Decline of private investments in the Greek economy and the way forward

Master Thesis

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Preface

This master thesis is the end result of a two-year journey. The lessons learnt during these years do not only extent to the academic knowledge acquired, but also to the non-academic knowledge. The courses provided by TU Delft, helped me determine my academic interest both on Economics and System Dynamics.

I would like to express my gratitude towards my committee members for giving me the chance to learn, form and implement this research. I would like to thank Dr. Servaas Storm for the valuable insights regarding economic aspects. The lessons and the insights provided by the professor concern not only the context of this thesis but also all his courses that I acquired during the last two years and helped me enrich my knowledge. I would also like to express my gratitude for his full support during the difficult times of this thesis. I would like to express my gratitude towards professor van Beers for the useful comments during the early stages of this thesis. Additionally, I would like to express my gratitude towards Dr. Auping and Dr. van Daalen for their enlightening comments and help during the course of this thesis from the early stages until the very end of it.

Next, I would like to specially thank all my friends that were nothing but supportive from the beginning of my studies at TU Delft and endured all my moments of frustration, anxiety and disappointment. With their valuable help and support, they made this journey an unforgettable experience.

Above all though, I would like to thank my family, my parents Stavroula and Thanasi and my two brothers Andrea and Taso for all the support that they have provided all these years until I reach the very end of my studies. Without them I couldn't make it all this way. This thesis is dedicated to them.

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Executive summary

Greece was amongst the first countries to be hit after the outburst of the European financial crisis in 2008. The crisis revealed the underlying intra-Eurozone macroeconomic imbalances and turned the attention of the global community and investors towards the very high level of Greek public debt. Debt crisis resulted in a sharp and persistent recession of the Greek economy that led to a cumulative loss of almost 25 % of country's GDP from 2008 until 2017. Private investments in the Greek economy suffered a heavy downfall since the beginning of the crisis. The level of private gross capital formation kept decreasing since 2008 and forecasts estimate an almost null growth for 2020.

The current research aims to answer the question of what the main factors behind the decline of private investments are and which policies can re-activate them. To investigate the factors behind the decline of private investments, a literature review is conducted to find the elements that contributed in the reduction of private investments. The very high public debt to GDP ratio at the beginning of the European financial crisis and the high public deficit, that proved to be higher than initially stated, triggered the need for a sharp decrease in its value. The approach followed by the Greek governments was the implementation of austerity measures with the purpose of increasing the revenue of the state and decreasing its expenses. The increase of taxes and the decrease of government expenditure and investments led to a decline of private consumption and real GDP.

To investigate further and answer the question about the link of public and private investments a System Dynamics model of the Greek economy is built based on a traditional macroeconomic approach. With the use of the System Dynamics model for the Greek economy. Next, the Exploratory Modelling & Analysis (EMA) Workbench tool is used to perform the analysis. Two different policies are introduced. The first one concerns a mix of lower taxes and lower government investments and the second one is based on a policy of higher taxes and higher government investment.

Results indicate that a policy mix of lower corporate tax rate, value added tax rate and personal income tax rate with lower ratio of government investments to public budget is the most efficient policy for increasing the private investments of the Greek economy, as lower taxes on households and companies stimulate profits and private consumption. On the contrary, public investments and public budget balance perform worse in the case of a policy with lower taxes, which indicates the trade-off between higher investments and higher public deficits.

Sensitivity analysis and scenario discovery analysis are used to explore the most sensitive factors with regard to private investment. High inflation, higher households' propensity to save and low percentage of investments as part of the companies' profits are slowing down the investment growth.

Further research could focus on the disaggregation of income classes to further explore more targeted policies for income tax. Moreover, a migration and a banking sector sub-model could be added to enrich the analysis.

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Table of Contents

List of Figures and Tables

1 Introduction

1.1 A short numerical description of the Greek financial crisis

The European financial crisis started in 2008, after the American crisis crossed the Atlantic. The crisis revealed the macroeconomic imbalances amongst the European Union members, which started accumulating after the common currency, euro, was introduced in 1999 (Storm, 2017b). The need for extensive bail-outs in countries' financial sectors, led to a quick escalation of the public debt issues (Kräussl, Lehnert, & Stefanova, 2016). Greece was amongst the Southern-European countries that faced the consequences from the outburst of the crisis rather quickly.

The tremendous public debt to GDP ratio of the country revealed the vulnerability of the Greek economy and drove the country to a persistent recession. Alongside with the high public debt, the country was facing a big public deficit and a trade deficit. These over the years accumulated issues that increased after the country joined the common currency, led to an adoption of austerity measures (Koratzanis & Pierros, 2017). As a result, Greece's nominal Gross Domestic Product (GDP) dropped from approximately 240 billion euros in 2008 to 180 billion euros in 2017 (ELSTAT, 2019a). Moreover, the unemployment rate exploded from 7,7% in 2008 to a peak of 27,5% in 2013 and ultimately fell to 21,5 % in 2017 (International Labour Organization, 2018). On the contrary, the general government debt to GDP ratio increased from 117% in 2008 to almost 189% in 2017 (OECD, 2019b). Additionally, it is estimated that around 280.000-350.000 Greeks emigrated from 2010 until the end of 2015. The vast majority, around 75%, were university graduates (Labrianidis & Pratsinakis, 2014).

The causes of the European financial crisis are well known and explored among the literature (Baldwin & Giavazzi, 2015; Jones, Kelemen, & Meunier, 2015; Pagano, 2011; Wijffelaars & Loman, 2015). Amongst scholars however there is a divergence of opinions regarding the question whether the crisis is over or not. Some argue that the Europe has overcome the crisis and the economic recovery is ahead (Janse, 2018). Other scholars are afraid that European economy is still fragile because of the persistent high public debts in some European countries such as Greece and Italy and another economic recession can still happen in the near future (Ezrati, 2018).

1.2 A short numerical description of the private investments' decline

From 1994 until 2009, the Greek economy had experienced a continuous increase of private investments. After 2009 however, private investments in the Greek economy suffered a heavy downfall. In 2014 and after a continuous decrease of 5 years the total gross capital formation returned to the 1990 levels (Mavridakis, Dovas, & Bravou,2015). The total decline in gross investment was 48% in the same period. The decline rate of public investment was around 13% while the gross private investment decline reached approximately 56%. To illustrate the difference with the rest of Eurozone, the average decline in public investments at the same period for the Eurozone countries was 13.2 % while the gross private investments

increased on average by almost 3 % (Mavridakis et al., 2015). Public investments as a rate of GDP were reduced due to the requirements of the austerity programs that various Greek governments were called to implement. Foreign direct investments also declined from 4.5 billion euros in 2008 to 0.3 billion in 2010 and managed to recover to almost 4.3 billion euros in 2018 (OECD, 2019a). Gross fixed capital formation declined by 12.2 % in 2018 compared to 2017 and according to European Commission (2018) the increase of private investments is predicted to follow a null growth, thus leaving the country in a stagnating level of investments even if the forecasts are proven to be right.

1.3 Societal Relevance-Private investments as a driver of desirable economic growth and employment rate

Greece's unemployment rate has decreased since its peak in 2013. However, an unemployment rate of 18% in the end of 2018 ranks the country in the first position amongst the European countries (ELSTAT, 2019a). The rate of unemployment is still far from its level before the beginning of the crisis. Furthermore, it is questionable if the decrease in the unemployment rate can continue, given the uncertainty of the current financial environment and the decline of private investments, amongst others, that Greece is experiencing during the years of the crisis.

Only between 2010 and 2011 six out of ten companies recorded a profit decrease which translated in 150.000 lost jobs (Chatzitheodoridis, Kontogeorgos, & Loizou, 2014). Various Greek governments have tried to attract private investments to boost the economy and create more jobs in various sectors of the economy, but their efforts seem to have failed so far. The Greek economy is still stagnating and is struggling to achieve a sustainable level of economic growth. Given that 82 % of employed people are in the private sector, it becomes apparent that increasing the volume of private sector activities and investments is a crucial step on achieving higher and desirable levels of employment. With the term desirable, one refers to levels of employment near the full employment. With the term full employment one refers to the situation where there is no involuntary unemployment (Singh, 2019).

1.4 Current research about the factors of decline in private investments

Austerity and internal devaluation measures was the main economic mix that was adopted after 2010 (Koratzanis & Pierros, 2017). Not only the financial sector was hurt (Kosmidou, Kousenidis, & Negakis, 2015), but also many other sectors of the real economy such as public health (Ifanti, Argyriou, Kalofonou, & Kalofonos, 2013) and higher education (Koulouris, Moniarou-Papaconstantinou, & Kyriaki-Manessi, 2014) were called to cut down expenses.

The reduction of the extra-ordinary public debt was the first target for the implementation of fiscal consolidation measures. The implementation of the austerity measures was in agreement with the 3 institutions that were called to Greece's financial help, the European Commission (EC), the International

Monetary Fund (IMF) and the European Central Bank (ECB) (Blanchard, Jaumotte, & Loungani, 2014; European Comission, 2018). The way for the reduction of public debt was through the reduction of the country's tremendous public budget deficit.

In exchange for the austerity measures, Greece has received tremendous financial help from the Troika. It is estimated that Greece has received more than 300 billion euros in the years that followed the European Financial Crisis (Bortz, 2015; Sinn, 2015). However, there is still heavy criticism on how much of this money was directed towards the real economy and the economic recovery. It is estimated that only 25 % of the loans received was directed to the real economy in order to boost private consumption and strengthen economic growth (Bortz, 2015).

Despite the estimations provided by the European Commission (European Comission, 2018) for the potential growth of the Greek economy, private investments remain still way lower than before the economic crisis of 2008.

The question then on how to attract and re-activate private investments in the Greek economy remains unanswered. Although there is a variety of papers and scientific research in the literature, the findings are contradictory. According to Blanchard & Perotti (2002): "Both increases in taxes and government spending have a strong negative effect on investment spending". On the other hand, Dreger & Reimers (2014) argue that the low level of public spending and investments, could have potentially led to a decline of private investments and GDP growth in the European Union countries.

Among the literature there is also a variety of research concerning the driving factors for private investments. Afonso & Sousa (2011) observe a negative relation of high government spending and real GDP, due to the "crowding-out" effects of government spending in private consumption and investment in the case of Portugal. Coenen & Straub (2005) also find that the effect of government fiscal policy is not likely to boost private consumption and investments due to the negative impact of this policy on wealth. Burriel et al. (2009) suggest that government fiscal shocks might have a positive effect on GDP and private consumption, but only in the short-term. They also note that government spending is also more likely to have a more positive impact on GDP than a policy that introduces a reduction of net taxes. The short-term impact of higher government expenditure on aggregate investment and private consumption is also among the findings of Burnside, Eichenbaum, & Fisher (2004).

The findings of Kuismanen & Kämppi (2010) in the case of Finland show a positive influence of government spending on GDP and investments, but the results are not so apparent when it comes to private consumption. Nevertheless, their findings show that government spending has a negative effect on private sector activity. Forni, Monteforte & Sessa (2009) conclude that government spending and more specifically the government purchases of goods and services and the public employees' compensations has a positive short-term impact on private investments, which however is crowded out in the long term. On the other hand, Forni et al. (2009) conclude that a decrease in labor income and consumption tax rates have negative impact on consumption and output, while a reduction in capital income tax has positive impact, in the medium run, on investment and output.

Edelberg, Eichenbaum, & Fisher (1999) conclude that a government expenditure shock will have a positive impact on employment, GDP and investments, but a negative impact on real wages and consumption. Finally, Attinasi & Klemm (2016) conclude that expenditure-based measures have a less negative impact on growth compared to revenue measures. GDP is slowed down if government investments and consumption are reduced. Additionally, indirect tax increases have a negative effect on GDP growth.

A research from Apergis (2000) for the Greek economy, concluded that in the period between 1948 and 1980 public investment expenditure had a positive impact on the private investments, while in the period 1980-1996 this relationship was reversed, and public investments were having a negative impact on private investments.

It becomes apparent then that there is a lack of consensus on which are the driving factors behind the decline of private investment in the Greek economy and the ways to re-activate them. *Aim of the current thesis then is to contribute to the already existing literature on the appropriate policies for re-activating and strengthening the private investments in the Greek economy.*

1.5 Research objective and research questions

The main objective research as mentioned in previous sections is to investigate the main factors behind the decline of private investments of the Greek economy. The goal is to provide a clearer and transparent view on how the economy behaves with respect to key performance indicators.

Based on the knowledge gap and the research objective, the following research question is formulated, and four sub-questions are proposed to help answer the main question.

Research question

"Which are the main factors behind the decline of private investments in Greece and which policies can help re-activate them?

Sub-questions

1. How did the European financial crisis impact the economic growth of Greece?
2. Why did a decrease of the private investments of the Greek economy occur?
3. What is the role of government intervention via fiscal and tax policy in reviving private investments?
4. Which are the sensitive factors with respect to the decline of private investments?

1.6 Modelling approach and methodology

To answer the main research question and the set of sub-questions that derive from the main question, the main research approach is a System Dynamics modelling approach. According to Sterman (2000a): "System dynamics is a method for developing and testing formal mathematical models and computer simulations of complex nonlinear dynamic systems". System Dynamics provides the opportunity to explore the over-time evolution of macroeconomic component relationships by using differential equations and help capture phenomena that evolve continuously over time (Judson, 2017).

The System Dynamics modelling approach also deals with dynamic complex systems. Complexity in dynamic systems emerges because those systems are constantly changing, they are tightly coupled, governed by feedbacks, non-linear, history-dependent and are characterized by trade-offs and policy resistance (Sterman, 2000). SD models can capture these dominant feedback loops of various components of the system and identify actual conditions that emerge from the interaction of those components (Forrester, 1992). They also deal with non-linearity, since even linear variable relations can develop non-linear behavior in a system dynamics' model. Historical dependence is easy to be captured in a systems dynamics model, since historical data can be imported in a model and the historical behavior can be replicated for a given time period.

The dynamic nature of the system properties' interactions is what also makes System Dynamics an attractive choice for macroeconomic analysis. For example, the evolution of the GDP in an economy has an impact in the country's imports. Simultaneously though, the change in a country's imports has an impact in the country's GDP. Those interactions are often non-linear. One of the biggest advantages of using system dynamics is its ability to capture these non-linear interactions.

A country's economy is a complex system with a big number of both negative and positive feedback loops. Feedback loops can consist from only 2 elements up to dozens of variables. The dynamic behavior of an economy then is the sum of all the feedback effects. The dominance of the most significant positive or negative feedback loops can greatly influence economic growth. The aim of the current research then is to explore those feedback loops that interact and influence each other and detect the ones that are of key importance for the increase or decrease of the private investments in the Greek economy.

For exploring the key feedback loops and the dynamics of an economy, a system dynamics model of the economy is constructed, by using Vensim software. Vensim is a system dynamics software, that is mostly used in constructing models that present a dynamic behavior (Ventana,2015). A modelling approach with the use of Vensim helps to reveal underlying causalities and dynamics that traditional economic models cannot capture. To explore the most sensitive parameters that influence changes in the system, global sensitivity analysis is used. The sensitivity analysis is contacted with SOBOL technique.

Another important aspect when one deals with complex systems is the uncertainty that derives in the system. In a model, uncertainty can occur in multiple levels, such as the model boundaries, the conceptual

model, input data or computer simulations (Kwakkel, Walker, & Marchau, 2010). Uncertainty in the model boundaries derives from the aspects of the reality that are not captured from the simulation model. The system boundaries in a modelling approach research are defined from the problem formulation and the research question. The conceptual model provides the theoretical set-up of a model and describes the most important relations and variables for the computer model. As it can be understood, the conceptual model cannot include all possible theories and views to integrate them. The uncertainty in the input data concerns the values of the input data. In the current research, this uncertainty is dealt by assigning a range of values in the uncertain input parameters instead of single values.

To explore the conditions under which policies can reach the desired goal in the space of uncertain input parameters, scenario discovery is used. Scenario discovery finds subspaces in the uncertainty space that result in characteristic outputs (Bryant & Lempert, 2010). Scenario discovery is done by using the Patient Rule Induction Method (PRIM) technique (Friedman & Fisher, 1999). Both scenario discovery and sensitivity analysis are conducted with the use of Exploratory Modelling & Analysis (EMA) Workbench tool. The EMA workbench is providing the possibility for simulation and analysis on models developed in various modelling packages, such as the Vensim software (Ventana, 2015). EMA workbench, was developed by J.H. Kwakkel of the Delft University of Technology with the use of the programming language Python (Python, 2018).

Finally, the variety of choices that continuous modelling provides alongside with the dynamic behaviors among the various variables that can be explored, provide a more complete picture of the dynamics that evolve over time in an economy and helps to reveal underlying causations that other modelling approaches fail to capture. To explore all of those interconnections and to come up with some meaningful results the most important indicators are monitored after the construction of the model. Indicatively, some of the key indicators, among others, that will be explored are the country's real GDP, real disposable income, companies' profits and export-import balance.

1.7 Report Outline

This chapter has introduced the research. The remainder of the document is structured as follows: Chapter 2 presents the methodology that is followed for the rest of the research. Chapter 3 provides a short history of the European financial crisis that burst out in 2008 and highlights the impacts that it had in the Greek economy. Additionally, provides evidence for the connection of private and public investments based on literature. In Chapter 4, the conceptual model, the basic structure of the sub-models and the validation of the model are presented. Additionally, the experimental set-up of the model is presented. Chapter 5 illustrates the results from the model runs both with the help of Vensim runs as well as EMA Workbench simulations. Finally, in chapter 6, the research is concluded and recommendations for the Greek government are made.

2 Methodology and theoretical framework

In the previous chapter it was mentioned that the quantitative system dynamics modelling approach is used for constructing the macroeconomic model of the Greek economy. In the current chapter it is argued why system dynamics approach is the appropriate one for constructing the macroeconomic model and answering the main research question (2.1). Next, the traditional macroeconomic theory is explained (2.2) and linked with the system dynamics approach. In the third part of this chapter, the level of uncertainty in the system is introduced and explained (2.3). Afterwards, the sensitivity and scenario discovery analysis with the use of EMA Workbench for their exploration are presented (2.4).

2.1 System Dynamics in economics

The idea of using System dynamics for constructing macroeconomic models is not new. In principle there are three approaches. The first one is to build a System Dynamics model by translating an existing traditional economic model. The second approach is by building a System Dynamics model from scratch based on the Systems dynamics framework of ideas provided among the relative literature (Forrester, 1992; Sterman, 2000; Yamaguchi, 2007). Normally, these kinds of models are very big in scale. Building a model with that approach though, could prove impossible for the purposes of a master thesis with limited amount of time. The third approach is a combination of the previous two approaches, a "hybrid" approach.

The approach that is chosen for the current research is the first one. Building an SD model based on the current literature from traditional economic models. Traditional economic models can be classified in four categories: written, mathematical, difference equation and ordinary differential equation models (Radzicki, 2011). Models with ordinary differential equations or difference equations, can be easily translated to SD models. Written models such as the one described in Adam's Smith "Wealth of Nations", for example, might capture the dynamics of a system, but they fail to provide mathematical basis for their ideas. On the other hand, mathematical models provide the mathematical equations that are necessary for the representation of a financial system, but they might fail to capture the dynamics of underlying processes (Radzicki, 2011). System Dynamics can overcome those barriers and combine all four categories, since there is no restriction on the kind of equations that can be incorporated in a model. At the same time, written models can be expressed by being translated into quantitative variables in the model.

