import price is

$$p_t^M\left(\frac{sp_t^M}{p^D}\right)^{-\frac{1}{1-\theta}} = \frac{p^X(A_t L_t^X)^{\gamma_L^X}(K_t^X)^{1-\gamma_L^X}}{(A_t L_t^D)^{\gamma_L^D}(K_t^D)^{1-\gamma_L^D}} \qquad (295)$$

Considering a simple case when $\frac{\gamma_L^X}{\gamma_L^D} = 1$, the ratio of domestic firms' labour demand to export firms' labour demand, and the ratio of domestic firms capital demand to export firms capital demand, the ratio of export price to import price and the aggregate price is reduced to

$$s = \frac{p^D}{p^X} \qquad (296)$$

$$\begin{aligned}\frac{L_t^X}{L_t^D} &= \left(\frac{sp_t^M}{p^D}\right)^{-\frac{\theta}{1-\theta}} \\ \frac{L_t^X}{L_t^D} &= \left(\frac{p^X}{p_t^M}\right)^{\frac{\theta}{1-\theta}}\end{aligned} \tag{297}$$

$$\begin{aligned}\frac{K_t^X}{K_t^D} &= \left(\frac{sp_t^M}{p^D}\right)^{-\frac{\theta}{1-\theta}} \\ \frac{K_t^X}{K_t^D} &= \left(\frac{p^X}{p_t^M}\right)^{\frac{\theta}{1-\theta}}\end{aligned} \tag{298}$$

$$\left(p^D\right)^{\frac{\theta}{1-\theta}} = 1 + \left(\frac{p^X}{p^M}\right)^{\frac{\theta}{1-\theta}} \tag{299}$$

Considering a simple case when $\frac{\gamma_L^X}{\gamma_L^D} = 1$

$$\begin{aligned}\left(p^D\right)^{-\frac{\theta}{1-\theta}} &= 1 - \left(sp^M\right)^{-\frac{\theta}{1-\theta}} \\ \left(p^D\right)^{\frac{\theta}{1-\theta}} &= 1 + \left(\frac{p^X}{p^M}\right)^{\frac{\theta}{1-\theta}}\end{aligned}$$

Using $\left(p^D\right)^{\frac{\theta}{1-\theta}} = 1 + \left(\frac{p^X}{p^M}\right)^{\frac{\theta}{1-\theta}}$, the capital accumulation equation can be rewritten as

$$I_{t,} = \left(p^D\right)^{\frac{\theta}{1-\theta}} K_{t+1}^D - (1-\delta)\left(p^D\right)^{\frac{\theta}{1-\theta}} K_t^D \tag{300}$$

The government budget constraint is

$$d_t = r_t d_{t-1} + G_t - \tau_t^w w_t L_t - (1-\delta)\,\tau_t^k r_t^K K_t \tag{301}$$

The household budget constraint, equation (121), can be rewritten in the implementability constraint form as below (See details in Appendix B.10)

$$\begin{aligned} & A_0 - \frac{1}{1-\beta} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu}\right) \\ = & \; 0 \end{aligned}$$

, where $A_0 = \frac{1}{C_0} R_{-1} d_{-1} + \frac{1}{C_0} \left(\left[1 - (1-\delta) \tau_0^k\right] r_0^k - \beta (1-\delta)\right) \left(K_1^D + K_1^X\right)$

Substituting equation (292).

$$\begin{aligned} & A_0 - \frac{1}{1-\beta} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \left[1 + s^{\frac{-1}{1-\theta}} \frac{p^M}{p^D} \left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}}\right] \\ = & \; 0 \end{aligned} \tag{302}$$

B.10 The implementability constraint of the small-open economy model with price markup

The households budget constraint (121) can be rewritten in the implementability constraint form as below:

Applying the $E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t}$ operator to the households budget constraint

$$\begin{aligned} & -E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t - E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} I_t - E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} d_t \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} R_{t-1} d_{t-1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (1 - \tau_t^w) w_t \left(L_t^D + L_t^X\right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left[1 - (1-\delta) \tau_t^k\right] r_t^k \left(K_t^D + K_t^X\right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu}\right) \\ = & \; 0 \end{aligned} \tag{303}$$

Analyzing the term $E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} R_{t-1} d_{t-1}$ and applying the Euler equation $\frac{1}{C_t} = \beta R_t \frac{1}{C_{t+1}}$

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} R_{t-1} d_{t-1} &= \frac{1}{C_0} R_{-1} d_{-1} + E_0 \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{C_{t+1}} R_t d_t \\ &= \frac{1}{C_0} R_{-1} d_{-1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} d_t \end{aligned} \tag{304}$$

Substituting above equation

$$\begin{aligned} & -E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t - E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} I_t \\ & + \frac{1}{C_0} R_{-1} d_{-1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (1 - \tau_t^w) w_t \left(L_t^D + L_t^X \right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left[1 - (1 - \delta) \tau_t^k \right] r_t^k \left(K_t^D + K_t^X \right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu} \right) + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu} \right) \\ = \;& 0 \end{aligned} \tag{305}$$