Various econometric models both for the Greek economy (Papadimitriou, Zezza, & Nikiforos, 2013; Sakellariou & Howland, 1993) and the economy in general (Rada, 2007; Taylor, 2004) can be found in the literature. There are also a lot of traditional economic models that try to capture the development of unemployment in dependence with other economic factors (Tramontana, Gardini, & Ferri, 2010). However, all of them have strong weaknesses. Sakellariou & Howland (1993) suggest a macro-econometric model of Greece of 39 equations, that focuses on the relationship between bank credit availability and private investments but does not include the unemployment variable. Both (Rada, 2007) and Rada & Taylor (2006) models are also not detailed enough to capture the driving factors that can lead

to higher or lower private investment levels. Papadimitriou, Zezza & Nikiforos (2013) propose a model for Greece that includes 68 equations and 150 variables that considers the private sector as a whole, and not in a disaggregated level.

As basis for the model is used the work of Papadimitriou, Zezza, & Nikiforos (2013). The model is based on a stock-flow consistent (SFC) approach that allows the economic analysis of a country's economy in a national level. One the one hand, one of the biggest advantages of this model is that it is modelled specifically for the Greek economy. On the other hand, one big difference with the current research lies upon the fact, that the economy is treated as a whole and is not disaggregated into different sectors, as the purpose is to investigate the growth of total private investments.

Finally, one important element for the economy that is considered as an exogenous variable in the model of Papadimitriou et al. (2013) is the population growth. Population change is an element that in most of the traditional economic models is either absent or set as an exogenous variable. The growth or decline of a country's population, influences the available workforce and thus also the unemployment level. The ageing of the population is also an important element. It not only influences the available workforce, but also the government expenses for the pension system, as the number of people in retirement increases.

System dynamics allows for constructing a macroeconomic model that forecasts the growth of the Greek population. The population sub-model allows for the calculation of population growth for different age groups. This way, we can keep track of the available workforce in the different age groups, as well as the number of people that are retired and thus distinguish the working age population from the non-working population. The population model is then a dynamic element of the macroeconomic analysis and not just a static variable.

2.2 Macroeconomic theory

In macroeconomic terms, aggregate demand is defined as the total demand for goods and services from all sectors in a country (Naastepad, 2002). The standard equation of Dos Santos & Macedo e Silva (2010) for the aggregate demand that is used as a starting point for the model and for the rest of the research is presented in equation 2.1 below:

$$\mathrm{AD}=\mathrm{Cp}+\mathrm{Cg}+Ip+Ig+\mathrm{X}-\mathrm{M}$$

Equation 2.1: Aggregate demand

Where:

AD: Aggregate Demand

Cp: Private consumption

Cg: Government consumption

Ip: Private investment

Ig: Government investment

X: Export Demand

M: Import Demand

Investments in an economy are separated into two categories: i) Private investments (Ip) and ii) government investments (Ig). Both categories are elements of the total aggregate demand as described in the equation above. Government investment is part of the government expenses, but it refers to expenses such as the construction of infrastructure. Government consumption refers to the government expenditures for i) purchase of goods and services and ii) compensation of public employees. The private sector in this equation, includes both households and companies' sectors. Private consumption is the total purchase of goods and services by households and companies and private investments is the total sum of investments, for example purchase of machines or equipment, from companies and households (Naastepad, 2002).

Governments have control over their own expenditures, but the macroeconomic policy instruments that they use, have an impact in all the other elements of the economy. A macroeconomic instrument for every government is the fiscal policy. To implement fiscal policy, a government can decide to increase or decrease the level of taxes and/or increase or decrease the government expenses (government consumption and investments).

In the standard Keynesian theory, an increase of public expenditure leads to an increase of consumption, which in return will increase the level of private investments. Private investments are dependent on what Keynes called "animal spirits". By this term, he was referring to the expectations of investors for the future of an economy. In times where expectations are low, investors are reluctant to investing and prefer to wait until the economic situation improves. In times where expectations are high due to an improved economic growth, investors are more eager to invest. Thus, investment in the Keynesian approach is an exogenous variable.

To endogenize the private investments, Papadimitriou, Zezza, & Nikiforos (2013) use a stock-flow consistent model for the Greek economy that follows the "New Cambridge" approach. The stock flow model uses social accounting matrices to represent the flows in payments and receipts in the sectors of an economy. In the model for Greece, private sector is considered as a whole, thus households and firms are not treated separately. In table 2.1 below the social accounting matrix is presented. Payments can be found in the columns, while receipts are found in the rows.

Table 2-1: Social accounting matrix for the Greek model (source: Papadimitriou et al., 2013)

	Production	*Private Sector*	*Government*	*Rest of the World*	*Capital account*	*Total*
Production		Private expenditures	Government expenditure	Net exports		GDP
Private Sector	Value added private sector		Transfers from government to private sector	Transfers from RoW to private sector		Private Sector output
Government	Net indirect taxes	Direct taxes		Transfers from RoW to government		Government sector output
Rest of the World	Net indirect taxes RoW	Transfers from private sector to RoW	Transfers from government to RoW			RoW output
Capital account		Private Savings	Negative government saving	Negative external current account		0
Total	GDP	Private sector output	Government sector output	RoW output	0	

As it can be seen from the table above, the economy is separated in 3 sectors: government sector, private sector and RoW. One of the main differences with the current thesis' model is that it is assuming the private sector as a combination of households and companies and thus it is impossible to disaggregate the companies' private investments from the households' investments. To do that separation, the current model is based on equations and data provided from the AMECO website (AMECO, 2019). In the website the distinction between household and companies' sectors is being made, thus providing a disaggregated picture of the two sectors.

Additionally, the capital transfers from and to the RoW are assumed to be 0 as a sum, for reasons of simplicity. That is a big assumption in the current model, but does not deviate a lot from the reality, although generally the governmental capital transfers receivable are lower than the governmental capital transfers payable (ELSTAT, 2019a).

2.3 Economic Uncertainty

Uncertainty is a major factor for policy design and especially for such an unpredictable field as the economic one. Economic field has a plethora of examples where uncertainty is involved. External shocks in an economy for example or a natural disaster are events that can heavily influence the evolution of an economy either in the short-term or the long-term. Exchange rate, inflation and import-export elasticities can also be considered uncertainties, depending on the boundaries of an economic model.

Uncertainty refers to unknown, uncontrollable or incalculable parameters of a system. In case that "The different parties cannot agree on the system model that related consequences to actions and uncertain model inputs", Lempert, Popper, & Bankes (2003) refer to deep uncertainty. To define the level of uncertainty, one can assign numerical probabilities (or a range of numerical probabilities), where possible, for a specific event to happen. In other cases, one can assign qualitative values such as more or less likely to happen (Kwakkel, Walker, & Marchau, 2010). In other cases, however, assigning probabilities to specific events is not possible.

The possibility for assigning probabilities in a specific event to happen, depends on the level of uncertainty. During a research it is important to know the level of uncertainty of the system. Kwakkel et al. (2010) consider four levels of uncertainty: shallow, medium, deep uncertainty and recognized ignorance. Table 2.2 below presents the four levels.

Table 2-2: Uncertainty Levels (source: Kwakkel et al., 2010)

Uncertainty Levels	**Likelihood**
Level 1 (shallow uncertainty)	can be specified with the use of probabilities
Level 2 (medium uncertainty)	can only rank order the perceived likelihood but not assign probabilities
Level 3 (deep uncertainty)	cannot either rank order or assign probabilities
Level 4 (recognized ignorance)	cannot either rank order or assign probabilities

In level 1 and 2 of uncertainty, one can assign probabilities or rank the order of the perceived likelihood for a specific event to happen. For example, if one deals with a level 1 uncertainty system it is possible to assign probabilities on the values of the input parameters of the system. In a macroeconomic system though, it is difficult to forecast the outcomes with probabilities (Kwakkel et al., 2010). The level of uncertainty in the system then is mostly found on level 3, deep uncertainty. Instead of assigning probabilities or rank the order of perceived likelihood in the system, uncertain input parameters can have a range of values with no weighted probabilities. It becomes apparent then, that there will be a range for the values of the outcomes too.

When dealing with an uncertain system, there is no single future. There are parameters in the system, that we cannot forecast their single future value. Instead, we examine a plausible range of these values and explore the outcomes on different scenarios. Knowing where uncertainty lies when mapping the space helps in paying the appropriate attention during the policy design and interpretation. It is then possible to explore the most sensitive factors for the system in a range of plausible futures and look at the conditions under which policies can reach their goal. To perform this exploration, we use Exploratory Modelling and Analysis.

2.4 EMA Workbench

To simulate, analyze and explore the uncertainties of the current model and the significance of the input parameters, the Exploratory Modelling and Analysis (EMA) workbench. The EMA workbench is providing the possibility for simulation and analysis on models developed in various modelling packages, such as the Vensim software (Ventana, 2015). EMA workbench, was developed by J.H. Kwakkel of the Delft University of Technology with the use of the programming language Python (Python, 2018). The EMA workbench offers support for setting up simulation runs, performing simulation runs, and analyzing the results (Kwakkel, 2012).

2.4.1 Global Sensitivity Analysis- SOBOL

Global sensitivity analysis (also called "uncertainty importance measure") can estimate the contribution of input parameters to the model output in the value domain of input parameters (Homma & Saltelli, 1996). With global sensitivity analysis, the estimation can be made by sampling all the uncertain input parameters at the same time.

In the current research, the technique that is chosen for applying global sensitivity analysis is SOBOL. SOBOL sensitivity analysis is used to identify the most sensitive factors with respect to the outcomes of interest. The SOBOL analysis is based on the SOBOL indices, named after the Russian mathematician I.M Sobol (Sobol, 1993).

SOBOL indices are a well-known quantitative measure for variance based global sensitivity analysis. It approximates the parametrized model as a sum of simpler functions, each depending on only a subset of the original set of variables. The sensitivity to each variable is then estimated as their relative contribution to the output's overall statistical variance (Ballester-Ripoll, Paredes, & Pajarola, 2019). In the SOBOL indices, we observe the first order effect S1, that represents the single influence of each parameter and the total effect ST, which contains also the interaction effects between the parameters. First-order gives the single sensitivity of the uncertain parameter with respect to the outcome of interest and the total effect gives the sensitivity of the uncertain parameter to the outcome of interest with respect to all the other uncertainties. Uncertain input parameters with high score of first-order effect are the ones that are most interesting for the analysis, since these are the ones that have the most significant influence in the outcomes of interest. To perform the SOBOL analysis, EMA Workbench is used.

2.4.2 Scenario Discovery-PRIM

To explore the model outcomes given the conditions of uncertainty that exist in an economy, scenario discovery is used. Scenario discovery has proven very useful as a method for assessing and communicating information in computer simulation models, such as the current Vensim model for the Greek economy,

when deep uncertainty parameters are involved (Dalal, Han, Lempert, Jaycocks, & Hackbarth, 2013). The impacts of the numerous uncertainties that exist and influence the evolution of an economy can be explored with scenario discovery by computational experiments (Halim, Kwakkel, & Tavasszy, 2016). The aim of the experiments is to define a set of scenarios that represent potential future status of the system and identify the conditions under which those policies perform poorly or highly (Bryant & Lempert, 2010).

For the implementation of scenario discovery, statistical or data-mining algorithms can be used to detect the regions that are the most relevant for policy design, always with respect to the input of uncertainty parameters (Bryant & Lempert, 2010). Such a tool that uses those algorithms is the Patient Rule Induction Method (PRIM) (Friedman & Fisher, 1999).

One can imagine PRIM as a box that contains a set of data. The PRIM algorithm follows a step by step procedure. In every step of this procedure the algorithm removes a certain part of the original box and creates another box with less data points, in order to improve the objective function (Kwakkel & Cunningham, 2016). The remaining space is now smaller but has a higher concentration of points of interest. The algorithm stops when an objective is met. After the algorithm is finished, the next step is to select an appropriate box for further exploration (Kwakkel & Cunningham, 2016).

Bryant & Lempert (2010) define three criteria for the selection. Density, coverage and interpretability. Density refers to the fraction of cases of interest in the box versus the cases that are not of interest and are found inside the box. Coverage is the fraction of all cases that are of interest that can be found within a PRIM box (Kwakkel & Cunningham, 2016). Ideally the desired outcome from PRIM would produce both quite high coverage and density, meaning having as many cases of interest as possible without having a lot of cases that are not of interest in that specific box. However, there is always a trade-off between density and coverage in PRIM analysis, because high density means that there is a higher likelihood that coverage will be lower, and vice versa. Finally, interpretability refers to how easy it is for a policy maker or an analyst to understand what a box represents and gain useful insight for policy proposal (Bryant & Lempert, 2010). Interpretability cannot be numerically estimated since it is a qualitative criterion for choosing a PRIM box.

In the current research, PRIM analysis is conducted with the use of EMA Workbench to explore the range of the values where the desired policies perform inadequately rather than finding the regions where the policies perform highly. That is useful insight for policy makers, since it helps revealing under which conditions policies can provide inadequate results for the important outcomes of interest.

3 European financial crisis and private investments

The current chapter aims to provide a short overview of the European financial crisis, how it was spread through the Greek economy and what were the impacts of it. In the second part of the chapter the measures taken by the Greek governments to tackle the crisis are mentioned and their impact on the Greek economy are analyzed. The third part of the chapter provides a literature review of the connection between the private and public investments. It aims to highlight the diversity of the results amongst the literature on whether there is a positive or a negative impact of public investments on private investments.

3.1 Short overview of European financial crisis and impacts on the Greek economy

Loužek (2015) comments in his paper about the Eurozone crisis, that the reasons behind the monetary unification of European Union were not only financial but also political. Stiglitz (2016) notes in his book about the impacts of Euro in the future of European union that politics cannot be fully separated from economics. But since the Maastricht treaty in 1993 and the introduction of the common currency, a political integration has not been achieved.

According to Loužek (2015) there are requirements for a common currency union to succeed. “Firstly, there should be a high mutual labor mobility. Secondly, they should have salaries with downwards flexibility. Thirdly, they should have intensive mutual trade and lastly there should be a symmetry in the exogenous positive and negative shocks”. The last point from the author is one of the main points of criticism among economists about the causes of the European Financial Crisis. The main idea of the European common currency was that it would eventually lead to a convergence of the participating countries. The economies of the Southern countries would follow the growth of the economy in the Northern countries, as the external risks would be mitigated, and the more vulnerable countries would be more effectively protected. Besides, the Maastricht treaty dictated that every European country should have a public budget deficit lower than 3% and a public debt to GDP ratio that is lower than 60% (Stiglitz, 2016).

Indeed, for a short period of time, most investors perceived the high growths of GDP of Southern countries, as a sign that the convergence was in progress and those countries were catching up with the traditionally most advanced of the North. Until, the European Financial crisis of 2008 burst out and the underlying diseases revealed themselves.

Although economists acknowledged beforehand, that for the single currency to work there needed to be sufficient similarity among the countries, in reality that was never the case. The Northern countries have traditionally a trade surplus (for example Germany, the Netherlands) while the Southern such as Greece or Spain traditionally run a trade deficit. With the adoption of the single currency countries had not only

a single interest rate, that was defined by the European Central Bank, but also the same exchange rate. When the crisis that started in the US spread to Europe, the first countries to go down were Greece, Portugal, Spain. These were countries that before the crisis had almost zero spread bonds compared to German bonds. In simple words, investors perceived that investments in Greece or Spain were as safe as investments in Germany or the Netherlands. Those countries had GDP growth rates of 4-5 %. But what investors and European politicians did not look closely were the driving factors of those growth rates.

For Southern countries, development came as a result of the cheap credit that was provided to those countries as a result of the surpluses produced in the Northern countries and the common currency that allowed same exchange rates for the countries. But excessive borrowing led to excessive public debt too. For example, the public debt of Greece in 2008 was 117 % and Italy's debt was 113 (OECD, 2019b). That was not perceived as a serious until 2008 when investors started getting nervous and anxious about the excessive debts and the vulnerability of those economies to a negative shock on the world economy. Economies that were perceived as safe for investments, started to be treated as potential defaulters (Baldwin & Giavazzi,2015).

Figure 3.1 presents the evolution of Greek public debt after the crisis burst out, from 2008 until 2017. The debt that was problematic at the beginning of 2008 for the investors, not only did not decline, but escalated rapidly after 2008 and 2011, with a small de-escalation in the year between 2010-2011.

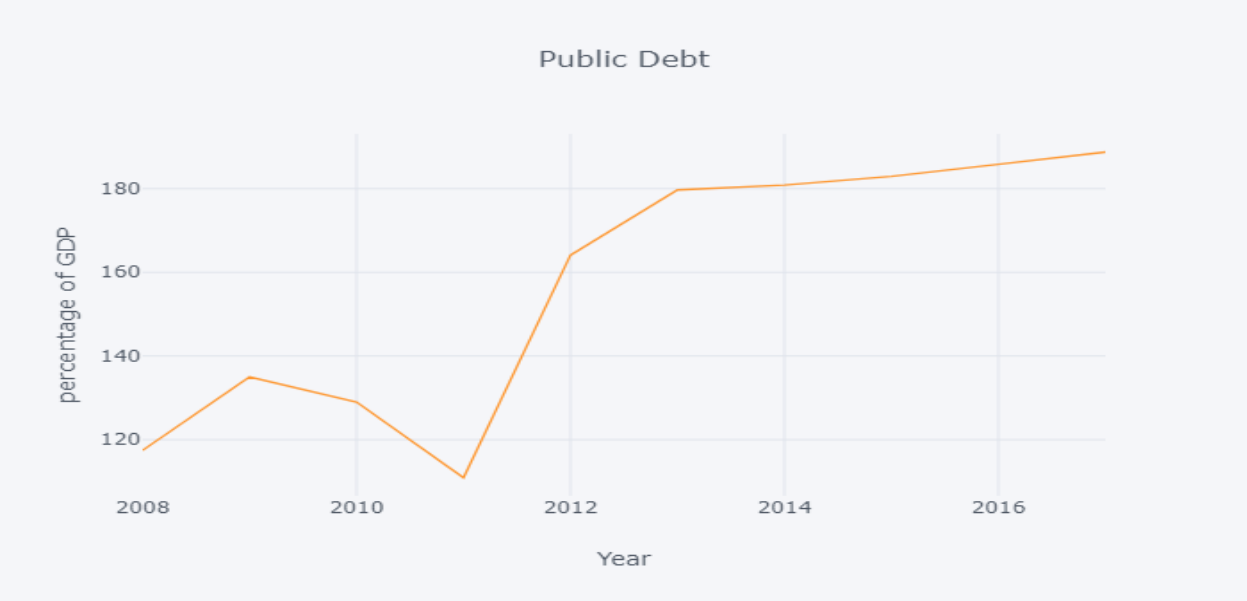


Figure 3.1: Evolution of Public Debt (source: OECD DATA, 2019)

That had as an immediate impact that government spreads started increasing rapidly. The investors' trust was lost, and the flows of cheap credit were immediately disrupted. Greece was at the first line. The country's spread increased from almost 5 % in 2008 to over 25 % in 2012 (OECD, 2019c). The country was not able to pay back the interest on its expiring debt. The next step was to find an alternative way of financing its debt.

Figure 3.2 shows the evolution of the long-term interest rate for Greece after 2008. As it can be observed, the interest rate remained around the values of 5 % until 2009. The response of the financial markets on the outburst of the financial crisis and the vulnerability of the Greek economy, that could turn out to be a liability for the whole European Union, led them to pull out their trust from Greece and look for safer ports to invest their money.

The long-term interest rate only started de-escalating only after the former president of the ECB Mario Draghi said in a conference in London at 2012 that "the ECB is ready to do whatever it takes to preserve the Euro" (ECB, 2012).

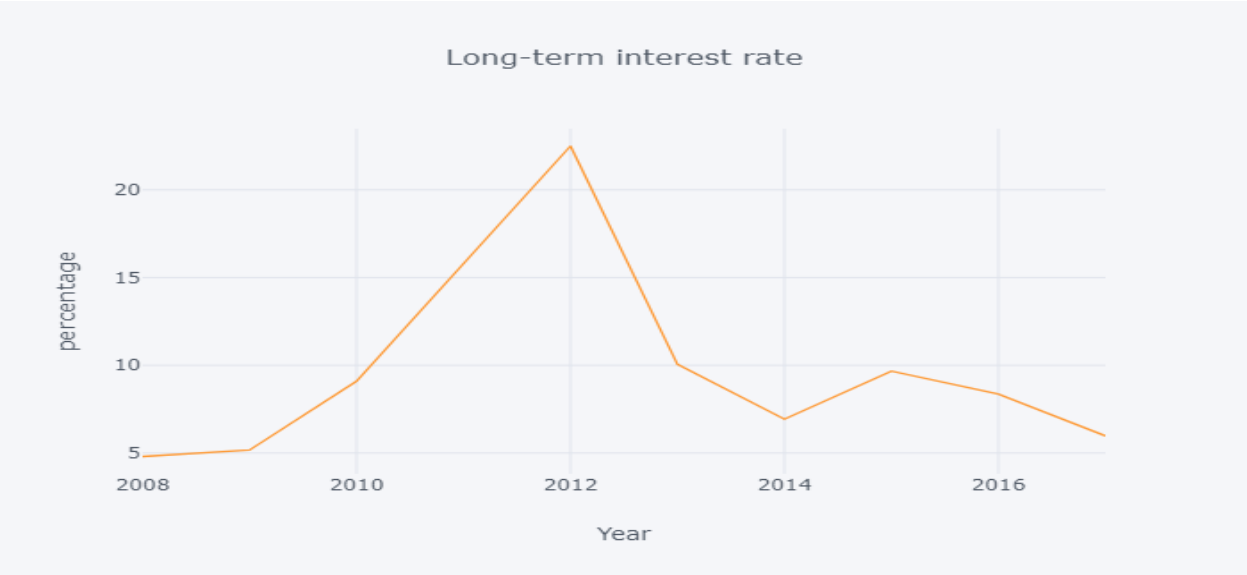


Figure 3.2: Evolution of long-term interest rate after 2007 (source: OECD Data,2019)

3.2 Austerity as a solution

Markets became extremely nervous about the viability of the Greek debt and as a response they raised their estimate of Greek default risk (Baldwin & Giavazzi, 2015). But this had as a result that debt-service payments were increasing, and consequently increasing the budget deficit. In Greek case, public deficit was also the trigger for the investors' anxiety. After the 2009 elections, it was revealed that the size of the public deficit was larger than previously thought. The real deficit was twice the size of the previously thought, 12.5 % (Pagano, 2011). The way that Greek governments followed to tackle the issue was the implementation of austerity measures, with the assistance of the so-called Troika, the ECB, IMF and EU. The goal of the austerity and internal devaluation measures was the elimination of the public deficit and trade deficit issues (Koratzanis & Pierros, 2017).

And indeed, as it can be seen in figure 3.3, the public deficit was reduced drastically after the adoption of the austerity measures.

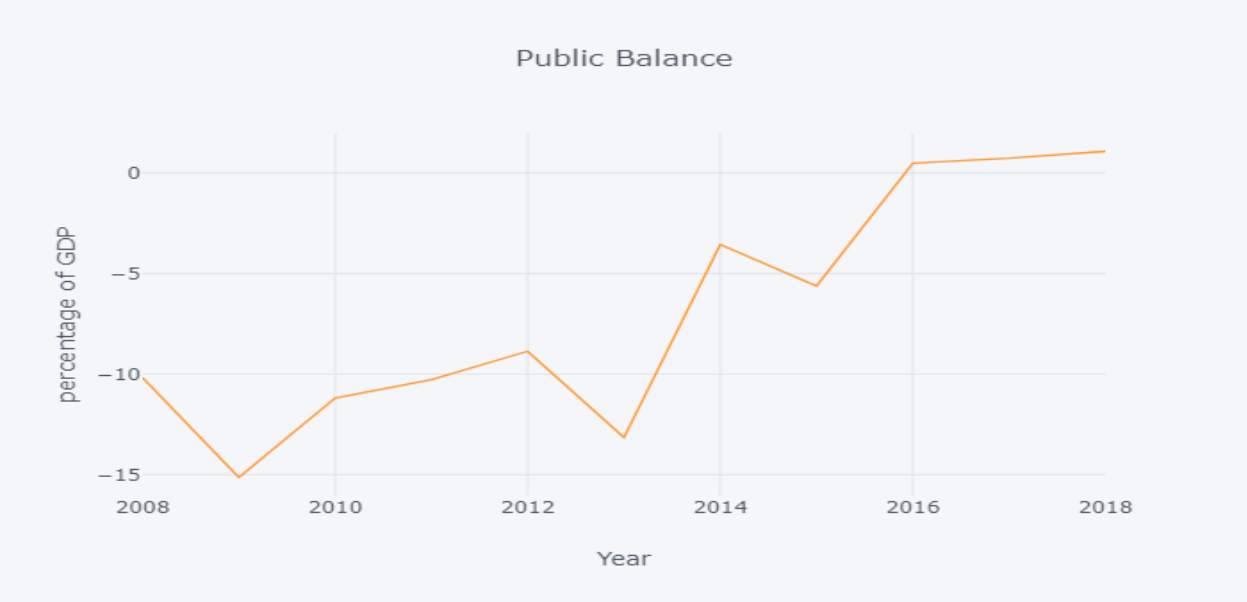


Figure 3.3: Public Budget Balance as a percentage of GDP (source: OECD Data,2019)

In exchange for the adoption of those austerity measures Greece received by the end of March 2015 almost 325 billion euros to help restore the economy (Sinn, 2015). From that amount, 54 % is estimated that it was directed towards repaying foreign debt and 21% for recapitalizing banks (Bortz, 2015). Despite, the rapid decrease in public spending and tax raises and the profound financial help from Troika, the Greek economy seemed to be sliding on a vicious spiral (Vike, 2016). Unemployment reached an all-time high of 27 % in 2013 (International Labour Organization, 2018). The explanation about this phenomenon could be found in the fact that austerity ignores the role of deficit spending as a stabilizer of employment and private sector's liquidity (Koratzanis & Pierros, 2017). Additionally, government spending contributes to a higher internal demand level (De Grauwe & Ji, 2014). This dual functionality of government spending was systematically ignored the years following the crisis. The focus of the financial help programs was the achievement of public budget surpluses even if that meant that private consumption and demand would be sacrificed.

Figure 3.4 presents the evolution of total consumption in Greece the years following the outburst of the crisis. Total Consumption fell from almost 190 Billion euros to almost 140 Billion in just 5 years.

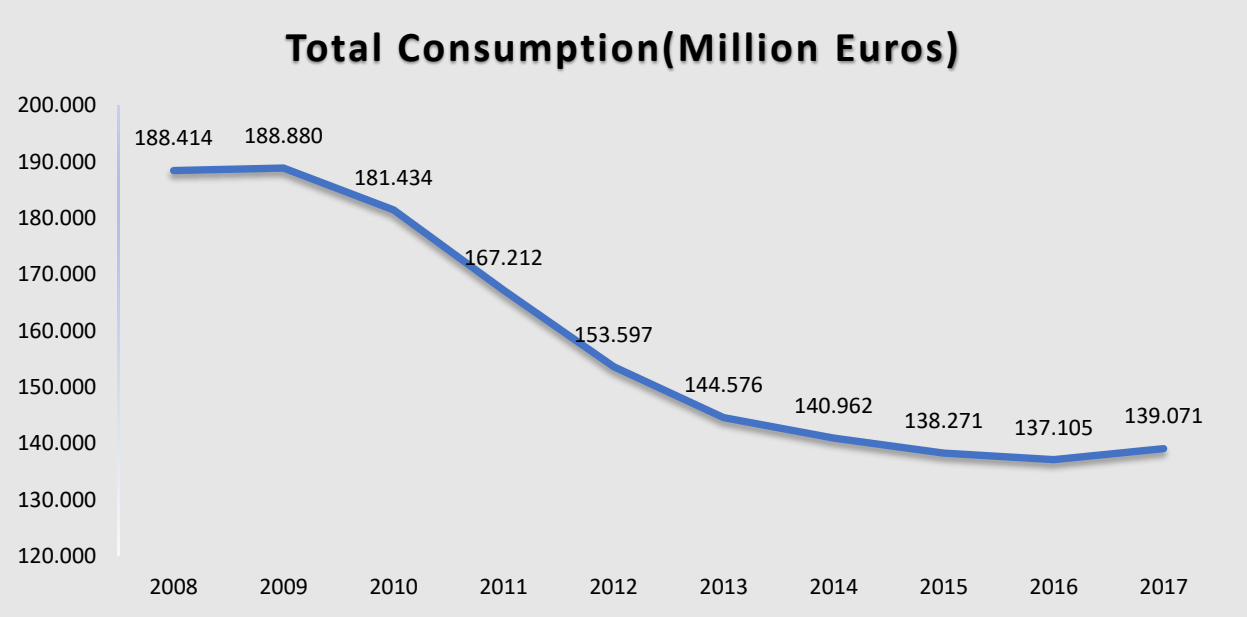


Figure 3.4: Total Consumption (source: ELSTAT,2019)

As we speak, Greek governments have committed themselves to achieving surpluses of 3,5 % for the upcoming years (Stiglitz, 2016). But these commitments are suppressing the ability of Greek governments for some fiscal space that could be using for trying to bring consumption and demand back on track. Total consumption decreased almost 18 % in the period 2010-2014 while in the Eurozone countries the decline was only 0.5 percent and in the European Union countries, consumption had a small increase of almost 1 percent. Cuts in pensions and salaries which consequently led to a decline of income are mostly responsible for the decline of consumption (Mavridakis et al., 2015). As a result of the private consumption and the uncertainty of the economic environment, private investments sunk.

3.3 Evidence on literature on the connection of private and public investments

In the introduction chapter of the current research, different studies on how the factors that can possibly influence either positively or negatively the growth of private investments were mentioned. The purpose of the current section is to provide a more thorough insight on those studies. Additionally, it aims to highlight not only the factors that influence the private investments but also the diversity of the results regarding the impact of public investments on private investments.

In the literature there is a variety of macroeconomic factors that could potentially influence private investment. Real interest rate, profit tax rate, as well as employees' compensations and level of private consumption amongst others. The institutional and political environment as well as real investment capital costs can be determinants of the private investment growth or decline (Sinevičienė & Deltuvaitė, 2014).

Table 3.1 below summarizes the relevant literature concerning the effect of public expenditures and tax increases in the private investments as well as other important indicators. The information provided is limited only on those variables of interest and not the total range of results presented in those papers. The impacts are separated into three categories: positive, negative or neutral.

From the table it can be concluded that despite the great variety of studies conducted and the different techniques used in order to investigate the impact of public investments in the evolution of private investments, the conclusions are not converging in all occasions. Some researchers conclude that the impact is definitely negative, such as Blanchard and Perotti, others conclude that they can increase private investments, such as Traum and Yang, and others detect an ambiguity or neutrality on the impacts ,such as Kasselaki and Tagkalakis.

Among the literature, there are additional papers of interest that could be investigated, but the most important and relevant ones are listed on the table below.

Table 3-1: Relevant literature on the impact of public investments on private investments

Authors	Title	Inputs	Positive Impact	Negative Impact	Neutral impact
Fuji, Hiraga and Kozuka, 2013	Effects of public investment on sectoral private investment: A factor augmented VAR approach	Public investments	Private investments(agriculture and utilities), GDP	Private investments(construction,estate, mining, manufacturing, transport and communication), long-term interest rate	Positive or negative depending on different sectors
Blanchard and Perotti,2002	An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output	Goverment spending		Private investments	
		Tax increases		Private investments	
Kasselaki and Tagkalakis, 2016	Fiscal policy and private investment in Greece	fiscal consolidation	financial markets, economic sentiment		
		government spending			Private investments
Alesina, Ardagna, Perotti and Schiantarelli, 2002	Fiscal policy, profits, and investment	public wages' increases, public employment increase, government transfer increases		companies profits, private investments	
		Tax increases		Private investments	
Forni, Monteforte and Sessa, 2009	The general equilibrium effects of fiscal policy: Estimates for the Euro area	government teansfer increases		Private investments	
Argimon et al., 1997	Evidence of public spending crowding-out from a panel of OECD countries	Public investments	productivity,private investments		
Apergis,2000	Public and private investments in Greece: Complementary or substitute 'goods'	Public investments	private investments (until 1985)	Private investments (1985-1996)	
Traum and Yang, 2013	When does government debt crowd out investment?	increased government investments, decreased capital tax rates	private investments	interest rate	
		labor tax reduction	labor demand	income tax, government spending	Private investments (ambiguous)
Burriel et al., 2010	Fiscal policy shocks in the euro area and the US: An Empirical Assessment	Tax increases		GDP, prices	
Edelberg, Eichenbaum and Fischer, 1999	Understanding the Effects of a Shock to Government Purchases	fiscal stimulus	government purchases, non-residential investment and GDP,short-term real interest rate	residential investment, real wage, production,long-term real interest rate	
Kuismanen and Kämmpi,2010	The effects of fiscal policy on economic activity in Finland	government expenditure	GDP	private investments, private consumption	
Baxter and King,1993	Fiscal Policy in General Equilibrium	government investments		tax rate, private investments, private output	

Fujii, Hiraga, & Kozuka (2013) argue that the impact of public investment can vary amongst different sectors of the economy. The paper argues that public investments in an economy can potentially have a positive impact on specific private sectors, while they can have a negative impact on other private sectors. The sectors of the economy are separated into 7 categories. Agriculture, utilities, construction, estate,

mining, transport and communications and wholesale and retail trade. Positive impact is noticed only in the agriculture and utilities sectors.

In the paper of Blanchard & Perotti (2002) on the other hand, results are clearer. The connection of government spending and taxation with private investments is examined. The authors' results suggest that both government spending and tax increases have a negative impact on private investments. Thus, a balanced-budget fiscal expansion is having a negative impact over private investments.

Kasselaki & Tagkalakis (2016) argue that a spending-based fiscal consolidation from the government can have a positive impact upon the financial markets and improve the economic sentiment. However, one of the most difficult tasks in economic theory is to forecast the behavior of the free market. John Maynard Keynes referred to this market's behavior as "animal spirits". It is thus difficult to forecast if financial markets will respond positively in an announcement of fiscal consolidation plan. As recent history suggested, in the case of Greece but also other Southern European countries, financial markets kept behaving nervously even after the announcement of fiscal consolidation measures that were implemented from the local governments. In the current model, built for the purposes of the current thesis, the behavior of financial markets in response to fiscal policies is out of scope because the modelling of such process is quite difficult to simulate and assess.

Keynesian theory also suggests that private consumption and disposable income increase in case of higher government spending. Kasselaki & Tagkalakis (2016) however argue that due to the fact that the European Central Bank (ECB) in its mandate has the task to keep the interest rate at a level of 2%, an increase in government spending will not necessarily have a positive impact on private investments. In fact, the effect is more likely to be neutral. Despite that, Greece experienced a period of high inflation, above 2%, until approximately 2010 and then a rapid drop and then an increase again in 2011. Afterwards though, Greece started experiencing a rapid drop of inflation which eventually led to deflation. The impact of this fluctuation in the inflation rate on private investments is not yet clear. But what is apparent, is that private consumption had a huge drop since the beginning of the crisis.

Additionally, Kasselaki & Tagkalakis (2016) argue that if government expenditure is financed from debt accumulation, that will lead to decrease of private investments because of higher future interest rates. According to Alesina, Ardagna, Perotti, & Schiantarelli (2002): "increases in public wages, public employment and government transfers increase the wage pressures in the private sector, both in unionized and competitive labor markets. This reduces profits and private investment. Also, taxes (in particular labor taxes) lower investment, however, the effects of government spending on investment are larger than those of taxes".

Another factor that it is introduced by Forni et al. (2009) is that private investments could drop because of a potential increase in government transfers due to higher rental rate of capital. The rental rate of capital is also out of scope in the current model of this thesis due to limited time availability.

In the paper of Argimón, González-Páramo, & Roldán (1997) conclude that targeted public investments on infrastructure can have a positive impact on private investments because they improve productivity.

In his attempt to explain the potential negative effect of public investments on private investments, Apergis (2000) identifies 3 main reasons: Firstly, private investments are negatively influenced by public investments when those are substantially subsidized and there are managed from ineffective companies that are partially owned by the government. Secondly, this negative relationship can occur, when investors expect an increase in tax rates, after the government announces plans for fiscal policy. Finally, this relationship appears, when public investment expenditure is in sectors that are competitive with private sector's interests. He is making the distinction between productive expenditure, such as investments in infrastructure and capital and non-productive expenditure such as increases on wages and salaries.

Traum & Yang (2015) in their paper about the potential crowding out of public investments on private investments construct a new-Keynesian based Dynamic Stochastic General Equilibrium (DSGE) model. From their research, they conclude that a fiscal stimulus can have direct and indirect effects and that investment can either increase or decrease based on the type of the fiscal stimulus. They suggest that increased government investments or decreases in the capital tax rate can have a positive impact on the private investments in the short-term, despite an increase in the interest rate. In the case of labor tax reduction, the results are ambiguous, since investments can either grow or decrease because on the one hand the labor demand increases, but at the same time there is higher probability for higher income tax and lower government spending.

Burriel et al. (2009) follow a similar approach to Blanchard & Perotti (2002) by constructing a standard Vector AutoRegressive (VAR) model that provides empirical evidence about the size of fiscal multipliers in US economy. Their main finding lies upon the fact that government fiscal stimulus appears to be more persistent in the US than in the EU. When taxes are increased, both GDP and prices follow a negative path.

Edelberg et al. (1999) conclude in their VAR model that a governmental fiscal stimulus results in a decrease of residential investment, real wage, production but also lead to an increase of government purchases, non-residential investment and GDP. Finally, real interest rates fall in the short-term but increase in the long-term.

Kuismanen & Kämppi (2010) investigate the impacts of fiscal policy in the Finnish economy. To do that, they use Vector Stochastic Process with Dummy Variables (VSPD). Among their main findings is that an increased revenue on public sector has a positive impact on investment and GDP, while it has negative impact on private consumption. However, they conclude that higher government expenditure has a negative impact on the private sector and investments.

Finally, Baxter & King (1993) investigate the effects of fiscal policy in general equilibrium by following a neoclassical model. According to Baxter & King (1993): "(i) permanent changes in government purchases can lead to short-run and long-run output multipliers that exceed 1; (ii) permanent changes in government purchases induce larger effects than temporary changes; (iii) the financing decision is quantitatively more important than the resource cost of changes in government purchases; and (iv) public investment has dramatic effects on private output and Investment ". The fourth point they make on their research is based on the logic that with higher public investments, a government needs to increase the tax rate which consequently leads people to have lower motivation to work and invest. The latter has as a result that the

tax base is reduced, and the government has to increase taxes even more to cover for the losses. This is in line with neoclassical macroeconomic theory regarding the impact of public investments on private investments.

3.4 Chapter Conclusion

The introduction of the European common currency was accompanied with common interest rates for the European countries that allowed for cheap credit in the Southern European countries. Greece's public debt, public budget deficit and trade deficit increased during that period. That left the country vulnerable to external shock that came via the loss of trust from investors when the European financial crisis began. *The immediate impact of the European financial crisis then was that the country had to borrow at extremely high interest rates to pay back its already substantial public debt. As a result, austerity measures were adopted with the target of decreasing the twin deficit, the public deficit and the trade deficit. Public expenditures were cut down, and taxes were increased. The public deficit dropped drastically, but private consumption, real GDP dropped also drastically, and unemployment exploded. As a result, private investments experienced a heavy downfall*. Finally, in the third part of the chapter, literature review showed that there is a variety of contradicting results on whether public investments influence positively or negatively the private investments and no definite conclusion can be made.

4 Model preparation and setup

To investigate further the relation of public and private investment and to explore the policies that can help re-activate private investment, we introduce the System Dynamics model of the Greek economy.