Substituting labour supply condition, $(1 - \tau_t^w) w_t \frac{1}{C_t} = \varphi^L \left(L_t^D + L_t^X \right)^{\eta}$

$$\begin{aligned} & -E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t - E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} I_t \\ & + \frac{1}{C_0} R_{-1} d_{-1} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X \right)^{\eta+1} \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left[1 - (1 - \delta) \tau_t^k \right] r_t^k \left(K_t^D + K_t^X \right) \\ & + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu} \right) + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu} \right) \\ = \;& 0 \end{aligned} \tag{306}$$

Considering the term $\sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} I_t$ and applying a dynamics capital accumulation, $K_{t+1}^D + K_{t+1}^X - (1 - \delta) \left(K_t^D + K_t^X \right) = I_t$,

$$\sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} I_t = \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left(K_{t+1}^D + K_{t+1}^X \right) - \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (1 - \delta) \left(K_t^D + K_t^X \right) \tag{307}$$

Using the FOC for interest rate

$$
\begin{aligned}
1 &= \beta E_t \frac{C_t}{C_{t+1}} \left[\left[1 - (1-\delta)\,\tau_{t+1}^k \right] r_{t+1}^K + (1-\delta) \right] \\
\frac{1}{\beta}\frac{1}{C_t} - E_t \frac{1}{C_{t+1}} (1-\delta) &= E_t \frac{1}{C_{t+1}} \left[\left[1 - (1-\delta)\,\tau_{t+1}^k \right] r_{t+1}^K \right] \qquad (308)
\end{aligned}
$$

Substituting the FOC for interest rate

$$
\begin{aligned}
& E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} \left[1 - (1-\delta)\,\tau_t^k \right] r_t^k \left(K_t^D + K_t^X \right) \\
= & \frac{1}{C_0} \left(\left[1 - (1-\delta)\,\tau_0^k \right] r_0^k - \beta (1-\delta) \right) \left(K_1^D + K_1^X \right) + E_0 \sum_{t=0}^{\infty} \beta^{t+1} \frac{1}{\beta} \frac{1}{C_t} \left(K_{t+1}^D + K_{t+1}^X \right) \\
& - E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} (1-\delta) \left(K_t^D + K_t^X \right) \qquad (309)
\end{aligned}
$$

Combining above term to the households budget constraint

$$
\begin{aligned}
& -E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} C_t \\
& + \frac{1}{C_0} R_{-1} d_{-1} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X \right)^{\eta+1} \\
& + \frac{1}{C_0} \left(\left[1 - (1-\delta)\,\tau_0^k \right] r_0^k - \beta (1-\delta) \right) \left(K_1^D + K_1^X \right) \qquad (310) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu} \right) + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu} \right) \\
= & \; 0 \qquad (311)
\end{aligned}
$$

Defining A_0

$$
A_0 = \frac{1}{C_0} R_{-1} d_{-1} + \frac{1}{C_0} \left(\left[1 - (1-\delta)\,\tau_0^k \right] r_0^k - \beta (1-\delta) \right) \left(K_1^D + K_1^X \right) \qquad (312)
$$

Finally, the implementability constraint is as follows:

$$\begin{aligned}
& A_0 - \frac{1}{1-\beta} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^X Y^X \left(1 - \frac{1}{\mu}\right) \\
= \; & 0 \qquad (313)
\end{aligned}$$

Substituting equation (292).

$$\begin{aligned}
& A_0 - \frac{1}{1-\beta} + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} \\
& + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \left[1 + s^{\frac{-1}{1-\theta}} \frac{p^M}{p^D} \left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}}\right] \\
= \; & 0 \qquad (314)
\end{aligned}$$

B.11 Lagrangian form of the Ramsey problem and the first-order condition of the small-open economy model

The Lagrangian form of the Ramsey problem ($\mathcal{L}^o$) is presented as follows:

$$\begin{aligned}
\mathcal{L}^o = \; & E_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - \varphi^L \frac{\left(L_t^D + L_t^X\right)^{1+\eta}}{1+\eta}\right] \\
& + \Gamma \left[-\frac{1}{1-\beta} + A_0 + E_0 \sum_{t=0}^{\infty} \beta^t \varphi^L \left(L_t^D + L_t^X\right)^{\eta+1} \right. \\
& \left. + E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{C_t} p^D Y_t^D \left(1 - \frac{1}{\mu}\right) \left(1 + s^{\frac{-1}{1-\theta}} \frac{p_t^M}{p^D} \left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}}\right)\right] \\
& + \lambda_{1,t} E_0 \sum_{t=0}^{\infty} \beta^t \left(-Y_t^D + (A_t L_t^D)^{\gamma_L^D} (K_t^D)^{1-\gamma_L^D}\right) \\
& + \lambda_{2,t} E_0 \sum_{t=0}^{\infty} \beta^t \left[Y_t^D - \left(C_t + \left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} K_{t+1}^D - (1-\delta) \left(p_t^D\right)^{\frac{\theta}{1-\theta}} K_t^D + G_t\right) \left(p_t^D\right)^{-\frac{1}{1-\theta}}\right]
\end{aligned} \qquad (315)$$