First, the conceptual model of the Greek economy is presented with 7 sub-models. The conceptual model describes the qualitative relations of the model's most important variables, the outcomes of interest and the policy levers that will be used for the analysis (4.1). Next, the basic stock-flow structures of the sub-models for the Greek economy are presented and explained (4.2). A validation of the model is done to determine its suitability for the purpose that it was built. The validation is made in the form of setting questions regarding its suitability and providing answers that establish the validity of the model. Extreme scenarios are explored to observe the model behavior (4.3). Finally, the experimental set-up for the next chapter that includes all the uncertainties, outcomes of interest and policy levers, described in the conceptual model, is presented (4.4).

4.1 Conceptual Model

As described in chapter 2, the starting point for the conceptual model is the equation of Dos Santos & Macedo e Silva (2010). Aggregate demand depends from private consumption (Cp), private investments (Ip), government investments (Ig), government consumption (Cg) and net export balance (Exports-Imports). The private investments variable is disaggregated in the households' investments and the companies' investments.

The conceptual model contains 7 sub-models that represent the 3 sectors of the economy (households, companies, government) as well as the exports-imports, population, unemployment and wages. The conceptual model and the 7 sub-models are presented in Figure 4.1.

The government sector refers to the general government and consequently the total government revenue, expenses and budget refers to the general government level. Public budget balance in this conceptual model represents the total budget balance including interest payments and thus it is directed linked with the public debt. Government has control over the policy levers that include taxes and public investment rate. These are the tools that a government can implement in case of expansionary fiscal policy (Naastepad, 2002). Increased public investments could of course come from external borrowing, but in the Greek case, that seems highly unlikely given the economic situation of Greece and the excessive public debt level, that does not allow for more borrowing in the near future.

The companies' sub-model includes only the profits and the companies' investments in the current conceptual model, since these are the most important variables, and the chosen outcomes of interest for the model. Households' sub-model includes the real disposable income of consumers and the private household consumption. Wages sub-model includes the average real wage level, that refers to both private and public sector. The model does not make a distinction between the average level of the two

sectors, but it rather takes an average value of both. Labor productivity is also included in the wages sub-model since it is an important variable of influence of the wage level change (Storm, 2017b, 2019).

The population model consists of only one variable in the conceptual model, but in the System dynamics' model it is divided in cohorts of 5 years. Thus, the population is divided in total of 11 cohorts that start from age 0 and end to a cohort of 80+ years. The population model is finally linked to the unemployment sub-model that includes the total workforce and the unemployment rate for the total population, which is one of the outcomes of interest for the current research.

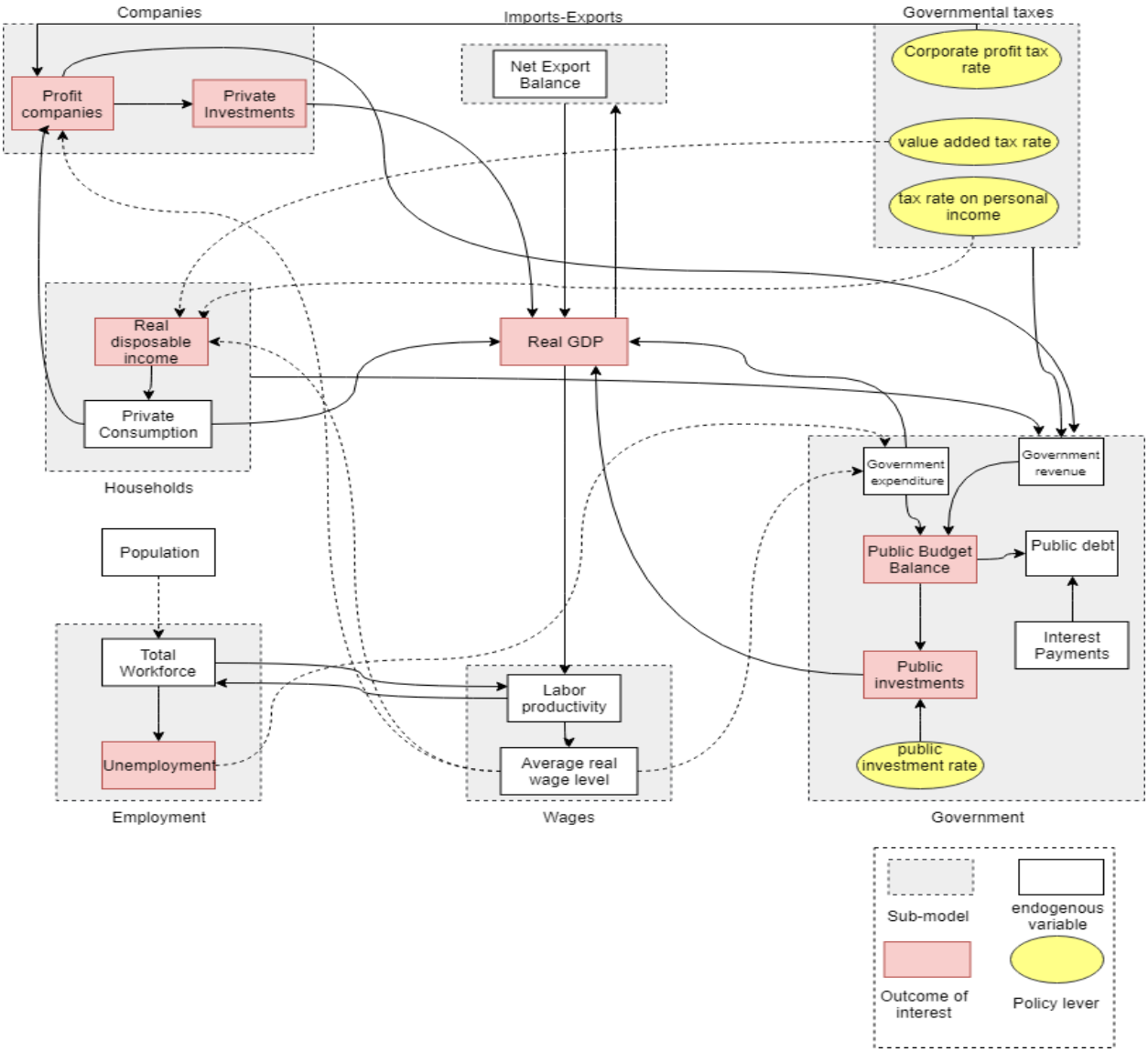


Figure 4.1: Conceptual Model

The dotted lines in the diagram do not have a different meaning than the other lines. They are presented this way in order to make the diagram more understandable. In the middle of the model, as presented in the conceptual model, is the real GDP that is connected as described in the equation of Dos Santos & Macedo e Silva (2010). The sub-models are found in the gray rectangle, with the exception of the population sub-model, as it consists of only one variable in the conceptual model. Governmental taxes are also presented in a grey rectangular, but they are not a different sub-model since they actually are part of the government sub-model. However, in the graphical presentation of the conceptual model it was chosen to be presented separately from the government sector, as most of the policy levers that are used in the current research, are found there.

The companies' profits are influenced by the corporate profit tax rate (policy lever), the average real wage level and the private consumption. The companies' profits in return, they influence the private investments level and the government tax revenue. Higher companies' profits mean higher private companies' investments and higher government revenue. At this point a significant trade-off of the model becomes apparent. Higher corporate tax profit rate increases the government tax revenue, but simultaneously it decreases the company profits, as the companies' expenditures increase too. Consequently, it is not certain that in case that the government increases (decreases) the tax rate will necessarily increase (decrease) its revenue. This is one of the points for investigation.

Additionally, an increase in personal tax and value added tax increases, in principle, the government revenue and the public budget balance that gives fiscal space for higher public investments. But as in the case of the corporate profit tax, there is a negative impact to another variable, the private consumption. Private consumption will decrease in case of higher tax, since the real disposable income of consumers decreases. Consequently, a decreased level of private consumption, decreases the level of companies' profits and eventually the level of private investments and the real GDP level.

Real GDP influences the level of labor productivity, which in return influences the total workforce and the level of unemployment. A higher level of GDP leads to increased labor productivity (Storm, 2019), higher workforce and lower unemployment. Total workforce is also influenced by the population and more specifically the working age population. The growth of population is an important economic variable, as a decrease in the population (lower birth rates, higher death rates) will eventually lead to a decrease of the total working population or an ageing of the population and thus the "pool" from where the workforce comes, gets smaller.

Finally, an increased real GDP leads to a higher import level, which in return leads to a decreased net export balance. In case that the imports exceed the country's exports, as is the case for Greece (ELSTAT, 2019a), the country faces a trade deficit. This a negative feedback loop in the system.

4.2 Sub-models

In the current section, the basic stock-flow structure of the 7 sub-models is presented. This division was chosen as it was easier to handle the size of the final model. The sub-models were built first during the course of the thesis and they were then integrated to the unified model. Adjustments were made after the integration in order to have a proper working model.

Before we dive into the sub-model equations it is useful to have a color code for the various variables of the model and what those represent. In table 4.1 below the it is presented what each color represents.

Table 4-1: Model color code

Color	Type	Explanation
Black	Variables	Endogenous model variables
Red	Constants	Exogenous model constants
Turquoise	Variables	Macroeconomic policy variables

Apart from those three categories, in the model there are also invisible variables. Those are the “Year”, “Billion” and “Time” variables. Time is only used to define auxiliary variables of the model. “Year” and “Billion” have value 1 and are used for unit check. Since they have a supportive role in the model and they did not influence the other model variables, they are not presented in the interface of the System Dynamics model.

4.2.1 Import-Exports

The exports of the Greek economy (X_G) depend on the real value of GDP of European Union (Y_{EU}), export elasticity (γ), price deflator of exports on goods and services of EU (P_E^{EU}), price deflator of exports on goods and services for Greece (P_E^G) and the export price elasticity (k). The export coefficient C_o is calculated based on the initial values of the equation variables (Papadimitriou et al., 2013).

The aggregate of European GDP was chosen, since almost two thirds of the Greek exports are directed towards the European countries (Workman, 2019). The price deflators are retrieved from the AMECO website (AMECO, 2019).

An assumption made during the construction of the imports-exports sub-model was that export and import elasticities are at 1. This is a limitation of the current model, as in the model of (Papadimitriou et al., 2013) export and import elasticities are calculated relative to Germany. Despite that, as they are considered uncertainties in the model, different values are examined in the next chapter were EMA workbench is used for uncertainty analysis.

Table 4-2: Greek exports

Exports of Greek economy	Units
$X_G=C_X * Y_{EU}^{\gamma} * (\frac{P_E^G}{P_E^{EU}})^k$	X_G: Billion Euros C_X: dimensionless Y_{EU}: Billion Euros γ : dimensionless P_E^G: dimensionless P_E^{EU}: dimensionless k: dimensionless

The imports of the Greek economy (M_G) depend from the real value of Greek GDP (Y_G), import elasticity (γ), price deflator of imports on goods and services of EU (P_M^{EU}), price deflator of imports on goods and services for Greece (P_M^G) and the import price elasticity (n). The import coefficient C_M is calculated based on the initial values of the equation variables (Papadimitriou et al., 2013).

Table 4-3: Greek imports

Imports of Greek economy	Units
$M_G=C_M * Y_G^{\gamma} * (\frac{P_M^G}{P_M^{EU}})^n$	**M_G**: Billion Euros **C_M**: dimensionless **Y_G**: Billion Euros **γ** : dimensionless P_M^G: dimensionless $\boldsymbol{P_M^{EU}}$: dimensionless **n**: dimensionless

Net trade Balance is simply defined as the difference between Exports and Imports (Papadimitriou, 2013). Both the cumulative net balance and the yearly net balance are calculated.

4.2.2 Government

For the construction of the government sector equation the ELSTAT quarter non-financial account report was explored as well as the AMECO website equations. The equations are adjusted accordingly in the model construction to provide a more dynamic behavior.

According to ELSTAT (2019) the total annual government revenue is calculated as:

$$Total\ government\ revenue = taxes\ on\ production\ and\ imports + taxes\ on\ income\ and\ property + social\ contribution + other + capital\ transfers$$

Equation 4.1: Total government revenue, ELSTAT

According to AMECO (2019) total annual government revenue is calculated as:

$$Total\ government\ revenue = sales + other\ subsidies\ on\ production + property\ income\ receivable + other\ current\ transfers\ receivable + taxes\ on\ production\ and\ imports\ receivable + social\ contributions\ receivable$$

Equation 4.2: Total Government revenue, AMECO

According to ELSTAT (2019) the total annual government expenditure is:

$$Total\ government\ expenditure = compensation\ of\ employees + social\ benefits + goods\ and\ services + subsidies + other\ current\ transfers + capital\ transfers + interest\ payments$$

Equation 4.3: Total government expenditure, ELSTAT

According to AMECO Database:

Total government expenditures (including interest payments)
= gross capital formation + compensation of employees payable + other taxes on production payable
+ subsidies payable + property income payable + current taxes on income and wealth payable
+ social benefits other than social transfers in kind payable
+ social transfers in kind related to expenditure on products supplied to households via market producers payable
+ other current transfers payable
+ adjustment for the change in the net equity of households on pension funds reserves
+ capital transfers payable + acquisitions of non − produced non − financial assets

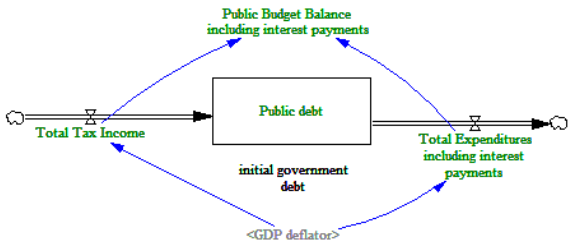
Equation 4.4: Total government expenditures, AMECO

The final equations for the stocks and flow of the government sub-model are presented in tables 4.4 and 4.5.

Public debt was model as a stock, since it accumulates over time and depending on the level of government revenue and expenditures can either increase or decrease. In 2017 the Greek public debt as a ratio of GDP was at 188 % and kept increasing. Total tax income is the sum of taxes (direct and indirect) to households and companies and the social contributions paid by employees and employers (Table 4.4).

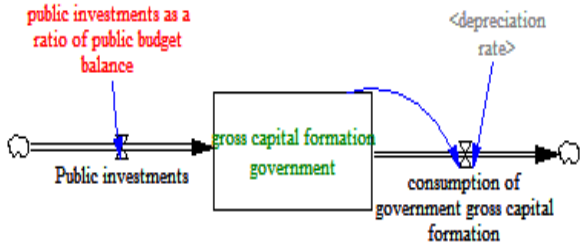
Government expenditures are described from the ELSTAT equation. Every element of the expenditure equation is constant as a percentage of the GDP except the compensation of the public employees that is dependent from the number of public employees and the average annual wage level.

Table 4-4: Public debt

Stock-Flow structure	Equations	Units
	Stock: **Public Debt**=Total Tax Income - Total Expenditures including interest payments	Billion Euros/Year
	Flows: **Total Tax income**= revenue from social contribution + revenue from property tax + revenue from corporate tax + revenue from value added tax + revenue from personal income tax **Total government expenditures (including interest payments) =**compensation of public employees + social Benefits + Goods and Services + subsidies + capital transfers paid + interest payments	Billion Euros/Year/Year

Initial Public Debt for the Greek government is 317 Billion in 2017 and the government presents a small primary budget surplus (ELSTAT,2019). The initial public budget balance is calculated in the model based on the initial values of the tax income and the expenditures.

Table 4-5: Gross capital formation government

Stock-Flow structure	Equations	Units
	Stocks: **Gross capital formation government** = Public investments - consumption of government gross capital formation	Billion Euros/Year
	Flows: Public investments= public investments as a ratio of public budget balance* Public budget balance including interest payments consumption of government gross capital formation= depreciation rate* gross capital formation government	Billion Euros/Year/Year

Gross capital formation of government is the stock derived from the difference of annual public investments and the capital depreciation. Capital is depreciated in a constant rate of 10 % every year. Public investments are also a percentage of the annual public budget balance. It is assumed that in case that there is a public deficit, then there is no public investment. That is unrealistic, as a government always has to invest a minimum amount just to retain the gross capital formation, but if there is a deficit, that amount is coming from borrowing. Since in the model, the banking sector is not included or any external financing, then the only choice for the government is to rely on its own funding.

4.2.3 Private sector

Private sector includes the country's companies. The main stocks here are the cumulative profits (net profits) of companies and the gross capital formation of companies. The equations for the stocks and flows are derived from the AMECO website (AMECO, 2019). The data for the initial values is also taken from the ELSTAT and AMECO website. The same databases were used in the paper of Papadimitriou et al. (2013) that is the basis of the macroeconomic model.

Table 4-6: Private sector stocks

Stocks	Equation
Net profit	Total Revenue companies -Total expenditure companies
Gross capital formation companies	Companies capital investments- Consumption of fixed capital

The net profit of the companies is again the difference of the companies' revenues and their total expenditures (including profit tax). Apart from the gross value added, the rest of the companies' revenue remains constant for the purposes of the current model. This assumption makes the model more static. Despite that, one can argue that the values of those variables do not change that much over time compared to the gross value added. Gross value added depends on value that vary over the years, namely the nominal GDP, the compensation of employees and the public investments.

Gross capital formation of companies follows the same structure as the gross capital formation of the government with the difference, that the capital investments depend on the profits of the companies.

Table 4-7: Private sector flows

Flows	Equation
Total Revenue Companies	Gross value added + net current transfers received+ net property income companies + other subsidies on production
Total Expenditure companies	Gross capital formation companies+ Corporate profit tax + Compensation of private employees + other capital expenditure + other taxes on production
Companies capital investments	investments as percentage of profit * profit
Consumption of fixed capital	depreciation rate * Gross capital formation companies

4.2.4 Households

The household sector is separated from the companies' sector in the current model. The purpose of this division is to investigate separately the private investments from the households and the companies. Household investments are kept stable during the run of the model since its value did not fluctuate a lot the past years (AMECO,2019). Combined the gross capital formation of companies' sector and households' sector account for 57% of the total gross capital formation (AMECO, 2019).

Real disposable household income is the total real household income minus the taxes that households need to pay (direct and indirect). Taxes include the personal income tax for all households, the valued added tax (indirect tax) and the property tax. Property tax as a percentage of the GDP was almost doubled after 2010 as a part of the austerity measures but has remained almost stable since then and thus it is assumed exogenous and constant for the model. Personal tax depends from the employees' income. The higher the income, the higher the revenue for the government and the expenditures for the households respectively.

Household income is the sum of compensation of employees, social benefits received and the net property income. The last two remain exogenous in the current model. Social benefits are provided by the government and include pension benefits, unemployment benefits, sickness, disability and survivors' benefits (ELSTAT,2019). They are modeled as a percentage of the GDP since it is rather difficult to find disaggregated data for each of these categories. Net property income is defined as property income receivable minus property income payable (AMECO,2019).

Table 4-8: Households' stocks

Stocks	Equation
Real disposable income	Total real income- taxes paid by households
Private gross savings	Savings rate

Table 4-9: Households' flows

Flows	Equation
Total real income	(Compensation of employees + net property income households + Social Benefits)/GDP deflator
Taxes paid by households	Revenue from personal income tax + Revenue from Property tax + Revenue from Social contribution + Revenue from value added tax
Savings rate	propensity to save * real GDP

4.2.5 Population

Population is divided in age cohorts every 5 years. In total there are 16 cohorts starting from age 0 up to 80 plus. Separating the age groups every 5 years provides a sufficient insight on the population change on difference. A more detailed population division, every year for example, would be more time consuming in terms of work and simulation and would necessarily provide extra information for the Greek population.

The death rate is also calculated for every cohort, based on UN Data (2019) for absolute number of deaths in 2017 and the population data of ELSTAT (2019). The cohorts are then subscripted and calculated in one single stock. Total Population is just the sum of the population of all age cohorts.

Migration is presented as a flow in the model, but it is not taken into consideration in the calculations. The justification of that choice is presented on the reflection section of the last chapter. Average fertility per woman, is assumed exogenous and stable. If one wanted to endogenize, one should come up with policies for giving motives for more births. The general trend in Greece, as in most European countries, is a constant decrease in the average fertility. As a result, the population is both decreasing and ageing. Financially, that impacts the number of working age population, that is the “pool” from where the labor force comes.

Table 4-10: Population stock

Stocks	Equation
Population	Births-Ageing[Age0to4] - Deaths[Age0to4]-migration + Ageing[PreviousAgeGroups]-Ageing[AllButYoungestAndOldest] - Deaths[AllButYoungestAndOldest] -migration+ Ageing[Age75to79] -Deaths[Age80plus]

Table 4-11: Population flows

Flows	Equation
Births	Average fertility per woman * relative share women in fertile age * SUM (Population [FertileAge!])/Years in fertile age
Ageing	Population [AgeGroups]/Average time per age group
Deaths	Population [AgeGroups] * death rate [AgeGroups]

4.2.6 Unemployment

The unemployment sub-model includes a subscripted stock for the workforce. According to OECD (2018) the labor force includes employed people from 15 years up to 64. Despite the fact that average age of retirement for public employees has increased from 61 to 65 years since 2010 (Asteriou, Lalountas, & Siriopoulos, 2011), the general definition of OECD is implemented in the current model.

The level of workforce depends mainly on three variables. The population that provides the "pool" of working age population, the real value of GDP and the labor productivity. As the total population is excepted to decrease in the next decades, even if the model included migration, the number of people in working age is expected to decrease. The labor force is derived as the direct relation of working age population and the labor force participation rate. This relation is also in compliance with the OECD definition for labor force. Nevertheless, there could be policies that could influence the percentage of labor force participation rate, but they are not examined in the current model.

The actual workforce depends on the hiring and firing flows. The hiring process and firing process depend on the demand for workforce and the ageing of the workforce. Labor demand depends on the average real wage level and the real GDP value. An increase in labor productivity implies that there is a lower demand for labor, which can lead to higher unemployment rate. But higher labor productivity has a positive impact on the companies' profits since expenditures are decreasing and thus private investments are increasing. This is a trade-off of between investments and employment but the magnitude that each impact has is not immediately clear.

Table 4-12: Workforce stock

Stocks	Equation
Workforce	Hiring[LaborForce]-Ageing of Workforce[LaborForce]-Firing[LaborForce]

Hiring and firing processes have a time dependency. In general, the time for hiring is lower than the time for firing. That of course depends on the labor regulations that every country implements. In the standard Neoclassical theory, if prices remain constant, a high level of unemployment will lead to a weakening of

the labor unions' power. That implies that labor regulations can also be weakened. Not only wage level, but average firing time can decrease.

$$u^* = \frac{a_0 - (1 - a_2) * \lambda + \alpha_3 * Z}{\alpha_1}$$

Equation 4.5: NAIRU equilibrium unemployment (Storm & Naastepad, 2012)

Where:

u^*= equilibrium unemployment

Z: institutions and policy

λ: productivity growth

Variable Z represents a whole set of institutional and regulatory variables that have an impact on the workers' wage, such as employment labor legislation, labor union density and unemployment benefits (Storm & Naastepad, 2012). The higher the value of Z the more extensive is the labor market regulation. An increase in the value of Z means that there will be a demand from workers for a higher real wage growth.

The coefficients a_0, a_1, a_2, a_3 are empirically estimated. Coefficient a1 represents the tendency of workers for higher wage demands when unemployment is low. Coefficient a2 represents the relation of labor productivity growth and real wage growth. For example, if a2 value is 1, that means that the real wage growth matches the labor productivity growth. Finally, the coefficient a3 represents the impact of a higher market regulation on the equilibrium unemployment rate.

As it is difficult to estimate the values of the coefficients in the above equation and the value of the variable Z a different approach was taken. In the current System dynamics model, average hiring/firing time are considered exogenous and do not follow the NAIRU approach. Instead, they are explored as uncertainties in the next chapter of the current research. The uncertainty in the average hiring or firing time derives mostly from the changes in the value of Z as described in the above equation.

Table 4-13: Workforce flows

Flows	Equation
Hiring	MAX(Relative difference between potential and actual workforce,0) / average hiring time for new workforce* (Available Labor Force[LaborForce]-Workforce[LaborForce])
Firing	MAX(-Relative difference between potential and actual workforce,0)/average firing time workforce*Workforce[LaborForce]
Ageing of Workforce	relative change working population per group[LaborForce]*Workforce[LaborForce]

4.2.7 Wages

The main variables of the wages sub-model are the GDP deflator, wage levels and labor productivity. GDP deflator is a measure for inflation in an economy (Chen, 2018). The rate of growth for the inflation is assumed exogenous in the model and constant at 2% in the basic scenario. The level of 2% is the desired level of inflation for every European Economy according to the mandate of the European Central bank (Stiglitz, 2016).

The European Central's Bank mandate for low inflation in an economy is based upon the assumptions of Neoclassical and Monetarist schools of Economics. Those assume, that there is no trade-off between inflation and output since money is neutral (Naastepad, 2002).

On the contrary, in the 1970s and 1980s both in US and European countries inflation was high. It was the time when Keynesian view was still dominant. According to Keynesian theory, real GDP growth can be achieved even if inflation is high, when nominal GDP growth is higher. The relation is described in simple words in equation 4.6.

$$Real\ GDP\ growth = \ \ Nominal\ GDP\ growth - inflation$$

Equation 4.6: Real GDP growth

The same relation applies for the wage levels. If nominal wage level growth is higher than inflation, real wage level will increase.

$$Real\ wage\ growth = \ \ Nominal\ wage\ growth - inflation$$

Equation 4.7: Real wage growth

The direct implication of those two relations is that nominal wage growth and nominal GDP growth should be higher than 2 % as assumed in the model. The real wage level growth is dependent also from the labor productivity growth. The higher the labor productivity, the higher real wage growth. In reality though, this relationship is not "1-1". A unit of increase in labor productivity does not lead to 1 unit of increase in real wage level. The exact estimation of the relation magnitude is explored in the next chapter of uncertainty analysis. Since, the purpose of the model is to assess the future behavior of important variables the estimation of the relation is not modeled based on past relation, but as an uncertainty.

Table 4-14: Wages' stocks

Stocks	Equation
GDP deflator	Inflation
Average real wage level	Wage level growth
Labour productivity	Labour productivity growth

Table 4-15: Wages' flows

Flows	Equation
Inflation	annual growth rate inflation*GDP deflator
Wage level growth	productivity growth factor*average real wage level
Labour productivity growth	productivity growth factor*labour productivity

4.3 Model Validation

In the current section the validity of the model is examined. Validation is used to examine if the model is suitable for the purpose that it was built for. Validation is both quantitative and qualitative. First it is examined if the model is consistent with prior knowledge of macroeconomic theory. Secondly, the level of aggregation of the model is examined. Next, an assessment of the exogenous parameters used in the model is made. Afterwards, an examination of the validity of the model boundary is made. Next, an examination of the system behavior is done. We examine if the system is behaving as it was supposed to, and if the outcomes have realistic values. Finally, the model behavior in the face of extreme variation in the inputs conditions or policies is examined. The full model validation description can be found on the appendix.

On table 4.16 below, the structural validation of the model is presented in a Q & A form. The full description of the model validation is presented on the appendix.

Table 4-16: Structure assessment of the model

Question	Answer
Is the model consistent with prior macroeconomic theory?	The current model is built on the basis of a traditional macroeconomic model (Papadimitriou et al., 2013). Apart from the equations used in this macroeconomic model, additional equations from AMECO database and ELSTAT definitions were used, where necessary, to expand the SD model. It can be concluded then that the model is consistent with prior macroeconomic theory.
Is the level of aggregation appropriate for the purpose of the research?	The purpose of the current research is to explore the economy in a macroeconomic level. All the components of the system and the outcomes of interest, such as the real GDP, unemployment rate or public budget balance are macroeconomic values in the aggregate level of a national economy. The research choice then to keep all the values in a national macroeconomic level seems to serve the purpose of the research analysis. It can be concluded then, that the level of aggregation is appropriate for the purposes of the current analysis.
Do exogenous parameters respond to reality?	Almost all exogenous parameters have accurate real-world values. Most data are retrieved from reliable sources, such as AMECO website, ELSTAT website and EU KLEMS. The main exogenous parameters that do not have real-world values, are public investments as a ratio of public budget balance and private investments as percentage of profit, but they are subject to uncertainty and sensitivity analysis.

Is the System boundary adequate for the purposes of the analysis?	Most of the economy's components are modelled as endogenous variables. The most important variables of an economy are the components of the GDP. Private consumption, public expenditure, private investments, public investments and net trade balance are all endogenous variables in the model. The purpose is to explore the evolution of the GDP over the course of 33 years. Of course, when we refer to such a long-term economic period, there are other important parameters that could influence the system, such as external financial shocks, natural disasters, wars. This are not included in the model, but their forecasting is very difficult at least. That does not weaken the argument that the system boundary is adequate for exploring policies. On the other hand, the system could be expanded in the future by endogenizing relevant exogenous parameters. The most important parameters are the inflation and the labor productivity growth.

Model Behavior

Does the model behavior respond to reality?

The main task of a system dynamics model is to reproduce a realistic system behavior rather than accurate quantitative values for the model variables (Radzicki, 2011). From that perspective, the analysis is not focused on reproducing a point-to point data neither from historical values nor for future values. Besides, forecasting future real values for macroeconomic variables for the GPD or public budget balance has proven challenging in the recent past even for big organizations, such as the IMF, ECB or OECD.

Apart from the contribution that a final System dynamics model provides, its great value derives from the modelling process itself (Radzicki, 2011). Having said that, most of the model outcomes do not seem to fit with realistic values of most economic components such as the GDP. But what fits is the model behavior that the model generates. The basic scenario for the real GDP shows, that in the short-term it increases. However, afterwards we observe a decrease in the real GDP.

The explanations for that decrease can rely upon many reasons, most of them well justified from macroeconomic theory. A lack of both private and public investments that is observed after that time period eventually leads to a decrease to consumption and consequently to a decrease of companies' profits. The reasons and the important elements for that behavior are analyzed in the next chapter. However, the model behavior from a macroeconomic perspective is valid with the theory.

Finally, the population sub-model results are in line with the forecast of the UN for the Greek population growth until 2050 with zero migration (United Nations, 2019). UN forecast for the total Greek population in 2050 is 8.8 Million people. In the basic scenario of the current model, the forecast of the population is 8.75 Million people. As it can be seen in figure 4.2, the difference is almost null.

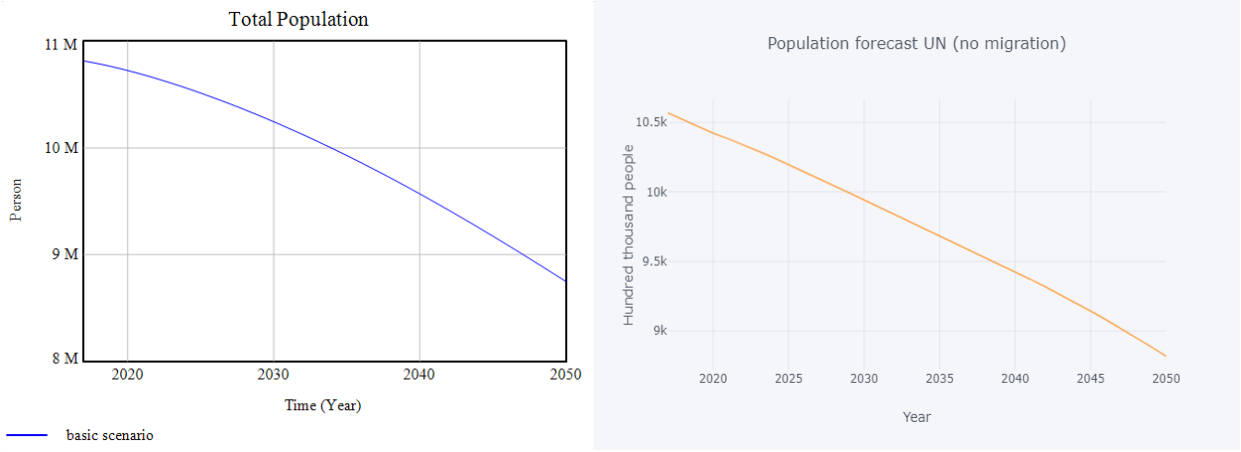


Figure 4.2: Population growth

Model behavior under extreme conditions

How does the system behave under extreme conditions?

We want to examine the model behavior in cases of extreme conditions. To do so, we explore 3 extreme scenarios for the economy, and we observe the model behavior compared to the basic scenario. The behavior of the model in every scenario is discussed on table 4.17. In every scenario, one of the exogenous variables receives a representative extreme value.

Table 4-17: Extreme scenarios

Scenario	Variable of interest	Value	Model Behavior
Long-term recession in the EU	Growth rate of GDP EU	**Initial**: 1% **Scenario value**: -2%	A negative growth rate of EU GDP leads to a decrease at the exports of the Greek economy. Net trade balance is lower than in the basic scenario and the difference occurs from the drop in the country's exports. Real GDP is dropping in a faster rate than in the basic scenario, as the impact of exports' decrease is pushing down economic growth.
Extreme inflation	Inflation rate	**Initial**: 2% **Scenario value**: 10%	Real GDP and imports present the same behavior in that scenario. The extremely high inflation rate leads to a rapid decrease of the real GDP and the Greeks imports from the beginning of the model. The economy is shrinking rapidly. The low values of the real GDP create a persistent public deficit. Although the behavior can be explained by macroeconomic theory, the magnitude of the GDP drop seems unrealistic. That could be explained by a high sensitivity of GDP values on the inflation rate.
Exceptional interest payments	Rate of interest	**Initial**: 3.1 % of GDP **Scenario value**: 10% of GDP	Real GDP graph has an expected behavior for such a high increase in the interest rate. As the expenses of the government increase and has to borrow in a much higher interest rate, real GDP value drops in a faster rate. There is a difference at the initial values for the total government expenditure that can be explained, as the

			increase in expenditures from the higher interest rates is assumed from the beginning of the model. The public budget balance has a logical behavior, as its value is lower than the one in the basic scenario.

Validation conclusion

It can be concluded that the System Dynamics model for the Greek economy is appropriate for its purpose. The model is consistent with prior macroeconomic theory and has the proper level of aggregation for the purpose of the research. The system boundary is adequate for the current analysis and allows for the exploration of the sensitive factors regarding the outcomes of interest of the model as well as the policies that can help revive the private investments. Almost all exogenous parameters that are used for constructing the model respond to real values and their validity is strengthened through the research regarding their values. Parameters that are not derived from the literature, such as public investments as a ratio of public budget balance and private investments as percentage of profit, are clearly mentioned as assumptions in the report and they are subject to uncertainty and sensitivity analysis.

From a numerical point of view, the model is not reproducing accurate real-life values for most outcomes of interest. Exception is the Greek population growth forecast that is in line with the UN prediction for the population growth, if migration is not taken into consideration. From a behavioral point of view, the model is consistent with real life behavior of the economy. The exploration of the model behavior under extreme conditions, did not reveal significant discrepancies in the system. It did reveal though some unrealistic behavior in some variables' magnitude, such as the very low value of real GDP in the scenario of high inflation. The model can be used in combination with the EMA workbench for sensitivity and scenario discovery analysis.

4.4 Experimental Set-up

For the simulations, the Exploratory Modelling and Analysis (EMA) workbench is used. The EMA workbench provides the possibility for simulation and analysis on models developed in various modelling packages, such as the Vensim software (Ventana, 2015). EMA workbench, was developed by J.H. Kwakkel of the Delft University of Technology with the use of the programming language Python (Python, 2018). The EMA workbench offers support for setting up simulation runs, performing simulation runs, and analyzing the results (Kwakkel, 2012).

The System Dynamics model of the Greek economy is simulated from 2017 until 2050. 2017 was chosen as a starting point for the model for data consistency reasons. Data for some initial values of the model are not available after this year. 2050 was chosen as the end year of the run, as we want to explore the long-term impacts of the implemented policies and the growth of the outcomes of interest in the long-term. The model time step is set on 0.03125/year. Graphs do not change if we set a smaller step size, half value of the current step size, thus chosen step size is appropriate for the analysis. Even with such a small step, simulation does not require a lot of time to finish. The chosen integration method is Runge-Kutta 4 Auto, since results do not different significantly if Euler method is used.

In the tables 4.17, 4.18 and 4.19 below the uncertainties, policy levers and outcomes of interest are presented.

4.4.1 Uncertainties

Uncertainties are used as the inputs in the EMA Workbench analysis to explore how model outcomes of interest look based on different scenarios. They can be found in all sub-models, but that is justified, given the complexity of a system such as a country's economy. Most of them can be detected in the Imports-Exports sub-model. The EMA workbench will help exploring the most significant uncertainties for the model and which uncertainties, do not really have an impact. The full table for uncertainties' initial values and the explanation behind the value range is given on appendix A of the current document. As some of the uncertainties' ranges cannot be set precisely, some of the values in the ranges are given approximate values. It is desirable to have a broader range for the uncertainties in some occasions, rather than setting too strict limits that can exclude plausible scenarios that are of interest for the analysis.

Table 4-17: Uncertainties

Uncertainties	Sector	Initial Value	Value Range
Capital depreciation rate	Companies, Government	0.1	0.075-0.125
Propensity to save	Households	0.075	0.05-0.1
Interest rate	Public sector	0.031	0.01-0.05
Growth rate GDP EU	Import-Exports	0.01	0.01-0.03
GDP deflator EU	Imports-Exports	1.091	1-1.2
Export elasticity	Import-Exports	1	1-2
Import elasticity	Import-Exports	1	1-2
Average fertility per woman	Population	1.3	1.2-2.1
Average hiring time for new workforce	Employment	0.5	0.5-1
Average firing time workforce	Employment	1	1-1.5
Labour force participation rate	Employment	0.683	0.6-0.8
Percentage public employees	Employment	0.18	0.1-0.2
Annual growth rate inflation	Wages	0.02	0-0.03
Productivity growth factor	Wages	0	-0.01-0.03
Investments as a percentage of profit	Companies	0.3	0.2-0.5

4.4.2 Policy Levers

Only the initial values for policy levers are presented based on 2017 values for the taxes. For public investments it is assumed that half of the public budget balance is directed through public investments. This is a starting point for the simulations and does not represent the real-life percentage value. But as it is presented in the policy design of chapter 5, the target is to explore the impact of a higher percentage of public investments from the budget and not the absolute value of the percentage. In other words, the impact of "higher" or "lower" percentage of public investments.

For the value added tax rate and tax rate on personal income average values are chosen. For personal tax income there are 4 income levels: 0-20.000 euros, 20.000-30.000, 30.000-40.000 and above 40.000 with tax rate of 22%, 29%, 37%, 45% (Foka, 2019). The average tax rate on personal income is calculated based on the total revenue of the government from personal tax income in 2017 (ELSTAT, 2019a) and the total number of employees at the end of 2017. The value added tax rate has 3 scales in 2017. The standard rate of value added tax is 24% since 2016. There are two other scales of reduced tax, 6% and 13% that apply in a limited category of goods and services. For that reason, in the current model, the standard value added tax of 24% is chosen.