(The differentiate with respect to taxes, τ_{t+1}^{k} and τ_t^w, R_t, w_t, and r_t^K implies that those multipliers are zero. Therefore, the restricted system is reduced as above)

The detail of all first-order conditions of the Ramsey problem with respect to K_t^D, Y_t^D, C_t, and L_t^D are shown as follows:

The first-order condition with respect to Y_t^D

$$\beta^{-t}\frac{\partial \mathcal{L}^o}{\partial Y_t^D} = \Gamma\frac{1}{C_t}p_t^D\left(1-\frac{1}{\mu}\right)\left(1+s^{\frac{-1}{1-\theta}}\frac{p_t^M}{p^D}\left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}}\right)-\lambda_{1,t}+\lambda_{2,t}=0 \quad (316)$$

The first-order condition with respect to K_t^D

$$\begin{aligned}\beta^{-t}\frac{\partial \mathcal{L}^o}{\partial K_{t+1}^D} &= \beta\lambda_{1,t+1}\left(1-\gamma_L^D\right)\frac{Y_{t+1}^D}{K_{t+1}^D}-\lambda_{2,t}\left(p_t^D\right)^{-\frac{1}{1-\theta}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} \\ &\quad +(1-\delta)\,\beta\lambda_{2,t+1}\left(p_{t+1}^D\right)^{-\frac{1}{1-\theta}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} \\ &= 0 \end{aligned} \quad (317)$$

The first-order condition with respect to C_t

$$\begin{aligned}\beta^{-t}\frac{\partial \mathcal{L}^o}{\partial C_t} &= \frac{1}{C_t}-\Gamma\frac{1}{C_t^2}p^DY_t^D\left(1-\frac{1}{\mu}\right)\left(1+s^{\frac{-1}{1-\theta}}\frac{p_t^M}{p^D}\left(\frac{p_t^M}{p^D}\right)^{-\frac{1}{1-\theta}}\right)-\lambda_{2,t}\left(p_t^D\right)^{-\frac{1}{1-\theta}} \\ &= 0\end{aligned} \quad (318)$$

The first-order condition with respect to L_t^D

$$\begin{aligned}\beta^{-t}\frac{\partial \mathcal{L}^o}{\partial L_t^D} &= -\varphi^L\left(L_t^D+L_t^X\right)^\eta+\Gamma\varphi^L(\eta+1)\left(L_t^D+L_t^X\right)^\eta+\lambda_{1,t}\left(\frac{\gamma_L^D}{L_t^D}(A_tL_t^D)^{\gamma_L^D}(K_t^D)^{1-\gamma_L^D}\right) \\ &= 0\end{aligned} \quad (319)$$

$$\Gamma=\frac{1}{(\eta+1)}\left[1-\lambda_{1,t}\frac{\gamma_L^D(A_tL_t^D)^{\gamma_L^D}(K_t^D)^{1-\gamma_L^D}}{\varphi^L\left(L_t^D+L_t^X\right)^\eta L_t^D}\right] \quad (320)$$

B.12 The small-open economy with perfectly competitive market

Proof. When $\mu^D = 1$, equation, the equation (316), (317), and (318) are reduced to

$$\lambda_1 = \lambda_2 \tag{321}$$

$$\begin{aligned} \beta^{-t}\frac{\partial L}{\partial K_{t+1}^D} &= \beta\lambda_{2,t+1}\left(1-\gamma_L^D\right)\frac{Y_{t+1}^D}{K_{t+1}^D} - \lambda_{2,t}\left(p_t^D\right)^{-\frac{1}{1-\theta}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} + (1-\delta)\,\beta\lambda_{2,t+1}\left(p_{t+1}^D\right)^{-1} \\ &= 0 \end{aligned} \tag{322}$$

$$\lambda_{2,t} = \frac{1}{C_t}\left(p_t^D\right)^{\frac{1}{1-\theta}} \tag{323}$$

Substituting $\mu r_t^K K_t^D = p_t^D\left(1-\gamma_L^D\right)Y_t^D$

$$\beta^{-t}\frac{\partial L}{\partial K_{t+1}^D} = \beta\frac{1}{C_{t+1}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} r_{t+1}^K - \frac{1}{C_t}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} + (1-\delta)\,\beta\frac{1}{C_{t+1}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} = 0 \tag{324}$$

Therefore, the optimal condition for interest rate is

$$r_{t+1}^K = \frac{C_{t+1}}{\beta C_t}\left[1-(1-\delta)\,\beta\frac{C_t}{C_{t+1}}\right] \tag{325}$$

Using $1 = \beta E_t\frac{C_t}{C_{t+1}}\left[\left[1-(1-\delta)\,\tau_{t+1}^k\right]r_{t+1}^K + (1-\delta)\right]$ to find the optimal capital tax

$$\begin{aligned} \frac{C_{t+1}}{\beta C_t} - (1-\delta) &= \left[1-(1-\delta)\,\tau_{t+1}^k\right]\frac{C_{t+1}}{\beta C_t}\left[1-(1-\delta)\,\beta\frac{C_t}{C_{t+1}}\right] \\ \tau_{t+1}^k &= 0 \end{aligned} \tag{326}$$