Table 4-18: Policy levers

Policy Levers	Sector	Initial Values	Units	Source
Corporate profit tax rate	Companies	0.29	Dimensionless	Trading economics
Value added tax rate	Public sector	0.24*	Dimensionless	Trading economics
Tax rate on personal income	Public sector	0.3**	Dimensionless	Trading economics
Public investments as a ratio of public budget balance	Public sector	0.5	Dimensionless	

*This is the highest value of added tax. There are reduced rates of 13% and 6% for specific categories of foods and services and distanced areas

** Tax rate on personal income had different values based on income level. Here a single average value is calculated

4.4.3 Outcomes of interest

The outcomes of interest focus mostly on the real GDP, the profit of companies and the gross capital formation of the companies. These variables are inherently connected as the change in the value of one has an impact on the value of the other. The connection of profits and gross capital formation is more direct as explained in previous sections of the research. The real disposable income of households is of

significant interest, as an increase in the purchasing power of households, will lead to an increase of the corporate activity.

The unemployment rate is of course among the outcomes of interest, as one of the goals of this research is to find policies that will decrease the unemployment to an acceptable level. As acceptable level of unemployment could be considered a level of unemployment close to full employment. With the term full employment, we refer to the fact that there is no involuntary unemployment.

Public budget balance cannot be excluded from the analysis. The main restriction that crisis had in the Greek economy, explained in chapter 3, is the target for a decrease in the public budget deficit and a decrease in the public debt. Thus, an economy recovery should be achieved, given that public budget balance cannot be derailed. Alongside the public budget balance though, it is crucial to investigate the development of the gross capital formation of the government. One of the main tasks of the current research is to investigate the impact of this value, if any, on the development of the GDP and the private investments, as was again explained in chapter 3.

Table 4-19: Outcomes of interest

Outcomes of Interest	Sector	Units
Real GDP		Billions Euros/Year
Profit	Companies	Billions Euros/Year
Gross capital formation companies	Companies	Billion Euros/Year
Gross capital formation government	Government	Billion Euros/ Year
Real disposable income	Households	Billion Euros/Year
Public budget balance including interest payments	Government	Billion Euros/Year
Unemployment rate	Employment	Dimensionless

For the SOBOL simulations 32.000 experiments are conducted. The number of experiments is sufficient, since after 24.000 and 28.000 experiments, results do not vary significantly. For the visualization results, 10.000 experiments that include the policies are conducted. Again, no significant change is observed compared to a run of 5.000 experiments. In chapter 5, the simulation results with the use of visualizations, SOBOL and PRIM analysis are presented.

5 Simulation Results

In Chapter 4, the conceptual and the System Dynamics model were introduced. The uncertainties, policy levers and outcomes of interest were presented. These are used for the simulation analysis for the current chapter, Chapter 5, that is conducted with the EMA Workbench. First the visualization analysis on the outcomes of interest is presented. The visualization analysis presents the different values of the outcomes of interest, given the system' uncertainties and the different policies. The visualization analysis provides clear view of the impact of the different policies. In the second part of the current chapter, the SOBOL analysis is introduced and presented, with the target of identifying the most sensitive factors with respect to the outcomes of interest. In the third part, the results from the scenario analysis with the use of PRIM are introduced. Purpose of PRIM analysis is to identify the uncertainty space where policies perform inadequately. The last part of this chapter concludes the results from the 3 sections.

5.1 Visual analysis on outcomes of interest

As discussed in chapter 4, 4 policy levers are defined that the government can influence. Namely these are the corporate tax profit rate, the value added tax, the tax on personal income and the public investments as a ratio of public budget balance. We want to explore policies that can influence the development of private investments as well as the other outcomes of interest.

Given the fiscal austerity that Greek government is facing, the policy design is based on a clear trade-off. If government wants to spend more on public investments, this can only come through increasing its revenue. In this model, the only policy levers that the Greek government can influence, are these three categories of taxes. Thus, an increase in public investments should come through an increase on those taxes. The first policy is then called "Higher taxes".

The alternative that the Greek government has, is to decrease the rate of taxes, with a parallel reduction of the government investments. A decrease of taxes on companies' profits, personal income, value added tax, would decrease the revenue of the government, and would slow down the government investment rate. Consequently, this could slow down consumption, and potentially GDP growth that would have an impact on the country's imports. On the contrary though, a decrease in the companies' profit tax would allow companies for a higher profit rate and the ability to invest more. For the purposes of the experiments this policy is called "Lower taxes".

The goal in this section is not to identify the optimal values of the policy levers that would maximize or minimize the values of the outcomes of interest. The goal is to get a visual verification of which policy is in general more effective for the outcomes of interest.

Only 4 out of total 7 outcomes are presented in this section. The rest of the visualization results can be found in appendix E. Jupyter Notebook. Additionally, on the same appendix, the scores for the mean

values, the 25 % percentile of values and the 75% percentile of the two policies are given. These values concern the numerical outputs for all the outcomes of interest at the end of the run, namely in 2050.

In Figure 5.1 we observe the simulation results for the real GDP with the 2 policies. On the x-axis, time is expressed in years, from 2017 until 2050. The 2 policies are presented with different colors for better understanding of the differences. The orange color is for the policy of lower taxes and lower public investments as a ratio of public budget balance and with blue color is the higher taxes policy.

For better understanding of the visualization results, we use the Kernel Density Estimation (KDE) plot. With KDE we can observe the probability distribution of outcomes' density in 2050. Higher density of values shows where most of the values for every outcome of interest can be found.

Two things become apparent from KDE in Figure 5.1. The first observation that can be extracted from the plot is the probability distribution of real GDP density. For the higher taxes policy, density is higher in lower levels of real GDP. That means that more expected values of real GDP in higher taxes policy are found in a lower level of GDP compared to the expected values of real GDP for lower taxes policy. That result indicates, that the policy with lower taxes combined with lower public investments, leads eventually to higher values of real GDP. In other words, lower taxes policy is more effective for the GDP growth in the majority of the scenarios at the end of the run.

The second observation that can be extracted from the graph is that with the lower taxes policy there are higher extreme values for the real GDP. That means that across the scenarios generated for the simulation runs and for certain values of the uncertainty parameters, max value of GDP has a higher value in lower taxes policy, than in higher taxes' policy. That difference on the maximum and minimum values of the two policies is clearer on the appendix E. Jupyter notebook, where only those values and their KDE plots are presented.

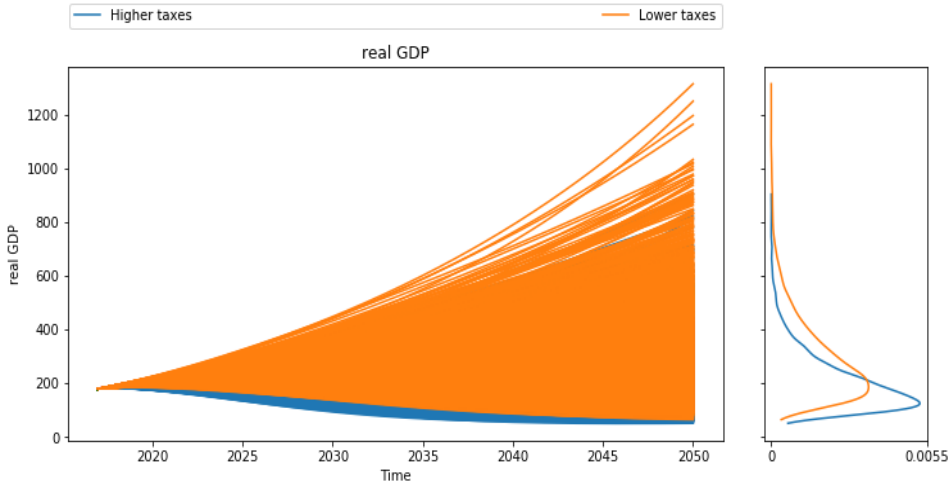


Figure 5.1: Real GDP visualization

The numerical values for the two policies presented in table 5-1 below confirm the conclusions extracted from the visualization and the KDE plot. In the EMA Workbench, 5.000 scenarios concern the policy of lower taxes and 5.000 scenarios the policy of higher taxes, in total 10.000 scenarios. The value of interest

in this case is the mean value for the two policies, because it is an indication of which policy is generally producing better results. As can be observed in the table, the mean value for a low taxes' policy is higher than the mean value of a high taxes' policy in 2050. In the long-term then, we observe that a low taxes' policy produces higher values of real GDP.

Table 5-1: Real GDP scores in 2050

Low taxes		High taxes	
count	5000.000000	count	5000.000000
mean	288.540320	mean	200.971240
std	152.016328	std	103.805743
min	64.498680	min	50.876015
25%	176.350855	25%	124.344610
50%	251.080330	50%	175.222010
75%	361.796388	75%	251.226165
max	1314.416600	max	903.664550

Additionally, results from the table indicate a big variance of final values for the real GDP, that is reflected on the standard deviation. The minimum value for the real GDP is approximately 50 Billion euros at the end of 2050, for the higher taxes policy, while the maximum value is almost 1.3 Trillion euros, in the case of lower taxes policy. Both values can be considered rather unrealistic, as the initial value of real GDP for the Greek economy in 2017 was 177 Billion euros (ELSTAT,2019). To find an explanation for these extreme values of real GDP, we must return back to Chapter 2 and the definition of Gross Domestic Product. In this chapter, GDP was defined as the sum of private consumption, government consumption, private and public investments and the net export balance. Every element of the GDP has a level of uncertainty. There are uncertainty parameters in the system, whose range can be set adequately, such as the inflation rate or productivity growth factor. But there are also uncertainties in the system, whose range cannot be specified with relative accuracy, such as the propensity to save in the household sector or the investments as a percentage of profit. We want to take a closer look then to the other outcomes of interest and observe their behavior.

In figure 5.2 the simulation results for the gross capital formation of the companies show again that the lower taxes' policy has in general higher values. The highest density for higher taxes' policy is found in a lower level than the lower taxes' policy. It is concerning, that in the graph appear extreme and unrealistic values for the gross capital formation of the companies, as in the real GDP graph. We observe from the graph that the maximum value for gross capital formation of companies in the lower taxes policy is almost 700 Billion. That accounts for almost 60 % of the maximum value of real GDP in the previous graph.

As discussed in Chapter 2, variables in a System Dynamics model, can influence each other through feedback loops. A higher value of real GDP leads to a higher value of gross capital formation of companies through higher profits and vice versa. Profits are translated to investments in the current model via the variable of investments as a percentage of companies' profits. The range of this variable cannot be specified with accuracy because of the lack of an average value for it on literature. Thus, a high value of this value, could be held responsible for a high value of gross capital formation.

Nevertheless, we can observe that for both policies, the highest density is found in a potentially realistic level that does not deviate so highly from the initial values of companies' gross capital formation.

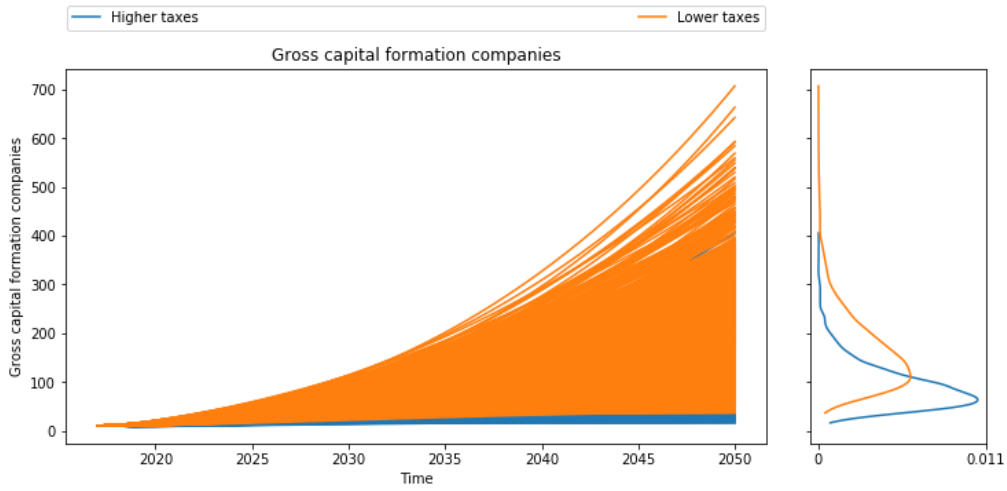


Figure 5.2: Gross capital formation companies' visualization

The numerical interpretation of the visualization results for the gross capital formation of the companies in 2050 is presented on table 5-2 below. The mean value for the companies' capital formation in the case of the low taxes policy is again higher than the mean value of the high taxes' policy. Low taxes' policy produces a mean value that is almost double the mean value of the high taxes. This finding confirms that the lower taxes combined with lower public investments is more efficient on achieving higher values of private investment.

Table 5-2: Gross capital formation companies' score in 2050

Low taxes		High taxes	
count	5000.000000	count	5000.000000
mean	162.656378	mean	91.485988
std	78.294524	std	46.479530
min	36.380890	min	16.112116
25%	106.430113	25%	58.028703
50%	146.467340	50%	81.630417
75%	201.263220	75%	113.313673
max	707.261900	max	405.559420

We now want to explore the correlation of the real GDP and the gross capital formation of companies. For that purpose, a scatterplot of the real GDP and the gross capital formation of companies is presented in figure 5.3. From the graph, the almost linear correlation of the real GDP and the gross capital formation of companies for both policies is confirmed. From a policy point of view, this observation is useful for confirming an almost obvious but not self-evident conclusion. An increase in the private investments in an economy requires a strong growth rate on the country's GDP and vice versa.

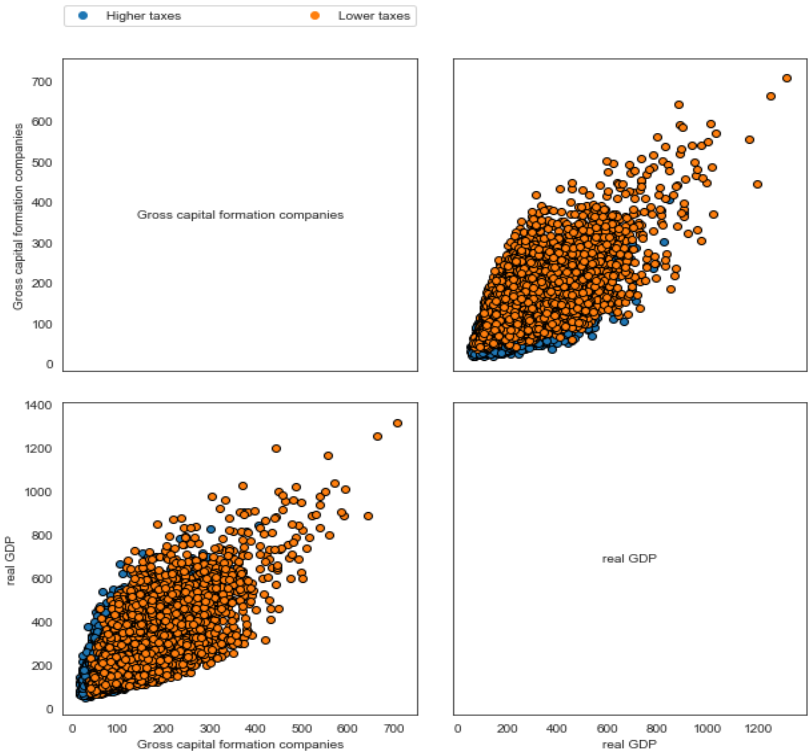


Figure 5.3: Real GDP-gross capital formation companies' correlation

As discussed at the beginning of this section, Greek governments are committed to achieving public surpluses in order to decrease the level of public debt. Thus, the public budget balance is an indication about the increase or decrease of the public debt in the Greek economy. In figure 5.4 below, the impact of the two policies on the public budget balance is presented. First, we observe that the highest density for higher taxes' policy is found closer to the zero-line boundary. On the contrary, the highest concentration for the lower taxes policy is found on the negative ax (public deficit). Additionally, the extreme values for both policies on the positive ax are almost identical, while the extreme values on the negative ax are much higher for the lower taxes policies.

The combination of three graphs presented above can be interpreted as such: A policy of lower taxes reduces the burden of households and companies and thus can lead in higher consumption and company profits. But at the same time, the revenue of the government is declining due to the lower percentages of taxes. The increase on the real GDP from the increase on public investments does not suffice for balancing the losses of the government from the tax decreases. In a schematic way it could be described as such: With lower taxes policy, the government is asking for a smaller piece of the pie and expects that the pie will grow enough that in the end the piece will be bigger, because the pie has grown in size. But as we observed from the results in the graphs, that expectation is not confirmed.

Finally, from figure 5.4 we can clearly observe the different starting values for public budget balance for both policies. The initial value of the variable is affected from the different initial values of variables, because of the uncertainty range they have, that are connected to the public budget balance. Such variable is the interest rate as a percentage of the GDP in the current model.

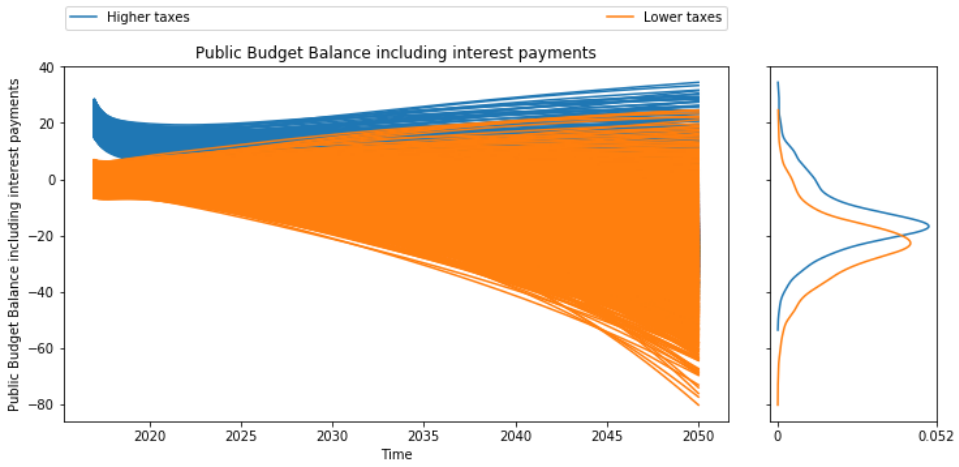


Figure 5.4: Public budget balance visualization

The numerical values for the public budget balance are presented in the table 5-3 below. The mean value of the low taxes policy can be found at a lower level than the mean value of the high taxes policy. That verifies the conclusion from the visualization analysis about the policy trade-off for the low taxes policy. However, it is noticeable that the mean values for both policies are negative. That implies, that even in the long-term, it is likely that the Greek government will be running a public deficit no matter what the implemented policy. The government's expenditure is higher in the long-term than the income of the government. The explanation can be found on the fact that the growth of the income of the government grows in a slower pace than the growth of the expenditures of the government for both policies. Of course, there are occasions were the government can run a public surplus for both policies. That can be confirmed from the table due to the fact that the maximum values for both policies are positive. From the EMA Workbench results we observe that positive values of public budget balance in the case of the low taxes policy can be achieved only if the inflation rate is close to zero. That finding can be explained by the fact that inflation rate in the current model is negatively influencing most of the main outcomes' values. More analytical explanation is provided in the second section of the current chapter, where SOBOL analysis is conducted.

Table 5-3: Public budget balance score in 2050

Low taxes		High taxes	
count	5000.000000	count	5000.000000
mean	-23.999388	mean	-14.411407
std	12.034727	std	11.287160
min	-80.299225	min	-53.644780
25%	-30.535736	25%	-20.970758
50%	-23.585062	50%	-15.797211
75%	-17.544052	75%	-8.858203
max	24.584290	max	34.440720

As with the real GDP, we want to explore the correlation of the public budget balance with the companies' gross capital formation. In section 3.3 of the current document, the literature review was focused on the findings of other studies, concerning the relation of public investments and private investments. In the

current model, this relation can be investigated by examining the relation of public budget balance and gross capital formation of the companies, because the higher taxes policy that is connected with higher public budget balance values, as observed in Figure 5.4 is also connected with higher values of public investments.

In the scatterplot of figure 5.5, their correlation is presented. From the graph, we can observe that the two variables have an almost reverse linear relation for both policies. Higher values for public budget balance are connected with lower values of companies' gross capital formation. This correlation is stronger in the lower taxes policy. The very high values of gross capital formation are also connected with very high levels of public budget deficit.