When lump-sum transfer is allowed ($\Gamma = 0$), the first-order condition with respect to L_t^D is reduced to

$$1 = \lambda_{1,t}\frac{\gamma_L^D(A_t L_t^D)^{\gamma_L^D}(K_t^D)^{1-\gamma_L^D}}{\varphi^L\left(L_t^D + L_t^X\right)^{\eta}L_t^D} \tag{327}$$

Using $\frac{(1-\tau_t^w)w_t}{\varphi^L C_t} = \left(L_t^D + L_t^X\right)^\eta$ to find the optimal payroll tax

$$\begin{aligned}(1-\tau_t^w)w_t L_t^D &= \lambda_{1,t} C_t \gamma_L^D (A_t L_t^D)^{\gamma_L^D} (K_t^D)^{1-\gamma_L^D} \\ (1-\tau_t^w)w_t L_t^D &= \left(p_t^D\right)^{\frac{1}{1-\theta}} \gamma_L^D (A_t L_t^D)^{\gamma_L^D} (K_t^D)^{1-\gamma_L^D} \end{aligned} \tag{328}$$

Substituting $w_t L_t^D = \frac{\gamma_L^D Y_t^D}{\mu^D}$, $\mu^D = 1$, and $p_t^D = 1$

$$\begin{aligned}(1-\tau_t^w)\frac{\gamma_L^D Y_t^D}{\mu^D} &= \left(p_t^D\right)^{\frac{1}{1-\theta}} \gamma_L^D Y_t^D \\ \tau_t^w &= 0\end{aligned} \tag{329}$$

■

B.13 The small-open economy with an imperfectly competitive market and lump-sum transfers

Proof. When $\Gamma = 0$, equation, the equation (316), (317), and (318) are reduced to

$$\lambda_1 = \lambda_2 \tag{330}$$

$$\begin{aligned}\beta^{-t}\frac{\partial L}{\partial K_{t+1}^D} &= \beta\lambda_{2,t+1}\left(1-\gamma_L^D\right)\frac{Y_{t+1}^D}{K_{t+1}^D} - \lambda_{2,t}\left(p_t^D\right)^{-\frac{1}{1-\theta}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} + (1-\delta)\,\beta\lambda_{2,t+1}\left(p_{t+1}^D\right)^{-1} \\ &= 0\end{aligned} \tag{331}$$

$$\lambda_{2,t} = \frac{1}{C_t}\left(p_t^D\right)^{\frac{1}{1-\theta}} \tag{332}$$

Substituting $\mu^D r_t^K K_t^D = p_t^D\left(1-\gamma_L^D\right)Y_t^D$ to $\frac{\partial L}{\partial K_{t+1}^D}$

$$\beta^{-t}\frac{\partial L}{\partial K_{t+1}^D} = \beta\frac{1}{C_{t+1}}\mu^D\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} r_{t+1}^K - \frac{1}{C_t}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} + (1-\delta)\,\beta\frac{1}{C_{t+1}}\left(p_{t+1}^D\right)^{\frac{\theta}{1-\theta}} = 0$$

Therefore, the optimal condition for interest rate is

$$\begin{aligned} 0 &= \beta r^K_{t+1} \frac{C_t}{C_{t+1}} \mu^D \left(p^D_{t+1}\right)^{\frac{\theta}{1-\theta}} - \left(p^D_{t+1}\right)^{\frac{\theta}{1-\theta}} + (1-\delta)\,\beta \frac{C_t}{C_{t+1}} \left(p^D_{t+1}\right)^{\frac{\theta}{1-\theta}} \\ r^K_{t+1} &= \frac{C_{t+1}}{\mu^D \beta C_t} \left[1 - (1-\delta)\,\beta \frac{C_t}{C_{t+1}}\right] \end{aligned} \tag{333}$$

Using $1 = \beta E_t \frac{C_t}{C_{t+1}} \left[\left[1-(1-\delta)\,\tau^k_{t+1}\right] r^K_{t+1} + (1-\delta)\right]$ to find the optimal capital tax

$$\begin{aligned} 1 &= \beta E_t \frac{C_t}{C_{t+1}} \left[\left[1-(1-\delta)\,\tau^k_{t+1}\right] r^K_{t+1} + (1-\delta)\right] \\ \frac{C_{t+1}}{\beta C_t} - (1-\delta) &= \left[1-(1-\delta)\,\tau^k_{t+1}\right] \frac{C_{t+1}}{\mu^D \beta C_t} \left[1-(1-\delta)\,\beta \frac{C_t}{C_{t+1}}\right] \\ \tau^k_{t+1} &= \frac{1-\mu^D}{(1-\delta)} < 0 \end{aligned} \tag{334}$$