From government policy perspective that would mean that the government should allow for high public deficits, that derive from lower tax rates, that would help in boosting the private investments. This is a clear policy implication for the government. Very high growth rates of private investments require a chronic public deficit. But as already discussed from the introduction of the current research, Greek governments have committed themselves to achieving public surpluses. Thus, very high values of private investments cannot be achieved, unless there is consensus among the Greek governments and the three institutions, namely the IMF, ECB and the European Commission, that supervise the growth of the Greek public budget balance the ratio of public debt.

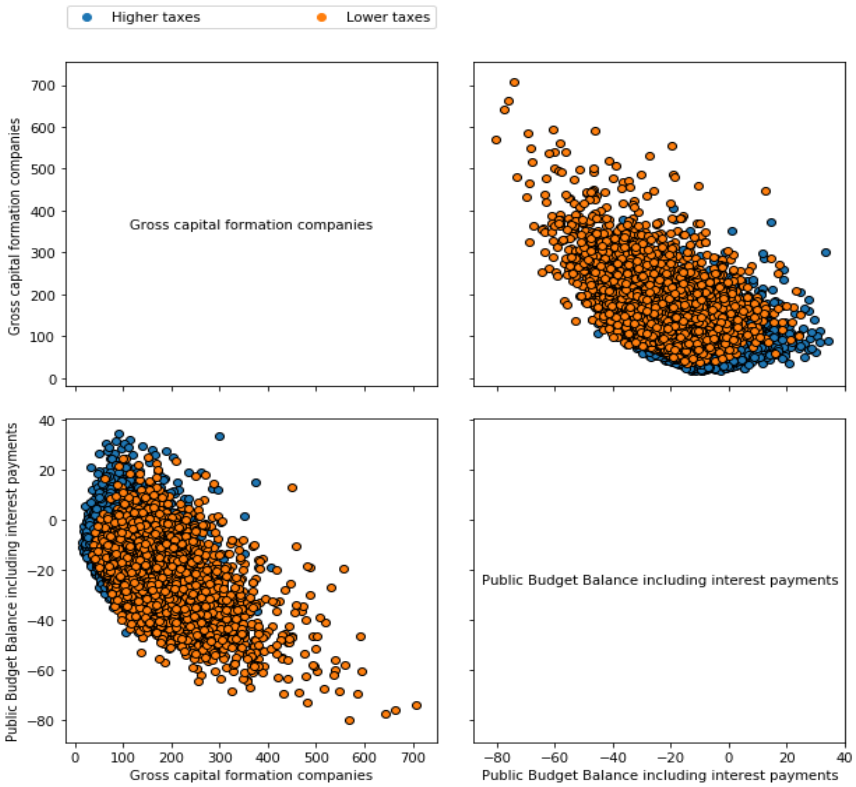


Figure 5.5: Public budget balance-gross capital formation companies' correlation

Next, we explore the impact of the two policies on the unemployment rate and consequently the correlation of unemployment rate and gross capital formation of companies. In the introduction Chapter

it was mentioned that private sector accounts for almost 80 % of jobs in Greece. It is important then to explore which policy is more effective on producing lower levels of unemployment.

Figure 5.6 shows the simulation results for the unemployment rate. Two things become immediately apparent in the graph. The first observation that is apparent in the graph, is the extreme variation of unemployment rate. For the lower taxes policy, the highest probability concentration is on low levels of unemployment. A policy of lower taxes seems then to achieve the target of reducing the unemployment rate for the Greek economy. As discussed before, the policy of lower taxes, leads to higher values of private investments. Higher private investments lead to higher values of real GDP and thus higher demand for labor. The higher demand for labor leads to more people getting hired and thus reducing the unemployment rate.

However, this conclusion cannot and should not be received as definite. We cannot tell with certainty if this holds true, since from the graph an extreme variation of values is observed. Both policies can produce really high values of unemployment. The extreme variation can be appointed to the big variance of the total demand for labor and not so much in the available labor force, that is mostly influenced by the growth of the population and the labor force participation rate.

Demand for labor is dependent on the value of real GDP and the growth of real wages. As observed in the graphs above too, the big variations of the real GDP values, heavily influence also the behavior of the unemployment rate. A combination of low value of real GDP in combination with a low productivity growth, the main determinant of real wage growth, could lead to extreme values of unemployment. On the contrary, if the conditions are reversed and there are high values of real GDP, as is the case for lower taxes policy, and labor productivity combined with sufficient labor force, the final outcome is a low level of unemployment.

In contrast to the lower taxes curve, the KDE curve for the higher taxes policy is almost flat. No significant point with higher concentration can be found on the graph. One plausible explanation could be found in the uncertainty level of the system. Hiring and firing process in the model are dependent on the demand for labor, but also in the uncertain variables of average hiring and firing time. A wide range of these values in combination with low values of labor productivity and real GDP, as is the case in some scenarios for the higher taxes policy, could be held responsible for the extremely high values of unemployment and the extreme values' variation.

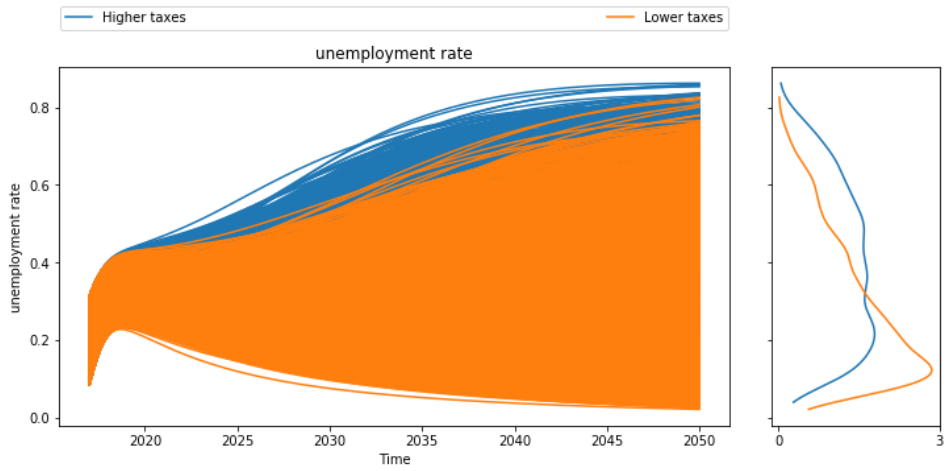


Figure 5.6: Unemployment rate visualization

The extreme variation of the unemployment values for both policies is reflected also in the standard deviation (std) of both policies in table 5-4 below. The standard deviation for both policies is almost 50 percent of the mean values. Thus, even though it can be clearly seen that the mean value of unemployment rate for low taxes' policy is lower than the mean value of high taxes' policy, no definite conclusion can be extracted. Furthermore, the high mean values for both policies, are rather unrealistic, since such high levels of unemployment in real life are socially unacceptable. An unemployment rate of 30 percent would cause tremendous social unrest to the population and would probably lead to governmental and political instability.

Table 5-4: Unemployment rate score in 2050

Low taxes		High taxes	
count	5000.000000	count	5000.000000
mean	0.281267	mean	0.393400
std	0.171608	std	0.190847
min	0.021911	min	0.040055
25%	0.137405	25%	0.230556
50%	0.243410	50%	0.383315
75%	0.400726	75%	0.541341
max	0.825865	max	0.862171

To get a better understanding of the correlation of companies' capital formation and unemployment rate, the two variables are presented in the scatterplot of figure 5.7. We observe that we cannot derive any specific type of correlation from the scatterplot. Even for low values of gross capital formation, unemployment can vary from very low values up to extremely high and unrealistic values. On the contrary, for high values of gross capital formation, the unemployment rate is in almost all cases quite low. The high values of private investments, in the lower taxes policy, can be held responsible for low levels of unemployment. As in the case of the real GDP and the companies' capital formation correlation, this conclusion might seem quite obvious, but it is not self-evident.

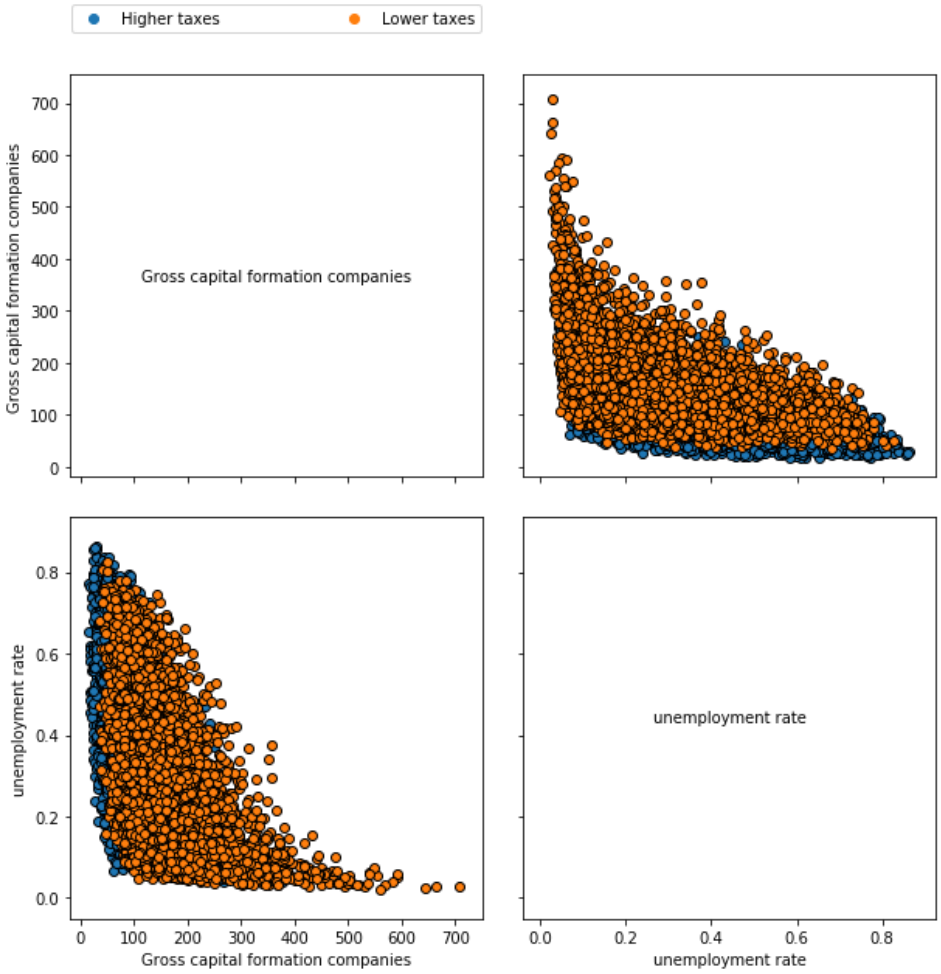


Figure 5.7: Unemployment rate-gross capital formation companies' correlation

The graphs for the rest of the outcomes of interest and the impact of the two policies upon them, can be found in the appendix of the current document. The policy of lower taxes is proven more efficient for the real disposable income. Lower taxes on personal income and value added tax, allow for lower households' expenses and thus more available income for private consumption or savings. A reduction on the corporate profit tax, allows for lower payments to the government and thus they can keep a bigger share for either investments that contribute to the increase of the GDP or distribute them as dividends to households and shareholders. Those dividends are again part of the households' income and can be directed towards private consumption or savings. On the other hand, the policy of higher taxes produces higher values for the government's gross capital formation. An increase in the 3 categories of taxes, allows for more government income and more fiscal space for public investments.

Visualization conclusion

Table 5.5 below summarizes the results from the visualization analysis*. A policy mix of lower taxes on households and companies, combined with lower public investments is proven more efficient for the real GDP, the companies' profits, the gross capital formation of the companies and the households' real disposable income. On the contrary, a policy of lower taxes combined with higher public investments*

produces, in general, higher values for the governments' gross capital formation and the public budget balance. The policy trade-off is then clear. A policy that favors the increase of private investments and real GDP is accompanied with a lower performance on the public budget balance.

Table 5-5: Table of outcomes with the most effective policy

Outcomes of interest	Most effective policy
Real GDP	Lower taxes
Companies' profits	Lower taxes
Gross capital formation companies	Lower taxes
Real disposable income	Lower taxes
Gross capital formation government	Higher taxes
Public budget balance including interest payments	Higher taxes
Unemployment rate	No definite conclusion

5.2 Global sensitivity analysis

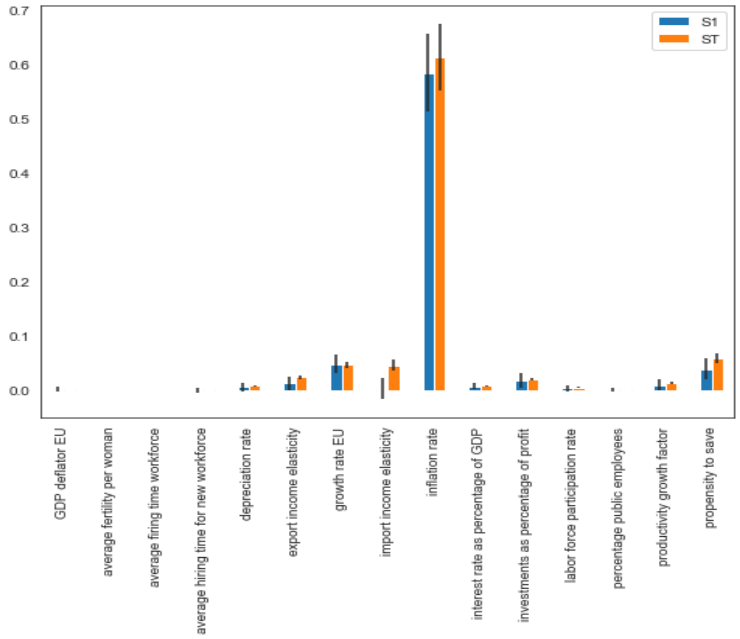
SOBOL sensitivity analysis is used to identify the most sensitive factors with respect to the outcomes of interest. For each of the 15 uncertain parameters, a first-order effect (S1) and a total effect (ST) is presented. First-order gives the single sensitivity of the uncertain parameter with respect to the outcome of interest and the total effect gives the sensitivity of the uncertain parameter to the outcome of interest with respect to all the other uncertainties. From the visual graphs we do not observe a significant difference on the first order effect and the total effect of the uncertainties. Thus, for the table of scores, that is presented next to the visualization results, only the scores for total effects are presented. The scores for both variables vary between 0 and 1, with the ones closer to 1 to be the most influential.

In figure 5.8 below we can observe the visual results and the scores for the total effect of every sensitive factor to real GDP. Real GDP is mainly influenced by the rate of inflation. It is only logical that a country's real GDP is often influenced from a high rate of inflation, especially when the growth rate of nominal GDP is not strong enough to overcome the inflation rate level. The mandate of the European Central Bank is focused precisely on keeping the inflation rate below the threshold of 2% in the European Union countries and protect the countries' economies from high and persistent inflation rates that slow down economic growth.

However, what is somehow troublesome in this result is the magnitude of the inflation rate's influence. A potential explanation for such high influence could be detected on the fact that the inflation rate is used for calculating the GDP deflator which is used for calculating all the real values of the variables in the model. In reality there are different deflators for the exports, imports, private consumption and disposable income. The use of a single deflator then instead of a set of deflators can contribute on making this single deflator more influential than in real life.

Additionally, real GDP is influenced by the export and import elasticities and the growth rate of the EU. That result is in line with Thirlwall's law as described by Setterfield (2011). According to Thirwall's law,

output is dependent on the income elasticity of exports, income elasticity of imports and the global income.



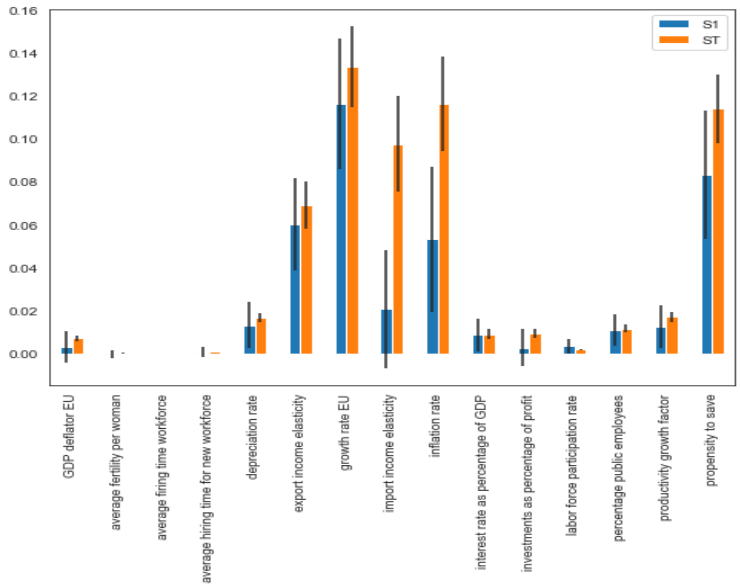
0	GDP deflator EU	0.002366
1	average fertility per woman	0.000073
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001984
4	depreciation rate	0.007874
5	export income elasticity	0.024250
6	growth rate EU	0.047072
7	import income elasticity	0.046036
8	inflation rate	0.613791
9	interest rate as percentage of GDP	0.008132
10	investments as percentage of profit	0.019990
11	labor force participation rate	0.004831
12	percentage public employees	0.001718
13	productivity growth factor	0.012998
14	propensity to save	0.059707

Figure 5.8: Sensitive factors for real GDP

As companies' profits', are closely related to the private investments, we want to explore the sensitive factors that influence them. The most sensitive factors, as presented in Figure 5.9, with respect to the companies' profits are the growth rate of European GDP, the propensity to save and the import and export income elasticities.

The European GDP influences the Greek exports and as a consequence has an influence in the real GDP. Real GDP as explained in the previous section, has an influence in the companies' profits and the gross capital formation of the government. A stronger growth rate of European GDP increases the country's exports and the profitability of the companies. Export and import income elasticities are again influencing the country's net trade balance. Higher export income elasticity strengthens the country's export extroversion and increase the companies' profits. Higher import elasticity on the other hand, strengthen the tendency of imports and thus consumption of goods and services from foreign companies.

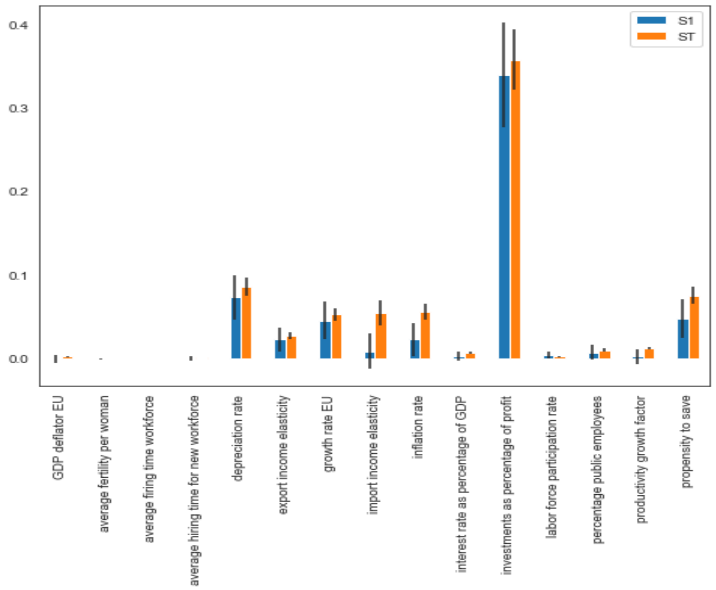
Additionally, it comes as no surprise that the propensity of households to save is influential in the corporate profits. Savings in the current model flow out of the system and are not used again for private consumption or tax expenditures. A higher propensity to save has a negative influence in the companies' profits, due to a lower private consumption from households.