Since $\mu^D > 1$ and $\delta < 1$, thus $\tau^k_{t+1} < 0$. When lump-sum transfer is allowed ($\Gamma = 0$), the first-order condition with respect to L^D_t is reduced to

$$1 = \lambda_{1,t} \frac{\gamma^D_L (A_t L^D_t)^{\gamma^D_L} (K^D_t)^{1-\gamma^D_L}}{\varphi^L \left(L^D_t + L^X_t\right)^\eta L^D_t} \tag{335}$$

Using $\frac{(1-\tau^w_t) w_t}{\varphi^L C_t} = \left(L^D_t + L^X_t\right)^\eta$ to find the optimal payroll tax

$$\begin{aligned} (1-\tau^w_t) w_t L^D_t &= \lambda_{1,t} C_t \gamma^D_L (A_t L^D_t)^{\gamma^D_L} (K^D_t)^{1-\gamma^D_L} \\ (1-\tau^w_t) w_t L^D_t &= \left(p^D_t\right)^{\frac{1}{1-\theta}} \gamma^D_L (A_t L^D_t)^{\gamma^D_L} (K^D_t)^{1-\gamma^D_L} \end{aligned} \tag{336}$$

Substituting $w_t L^D_t = \frac{\gamma^D_L Y^D_t}{\mu^D}$

$$\begin{aligned} (1-\tau^w_t) \frac{\gamma^D_L Y^D_t}{\mu^D} &= \left(p^D_t\right)^{\frac{1}{1-\theta}} \gamma^D_L Y^D_t \\ \tau^w_t &= 1 - \mu^D \end{aligned} \tag{337}$$

Since $\mu^D > 1$, and $p^D_t = 1$, thus $\tau^w_t < 0$. ■

C APPENDIX: Government spending on health and economic growth

C.1 Unit root test of health model

This paper employs Fisher type unit root tests to examine the stationarity of all variables. The advantage of Fisher type unit root tests is that they do not require strongly balanced data and gaps in series are allowed.

The null hypothesis of the unit root test is

H_o	All panels contain unit roots
H_a	At least one panel is stationary

In order to remove a cross-sectional correlation, the option "demean"[28] is added to the unit root analysis. The cross-sectional correlation usually appears in a group of countries that share similar characteristics (Levin, Lin & Chu 2002). In addition, the unit root test command also includes the "drift" option for non-zero variables and uses 8 lags in ADF regressions. According to Choi (2001), the most useful statistic result of unit root test is the inverse normal Z statistic. It provides the best trade-off between the influence and magnitude of variables. Therefore, this paper selects the inverse normal Z statistic as a unit root test statistic.

The unit root test results for the life expectancy regression, infant mortality regression and under-five mortality regression are in Table 19, 20, and 21.

C.2 Unit root test of production function model

The unit root test results for the production function model are shown in Table 22. Most OECD countries have increasing trends in life expectancy, except for Estonia and Latvia, which show lower life expectancy during the 1990-1994 period after their independence from the Soviet Union.

[28] "demean" is the option of xtunitroot command in STATA.

Table 19: The results of unit root test of life expectancy regression; Inverse normal Z

	FE , $FE^{(2)}$, RE , $RE^{(2)}$	2SLS FE, 2SLS RE
life	-1.27*	-1.06
	(0.10)	(0.14)
govhealth	1.19	0.89
	(0.88)	(0.81)
gov		-1.93**
		(0.03)
govdef		-0.91
		(0.18)
govedu		-0.46
		(0.32)
govpub		-1.90**
		(0.03)
gdpcap	-1.92**	-1.06
	(0.03)	(0.14)
sani	-2.36***	-3.44***
	(0.01)	(0.00)
phealthgdp	-1.95**	-1.82**
	(0.03)	(0.03)

p-values are shown in parentheses.

*Indicates that at least one panel is stationary at the 10% level

**Indicates that at least one panel is stationary at the 5% level

***Indicates that at least one panel is stationary at the 1% level

Table 20: The results of unit root test of infant mortality regression; Inverse normal Z

	FE, RE	2SLS FE, 2SLS RE
mortainf	-8.21***	-8.26***
	(0.00)	(0.00)
govhealth	-6.95***	-7.20***
	(0.00)	(0.00)
gov		-5.94***
		(0.00)
govdef		-4.99***
		(0.00)
govedu		-6.20***
		(0.00)
govpub		-6.10***
		(0.00)
gdpcap	-5.76***	-5.93***
	(0.00)	(0.00)
sani	-9.90***	-11.98***
	(0.00)	(0.00)
phealthgdp	-8.14***	-8.07***
	(0.00)	(0.00)

p-values are shown in parentheses

*Indicates that at least one panel is stationary at the 10% level.

**Indicates that at least one panel is stationary at the 5% level.

***Indicates that at least one panel is stationary at the 1% level.

Table 21: The results of unit root test of under-five mortality regression; Inverse normal Z

	FE, RE	2SLS FE, 2SLS RE
mortaunder5	-8.51***	-10.81***
	(0.00)	(0.00)
govhealth	-6.95***	-7.77***
	(0.00)	(0.00)
gov		-6.45***
		(0.00)
govdef		-5.52***
		(0.00)
govedu		-5.58***
		(0.00)
govpub		-6.01***
		(0.00)
gdpcap	-5.76***	-5.93***
	(0.00)	(0.00)
sani	-9.90***	-9.09***
	(0.00)	(0.00)
phealthgdp	-8.14***	-7.99***
	(0.00)	(0.00)

p-values are shown in parentheses.

*Indicates that at least one panel is stationary at the 10% level.

**Indicates that at least one panel is stationary at the 5% level.

***Indicates that at least one panel is stationary at the 1% level.

Table 22: The results of unit root test of production function model; Inverse normal Z

	Global	Developed countries	Developing countries	OECD countries
gdp	-18.03***	-6.98***	-15.95***	-5.89***
	(0.00)	(0.00)	(0.00)	(0.00)
capital	-14.52***	-5.74***	-14.50***	-4.38***
	(0.00)	(0.00)	(0.00)	(0.00)
labour	-16.56***	-8.26***	-14.76***	-8.51***
	(0.00)	(0.00)	(0.00)	(0.00)
life	-16.61***	-8.46***	-12.96***	-7.26***
	(0.00)	(0.00)	(0.00)	(0.00)
sugar				-6.15***
				(0.00)
fat				-5.92***
				(0.00)
alcohol				-6.28***
				(0.00)
tabocco				-5.76***
				(0.00)

p-values are shown in parentheses[29].

*Indicates that at least one panel is stationary at the 10% level.

**Indicates that at least one panel is stationary at the 5% level.

***Indicates that at least one panel is stationary at the 1% level.

C.3 Descriptive statistics

The descriptive statistics for the health model and the production function with the human capital model are shown in Table 23, 24, 25, 26, and 27.

Table 23: Descriptive statistics of health model

Variable		Mean	Std. Dev.	Min	Max	Observations
elect	overall	73.87	32.01	-	100.00	N = 847
	between		31.44	1.64	100.00	n = 211
	within		6.38	- 4.53	95.00	T = 4.01422
gov	overall	38.28	11.17	11.32	85.26	N = 1209
	between		10.15	16.38	62.51	n = 90
	within		4.16	2.84	65.27	T = 13.4333
govdef	overall	1.91	2.70	-	39.57	N = 956
	between		2.87	-	23.32	n = 70
	within		1.29	- 19.56	18.16	T = 13.6571
govedu	overall	5.12	1.56	-	12.35	N = 964
	between		1.63	1.49	10.38	n = 72
	within		0.62	2.80	8.41	T = 13.3889
govpub	overall	6.68	3.35	0.23	30.59	N = 966
	between		3.26	1.34	21.12	n = 73
	within		1.80	- 2.12	19.84	T = 13.2329
govhealh	overall	4.79	2.11	0.34	8.91	N = 965
	between		2.11	0.40	7.76	n = 72
	within		0.77	1.16	8.28	T = 13.4028
govsocial	overall	11.60	6.64	-	26.28	N = 962
	between		6.40	0.00	23.54	n = 72
	within		1.63	5.32	20.44	T = 13.3611
gdpcap	overall	12.38	17.92	0.14	245.08	N = 7845
	between		15.38	0.70	123.42	n = 179
	within		8.96	- 54.56	134.03	T = 43.8268
phealtgdp	overall	2.50	1.51	0.03	11.05	N = 3764
	between		1.41	0.13	9.14	n = 192
	within		0.58	- 1.69	7.12	T = 19.6042
sani	overall	69.54	30.46	2.60	100.00	N = 5024
	between		30.21	6.66	100.00	n = 202
	within		4.96	32.85	97.62	T-bar = 24.8713
life	overall	64.70	10.93	19.27	83.98	N = 9068
	between		9.81	40.04	81.49	n = 199
	within		4.86	34.42	83.37	T = 45.5678

Continued on the next page

Table 23: Descriptive statistics of health model (continued)

Variable		Mean	Std. Dev.	Min	Max	Observations
pop	overall	31.13	117.14	0.01	1,369.44	N = 7845
	between		109.99	0.02	1,118.30	n = 179
	within		25.33	- 342.80	437.42	T = 43.8268
motainf	overall	35.02	34.74	1.50	221.10	N = 1876
	between		28.49	3.12	119.72	n = 193
	within		19.97	- 4.49	190.12	T-bar = 9.72021
*motaunder*5	overall	49.73	56.84	1.90	400.00	N = 1876
	between		45.93	3.92	187.10	n = 193
	within		33.59	- 25.14	288.13	T-bar = 9.72021

Table 24: Descriptive statistics of production function with human capital model for global data

Variable		Mean	Std. Dev.	Min	Max	Observations
gdpcap	overall	12,806.46	18,119.86	142.39	245,077.80	N = 7641
	between		15,428.07	708.02	123,423.00	n = 182
	within		8,998.04	- 54,126.40	134,461.30	T-bar = 41.9835
empcap	overall	0.38	0.09	0.12	0.76	N = 6816
	between		0.09	0.14	0.62	n = 178
	within		0.04	0.18	0.60	T-bar = 38.2921
kcap	overall	50,080.12	67,351.52	157.77	834,714.40	N = 7621
	between		60,470.95	893.52	460,248.30	n = 180
	within		27,355.28	- 182,400.60	424,546.30	T-bar = 42.3389
life	overall	65.16	10.97	19.27	83.98	N = 6362
	between		9.99	40.50	78.96	n = 142
	within		4.60	34.40	83.35	T-bar = 44.8028

Note : *empcapa* = labour force per capita, *kcap* = Capital stock at constant 2011 per capita

Table 25: Descriptive statistics of production function with human capital model for developed country data

Variable		Mean	Std. Dev.	Min	Max	Observations
gdpcap	overall	25,277.30	12,850.50	2,779.60	95,175.73	N = 1435
	between		9,175.39	8,517.69	52,486.00	n = 35
	within		8,997.66	- 2,410.87	67,967.02	T-bar = 41
empcap	overall	0.45	0.07	0.27	0.76	N = 1435
	between		0.05	0.35	0.56	n = 35
	within		0.04	0.33	0.67	T-bar = 41
kcap	overall	105,216.30	53,125.82	3,468.43	312,756.90	N = 1435
	between		41,419.00	14,382.74	213,326.00	n = 35
	within		33,198.90	17,518.58	204,647.10	T-bar = 41
life	overall	75.13	3.74	65.66	83.59	N = 1575
	between		2.55	70.13	78.96	n = 35
	within		2.77	67.63	81.74	T = 45

C.4 List of developed countries and OECD countries

The list of developed countries is obtained from the World Economic Situation and Prospects report 2014 (UN)[30] and it is shown in Table 28. The list of OECD countries is shown in Table 29.

C.5 The effect of non-medical determinants on health on life expectancy

The correlation of non-medical determinants on health and life expectancy is shown in Table 30. All non-medical determinants of health variables and life expectancy are slightly correlated. Only tobacco consumption is negatively correlated with life expectancy. The effect of non-medical determinants on health on life expectancy is estimated by the fixed-effects model and the random effects model. Both models are included in the time fixed effect to test whether the

[30] https://www.un.org/development/desa/dpad/document_gem/global-economic-monitoring-unit/world-economic-situation-and-prospects-wesp-report

Table 26: Descriptive statistics of production function with human capital model for developing country data

Variable		Mean	Std. Dev.	Min	Max	Observations
gdpcap	overall	9,922.85	17,939.17	142.39	245,077.80	N = 6206
	between		15,297.24	708.02	123,423.00	n = 147
	within		8,998.85	- 57,010.01	131,577.70	T-bar = 42.2177
empcap	overall	0.36	0.09	0.12	0.75	N = 5381
	between		0.09	0.14	0.62	n = 143
	within		0.04	0.16	0.56	T-bar = 37.6294
kcap	overall	37,289.88	63,760.41	157.77	834,714.40	N = 6186
	between		57,147.90	893.52	460,248.30	n = 145
	within		25,814.54	- 195,190.90	411,756.00	T-bar = 42.6621
life	overall	61.88	10.58	19.27	83.98	N = 4787
	between		9.35	40.50	78.03	n = 107
	within		5.06	31.12	80.07	T-bar = 44.7383

dummies for all year are equal to zero or not. The coefficients of time dummies are not presented due to a large number of coefficients.

The regression results are shown in Table 31. The explanatory variables can explain 89-92% of cross-country variations in the OECD countries's life expectancies. The F-Statistics of all regression, which shows overall significance of the model, are significant at the 1% level[31]. This value implies that the chance for all regression parameters to equal zero is less than 1%. In addition, all regressions are estimated by using the 'robust' command in order to obtain heteroskedasticity-robust standard errors as recommended by Torres-Reyna (2007). The Hausman test indicates that all life expectancy regressions prefer the random effects model.

Alcohol consumption is statistically significant in regressions (L1) and (L5) for both the fixed-effects and random-effects models. The coefficient of alcohol is negative for life expectancy regression. One liter per capita increases in alcohol consumption lead to 0.12 to 0.13 year decreases in life expectancy cross-country.

[31] Some regression does not show F-Statstic (N/A) because the computation software (STATA) concerns the misleading, nothing necessarily wrong with the model.

Table 27: Descriptive statistics of production function with human capital model for OECD country data

Variable		Mean	Std. Dev.	Min	Max	Observations
gdpcap	overall	25,351.10	12,852.64	2,099.99	95,175.73	N = 1430
	between		9,188.89	10,480.58	52,486.00	n = 34
	within		8,988.66	- 2,337.07	68,040.83	T-bar = 42.0588
empcap	overall	0.45	0.07	0.23	0.76	N = 1430
	between		0.06	0.30	0.56	n = 34
	within		0.04	0.32	0.66	T-bar = 42.0588
kcap	overall	103,415.50	54,247.27	3,951.80	312,756.90	N = 1430
	between		42,604.18	24,603.54	213,326.00	n = 34
	within		33,301.12	15,717.77	202,846.30	T-bar = 42.0588
life	overall	74.95	4.52	52.26	83.59	N = 1530
	between		3.03	65.03	78.96	n = 34
	within		3.40	62.18	85.10	T = 45
tobacco	overall	1,720.35	688.81	544.00	3,741.00	N = 300
	between		695.89	893.47	3,541.22	n = 24
	within		245.49	1,075.42	2,495.42	T = 12.5
fat	overall	130.59	23.98	75.80	175.50	N = 410
	between		23.61	85.28	166.81	n = 34
	within		5.21	105.72	145.04	T = 12.0588
alcohol	overall	9.37	2.74	1.20	14.50	N = 481
	between		2.71	1.43	12.65	n = 33
	within		0.74	6.58	12.10	T = 14.5758
Sugar	overall	42.83	10.27	20.10	70.90	N = 410
	between		9.77	22.98	66.13	n = 34
	within		3.61	32.03	62.06	T = 12.0588

Table 28: List of developed countries

Country	Country	Country	Country
Australia	Estonia	Japan	Portugal
Austria	Finland	Latvia	Romania
Belgium	France	Lithuania	Slovakia
Bulgaria	Germany	Luxembourg	Slovenia
Canada	Greece	Malta	Spain
Croatia	Hungary	Netherlands	Sweden
Cyprus	Iceland	New Zealand	Switzerland
Czech Republic	Ireland	Norway	United Kingdom
Denmark	Italy	Poland	United States

Table 29: List of OECD countries

Country	Country	Country	Country
Australia	France	Korea	Slovak Republic
Austria	Germany	Latvia	Slovenia
Belgium	Greece	Luxembourg	Spain
Canada	Hungary	Mexico	Sweden
Chile	Iceland	Netherlands	Switzerland
Czech Republic	Ireland	New Zealand	Turkey
Denmark	Israel	Norway	United Kingdom
Estonia	Italy	Poland	United States
Finland	Japan	Portugal	

Table 30: The correlation of life expectancy and non-medical determinants on health

	Life	Alcohol	Sugar	Fat	Tobacco
Life	1.000				
Alcohol	0.051	1.000			
Sugar	0.125	0.238	1.000		
Fat	0.210	0.230	0.352	1.000	
Tobacco	-0.126	0.160	-0.135	-0.192	1.000

In contrast, other non-medical determinants on health variables are not significant. Therefore, tobacco consumption, fat supply and sugar supply cannot explain the cross-country variations in the OECD countries's life expectancy.

Table 31: The regressions of non-medical determinants of health on life expectancy of OECD countries

Life expectancy	(L1)		(L2)		(L3)	
	FE	RE	FE	RE	FE	RE
Alcohol	-0.13***	-0.12***				
	(-3.42)	(-3.34)				
Tobacco			$1.47*10^{-5}$	$-1.37*10^{-5}$		
			(0.05)	(-0.05)		
Fat					$-2.79*10^{-3}$	$-7.03*10^{-3}$
					(-0.31)	(-0.08)
Sugar						
Constant	78.09***	78.05***	77.10***	77.05***	77.06***	76.81***
	(217.80)	(122.25)	(138.32)	(103.12)	(67.40)	(65.74)
R-squared	0.92	0.92	0.91	0.91	0.89	0.89
Number of observations	481	481	300	300	410	410
F-Statistic/Wald chi^2	92.49***	1389.42***	113.39***	1662.22***	N/A	N/A
Hausman test (chi^2)	1.21	1.21	2.55	2.55	12.42	12.42

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Table 31: The regressions of non-medical determinants of health on life expectancy of OECD countries (continued)

Life expectancy	(L4)		(L5)	
	FE	RE	FE	RE
Alcohol			-0.14***	-0.13***
			(-2.77)	(-2.81)
Tobacco			$-1.41*10^{-4}$	$-1.41*10^{-4}$
			(0.48)	(-0.48)
Fat			0.0184	0.0185
			(1.21)	(1.26)
Sugar	$6.06*10^{-3}$	$6.28*10^{-3}$	0.0113	0.0117
	(0.58)	(0.60)	(1.08)	(1.13)
Constant	76.44***	76.45***	75.96***	75.87***
	(164.08)	(125.81)	(31.67)	(30.79)
R-squared	0.89	0.89	0.92	0.92
Number of observations	410	410	247	247
F-Statistic/Wald chi^2	N/A	N/A	203.87***	3435.69***
Hausman test (chi^2)	0.33	0.33	0.20	0.20
Continued on the next page				

Table 31: The regressions of non-medical determinants of health on life expectancy of OECD countries (continued)

$t - statistics$ (FE model), and z (RE) are shown in parentheses.
F-Statistic is shown for fixed-effects model, Wald chi^2 is shown for random-effects model.
$*$ Indicates significance at the 10% level.
$**$ Indicates significance at the 5% level.
$***$ Indicates significance at the 1% level.