0	GDP deflator EU	0.007164
1	average fertility per woman	0.000326
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001028
4	depreciation rate	0.017015
5	export income elasticity	0.069074
6	growth rate EU	0.133558
7	import income elasticity	0.097721
8	inflation rate	0.116311
9	interest rate as percentage of GDP	0.009243
10	investments as percentage of profit	0.009421
11	labor force participation rate	0.001974
12	percentage public employees	0.011734
13	productivity growth factor	0.017292
14	propensity to save	0.114036

Figure 5.9: Sensitive factors for companies' profits

In figure 5.10 the sensitive factors for the gross capital formation of companies are presented. It is unsurprising, that the investments as a percentage of profits' factor is the most influential factor. The high influence can be verified also by the high value in the table of scores. The higher the percentage of profits that are invested, the stronger the gross capital formation of the companies will be. Additionally, as gross capital formation of companies' is closely related to the profits of the companies, it is only reasonable, that uncertainties that appear in the profits, will also appear in the capital formation too. The difference is detected on the magnitude of the various uncertainties. The investments of the companies are highly dependent on the level of profits that are invested and not distributed to shareholders or dividends.



0	GDP deflator EU	0.002509
1	average fertility per woman	0.000142
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001082
4	depreciation rate	0.085772
5	export income elasticity	0.027443
6	growth rate EU	0.052685
7	import income elasticity	0.054908
8	inflation rate	0.056182
9	interest rate as percentage of GDP	0.006392
10	investments as percentage of profit	0.358297
11	labor force participation rate	0.002338
12	percentage public employees	0.010096
13	productivity growth factor	0.012355
14	propensity to save	0.075761

Figure 5.10: Sensitive factors for Gross capital formation companies

The rest of the outcomes of interest are presented on appendix E. Jupyter Notebook.

The most influential uncertainly for unemployment rate is the inflation rate and important one is the productivity growth factor and labor force participation rate. As discussed above, the inflation rate is the most sensitive factor with respect to real GDP. Real GDP decrease or increase influences the total demand for labor which consequently influences the total workforce and the unemployment rate. Labor productivity influences the total demand for labor which is a determinant for the unemployment rate. Labor force participation rate is influencing the other important factor for unemployment rate which is the total labor force. Higher labor force participation rate leads to higher labor force and, if total workforce remains constant, to higher unemployment.

For the gross capital formation of the government and the public budget balance important sensitivities appear for inflation rate, interest rate as a percentage of the GDP, percentage of public employees and labor force participation rate. The levels of interest rate influences significantly the public budget balance. During the crisis, Greek governments were subject to very high interest rates that led to higher government expenditure and lower government budget balance. Consequently, that affects also the government investments, because they are cut down and the government capital formation decreases. The percentage of public employees can also attribute for higher government expenses and thus less fiscal space for government investments, as higher part of the government revenue is directed towards the employees' salaries. Finally, in the current model important variables that determine both the government revenue and expenditures, such as revenue from property tax or the social benefits are calculated as a percentage of the GDP. As observed above, the real GDP is influenced by the inflation. It is logical then that inflation rate is also influencing elements of the public budget balance and the government gross capital formation.

Real disposable income is highly sensitive to the inflation rate. As prices rise, the disposable income of households drops, and the private consumption rate is slowed down. Inflation affects significantly the real wage level. Assuming that the nominal wage growth rate is lower than the inflation rate, then the real wage level drops and the real disposable income decreases.

Global Sensitivity analysis conclusion

Inflation rate is an important uncertain input parameter for all the seven outcomes of interest. Real GDP and real disposable income are especially sensitive to the inflation rate. Inflation rate, productivity growth factor and labor force participation rate are the most sensitive factors for unemployment rate. Finally, for the gross capital formation of the government and the public budget balance the most sensitive factors are the inflation rate, the interest rate that the government has to pay for new loans and the percentage of the public employees. *The most sensitive factors for the companies' profits, apart from the inflation rate, are the growth rate of the European GDP, the import and export income elasticities and the households' propensity to save. The gross capital formation of the companies' is additionally influenced by the capital depreciation rate and the investments as a percentage of the profits.*

5.3 Scenario discovery

After sensitivity analysis, scenario discovery analysis is conducted to explore the areas where policies perform inadequately. To do that, we define the space where the outcomes of interest have lower performance. Since in PRIM failure or success is defined by the user, a threshold needs to be set. Since PRIM cannot do analysis over time series, the mean value of the outcomes of interests over time is chosen. After we find the mean values for every outcome of interest over the set of scenarios, we define the threshold. The tables with the scores for the means values is found on appendix E. Jupyter notebook. It is chosen then to explore the 25 % of lower mean values. Based on the scores of the outcomes the definition of failure or success is a clear-cut.

Once PRIM algorithm is done, we need to select a box for further exploration. As discussed in chapter 2, the criteria for that are density and coverage. However, there is always a trade-off between density and coverage. If density is very high, it is likely that coverage will be low and vice-versa. For that purpose, we want to look into PRIM boxes where none of the two is low. Unfortunately, there is not a way to immediately find the box of interest, thus we need to explore a few boxes and observe the increase or decrease of coverage and density relative to the other. Ideally, we are looking for boxes where coverage and density is more than 0.6. If that is not possible, we investigate boxes that both are as close as possible to the 0.6 value.

In table 5.6 below the results from the scenario discovery are summarized. The rows indicate the outcomes of interest with the values for density and coverage from the PRIM boxes. The columns indicate the most sensitive input parameters, their initial range and the range values that lead to low values for the outcomes of interest. Only exception is the unemployment rate, where we investigate the 25% of higher values.

Table 5-6: Uncertainty ranges for the 25% of outcomes' lower values

	Uncertainty input parameters						
	Depreciation rate	Growth rate EU	Inflation rate	Interest rate as percentage of GDP	Investments as percentage of profit	Productivity growth factor	Propensity to save
Uncertainty range / Outcomes of interest	0.075-0.125	0.01-0.03	0-0.03	0.01-0.05	0.2-0.5	-0.01-0.03	0.05-0.1
Real GDP Coverage:0.63 Density:0.6		0.01-0.023	0.018-0.03				
Profit Coverage:0.6 Density:0.6		0.01-0.023	0.003-0.03				0.06-0.1

Gross capital formation companies Coverage:0.6 Density:0.51	0.085-0.12				0.2-0.3		
Gross capital formation government Coverage:0.76 Density: 0.56			0.0057-0.03	0.014-0.05			
Real disposable income Coverage:0.72 Density: 0.51			0.02-0.03				
Public budget balance including interest payments Coverage:0.68 Density:0.71			0.014-0.03	0.014-0.05			
Unemployment rate Coverage:0.71 Density:0.6			0.016-0.03			0.004-0.03	

The uncertainties that then influence the values of real GDP are the growth rate of European GDP and the inflation rate. For the growth rate we observe that only some small range of the total range is not influencing the real growth and can be found close to the upper limit of the uncertainty range. In the current model, growth rate of European GDP is linked to the real GDP via the exports. As discussed in the previous section of sensitivity analysis, a stronger growth rate of European GDP leads to higher exports and higher real values of GDP.

The rate of inflation is the second uncertainty that is leading to lower value for real GDP. More specifically, we observe that the higher range of inflation is influencing the real GDP. As discussed in Chapter 4, real GDP is nominal GDP divided by the GDP deflator, which is the measure of inflation in the current model. It is then only natural that inflation will influence the real GDP values. If nominal GDP growth is smaller than the growth of the inflation rate, then the real GDP falls. This finding is in line with the mandate of the ECB that is focusing on keeping the inflation rate in lower level than the 2%.

High inflation rate also influences all the low values for the rest of the outcomes of interest, with the exception of government's gross capital formation. Companies' profits are sensitive to almost the entire range of the inflation rate, thus does not provide any useful information about a tighter range that profits are more vulnerable to. Profits' values are also influenced by a low range of EU GDP growth rate and high values of propensity to save from households.

Low levels of investments as percentage of companies' profits can be held accountable for the low value of the companies' gross capital formation. Companies should increase and channel high percentage of their profits towards investments, as this not only help increase the country's GDP but also increase their future profits from the increase in GDP.

On the government side, the gross capital formation and public budget balance are influenced from the high values of interest rate. Lower interest rate values are needed for the government to manage to balance its budget and also be able to increase its investments.

Finally, unemployment rate is influenced, apart from the high rate of inflation, by positive values of productivity growth factor, the exogenous variable that influences the labor productivity. Higher labor productivity creates the need for less workforce, if everything else were to remain constant. Higher labor productivity leads to lower costs for the companies and the government, but on the other hand, it also contributes to higher level of unemployment via the lower workforce.

Scenario discovery conclusion

From the PRIM analysis we conclude *that higher values of inflation rate have a negative impact in almost all the outcomes of interest. Additionally, lower values of investments as percentage of profit have a negative impact on the gross capital formation of the companies. Lastly, higher values of propensity to save, have a negative impact on real GDP and corporate profits*.

5.4 Chapter conclusion

Results indicate a clear trade-off for the two policies. On the one hand, companies' profits and private investments are favored from a policy of lower taxes and lower public investments. The real GDP that is positively correlated with the private investments is also increasing when a lower taxes policy is implemented. The households' real disposable income is also higher. The decrease of the taxes both in households and companies boosts the private consumption that influences the companies profits and the real GDP. The decrease on the GDP value from the lower public investments is not enough to offset the increase from the tax reduction. On the other hand, public investments and public budget balance is lower. This constitutes a policy dilemma for the government, since Greek governments have committed themselves on achieving public budget surplus in order to reduce the public debt. Higher taxes favor the income of the government and allow for more fiscal space for public spending and investment. It is difficult to make a definite conclusion on which policy favors lower unemployment rates, since there is a big scattering of data from the results. For the low values of companies' gross capital formation, unemployment can vary from very low levels up to very high levels. However, it is important to notice that such high values of unemployment are unrealistic. Given the big social unrest during the years of the Greek crisis, where unemployment exploded from almost 7% to 27%, that even higher values of unemployment are social unacceptable.

The influence of the inflation rate, as observed by the sensitivity analysis, in almost all the outcomes of interest, namely the real GDP, companies' profits, companies' gross capital formation, real disposable income, unemployment, public budget balance and government's gross capital formation indicate that

Greek governments and the European Central Bank should be careful about the rate of inflation for the upcoming years. As the scenario discovery showed, the high rates of inflation lead to inadequate results on the magnitude of outcomes of interest for the chosen policies.

Additionally, a low growth rate of the European GDP is a troublesome factor for the Greek exports and the growth rate of the Greek GDP. Companies' profits are also negatively influenced from a lower value of EU growth. Profits are also negatively influenced from high values of households' propensity to save and consequently private investments will be influenced, since investments are calculated as a percentage of the companies' profits. High values of interest rate are also troublesome for the public budget balance, since there is higher government expenditure that cause a public budget balance decrease.

6 Conclusion, Discussion and Recommendations

6.1 Conclusions

The current research aimed to answer the question of *what the main factors are behind the decline of private investments and which policies can re-activate them.*

To answer the main research question a set of 4 sub-questions was introduced. The first two questions aimed to answer the first part of the research question. Firstly, we answered the question: *How did the European financial crisis impact the economic growth of Greece?*

After years of public debt accumulation and persistent trade deficits, the country's economy was vulnerable. The immediate impact at the start of the European financial crisis was that investors lost confidence and the country had to borrow at extremely high interest rates to pay back its already substantial public debt.

The answer to the second question follows the answer of the first question: *Why did a decrease of the private investments of the Greek economy occur*?

As a result of the financial environment created after the outburst of the financial crisis, austerity measures were adopted with the target of decreasing the twin deficit, namely the public deficit and the trade deficit. Public expenditures were cut down, and taxes were increased. The increase of taxes and the decrease in the income of households, led to a decline of private consumption and real GDP. As a result of lower private consumption, companies' profits fell. At the same time, an increase in the companies' profit tax rate had a direct impact on their profits, by increasing their expenses. Consequently, that led to a decrease of the private sector' investments.

The second part of the thesis aimed to answer the question of how to re-activate private investments. The answer is given by answering the third and fourth sub-question:

- *What is the role of government intervention via fiscal and tax policy in reviving private investments?*
- *Which are the sensitive factors with respect to the decline of private investments?*

To answer them, a System Dynamics model of the Greek economy was built. The model was built based on a traditional macroeconomic model of the Greek economy that was enriched with equations from the AMECO database and the definitions of the Hellenic Statistical Agency (ELSTAT). Next, we performed the Exploratory Modelling & Analysis. First, two different policies were introduced. The first one concerned a mix of lower taxes and lower government investments and the second one was based on a policy of higher taxes and higher government investment.

Results from the EMA Workbench visualization indicate that a policy mix of lower taxes on households and companies, combined with lower public investments is proven more efficient for the real GDP, the companies' profits, the gross capital formation of the companies and the households' real disposable

income, as an introduction of the taxes is more favorable for the economy than an investment boost provided by the government via increased public investment. On the contrary, a policy of lower taxes combined with higher public investments produces, in general, higher values for the governments' gross capital formation and the public budget balance. The policy trade-off is then clear. A policy that favors the increase of private investments and real GDP is accompanied with a lower performance on the public budget balance.

The answer to the fourth sub-question derives from the sensitivity and scenario discovery analysis. Sensitivity analysis was performed by using the SOBOL technique. SOBOL results show that the most sensitive factors for the companies' profits are the inflation rate, the growth rate of the European GDP, the import and export income elasticities and the households' propensity to save. The gross capital formation of the companies' is additionally influenced by the capital depreciation rate and the investments as a percentage of the profits. More specifically, the scenario discovery analysis and the PRIM results show that higher levels of inflation and higher propensity to save from households is responsible for the lower values of real GDP and corporate profits. Lower investments as a percentage of profits, lead to lower values of the companies' gross capital formation, as less money is directed towards private investments from the companies.

6.2 Discussion and Recommendations

Ten years after the outburst of the European financial crisis, the Greek economy is still struggling to return to economic growth. GDP growth is anemic, private consumption remains significantly lower than pre crisis levels and private companies strive to regain their lost profits. Greek governments strive to find the appropriate policies for reviving the Greek economy. The first goal of the austerity programs for decreasing the tremendous public deficit was reached. But that came with a high cost. The increase of taxes both for households and companies resulted in a rapid decrease of private consumption and consequently to the companies' sales.

As the results of the current research show, there is a need for a decrease of tax rates for the companies and the households, in order to boost private consumption and private investments. The effect of a decrease is twofold. A direct effect on the companies' profits that results in a decrease of the companies' tax burden and an indirect effect from the private consumption. Given the restrictions that still exist for Greek governments from the still extra-ordinary ratio of public debt to GDP, a policy of increased government investments that is based on an increase of taxes is not effective in terms of real GDP and private investment growth. However, it is more beneficial for the public budget balance. At this point, the trade-off for Greek governments becomes apparent. Lower taxes boost the economy, but at the expense of public budget balance. It is at least questionable that given the commitments of Greek governments for not only balanced public budget, but also for surpluses that will contribute in holding back the increase of the public debt, the three institutions that were responsible for monitoring the growth of Greek economy (ECB, IMF, European Commission) will give their consent for such policy. Thus, a policy of lower taxes, will probably need to be combined with additional banking financing, after there is a consensus

between the Greek government and the three institutions. Another policy that could be considered from the Greek government but is not explored in the current research is the policy of targeted tax reductions.

A policy of tax reduction would target a mix of decreases on the tax income of certain categories of citizens, for example low income earners, with a simultaneous increase on the taxes of other categories, higher income earners. This way, the total revenue from taxes for the government could remain stable, neither increasing nor decreasing. Important factor for taxes, that is not mentioned in the current model is a stable tax system. Given the extreme variation on the tax rates since the beginning of the European financial crisis, investors became highly uncertain about their potential on investing in the Greek economy. As mentioned in traditional Keynesian macroeconomic theory, investors incentive to invest is based upon the "animal spirit" theory. When investors are highly uncertain about the potential of an economy, they become more reluctant to invest, and they remain reluctant until some of the uncertainties are minimized. Thus, a policy of lower taxes should be accompanied with some commitment of Greek governments, that the general tax system and especially the corporate tax rates will not change in the short term.

On the contrary to the traditional Keynesian macroeconomic theory, additional public investments do not suffice for boosting the private investment level as efficiently as a policy of lower public investments that is accompanied by lower tax rates. The effect of an increase on the real GDP from increased public investments does not balance the losses on GDP from the lower consumption.

An additional conclusion that can be extracted from the current research and is useful in a policy analysis level is the effect of import and export elasticities on real GDP and companies' profits. An improvement of export elasticities, by making the Greek goods and services more attractive to foreigners, and improvement of the import elasticities by making foreign goods and services less attractive to the local population, will have a positive effect on the corporate profits and the private investments. Lastly, in the export-import sector, it is important to note that an increase of the total European GDP has a positive impact on the real GDP growth rate and the companies' profits and although it is out of the hand of Greek governments, it is important to be kept in mind in the analysis of private investments.

Finally, from the results it is also indicated that a high rate of inflation is concerning for the growth of the economy and the growth of private investments. Despite the fact that to a big extent, inflation rate cannot be controlled by the Greek government, given the fact that the interest rate and thus the level of inflation is mostly controlled from the European Central bank the knowledge that a high rate of inflation is a threatening issue for economic growth, should be taken into consideration from the policy makers.

6.3 Reflection and limitations

Translating a macroeconomic model into an SD model in the context of a master thesis is an ambitious task on its own. With moderate confidence we can say that this goal was achieved. The macroeconomic model that was built includes 7 sub-models that describe almost the entire range of the Greek economy. The private sector was disaggregated into corporate and household sector, that provides extra insight on the role of the two in the growth of the Greek economy. It also allows for a closer look on the companies'

private investments and how these are influenced from the taxes imposed by the government and the public investments. The population model included in the analysis, allows for a forecast of the growth of the Greek population until 2050 and how this growth influences the economy.

The short overview of the European financial crisis upon the Greek economy and the reasons behind the decline of the private investments allowed for a more focused research of policies for reviving them. The trade-off between different policies on private investments and public budget balance became apparent from the analysis and the factors that the Greek government should focus in future policy making are highlighted.

Of course, during the process of completing such an ambitious task there will always be limitations. During the process of translating, building and analyzing a model there will always exist the chance of mistakes in every stage. We tried to capture as many mistakes as possible by reviewing the model continuously during the building and analyzing process. The most important limitations of the model include various parts of the model and the simulation.

6.3.1 Model Limitations

Every model is a simplification of the reality. No model can be characterized as strictly correct. But a proper model has to be useful. In terms of forecasting future values for the outcomes of interest, the current model is not performing well. But in terms of model behavior, the current model is managing to capture the dynamics developing in different parts of an economy with respect to uncertainties and policy levers.

Banking sector

An important part of an economy is the banking sector. The banking sector was absent from the model due to time limitations and the complexity of building up a banking sector. It is a fact that the Greek economy kept growing until the crisis begun, due to a debt-financing approach from both the government, as well as the households and businesses (Papadimitriou et al., 2013). The issue of loans and finance from banks is an important factor for keeping consumption and private investments' levels high. In the current model, the only strategy for the Greek government is to base its extra investments, with its own money. That is not per se a negative point, since the public debt of Greece is still at unacceptable levels, but it limits the choices for a fiscal stimulus.

Public investment increase in the model is closely linked with the public budget balance of the government. If the government does not have a public surplus, it cannot provide investments. External financing through borrowing, would increase the public expenditures for debt repayments in the short-term but at the same time it would allow for higher public investments without the need for more taxes from the government. However, as seen in the previous section, an accumulation of more public debt and a deviation from the commitments of the Greek government for public budget surpluses is likely to face resistance from the European Institutions that supervise the development of the Greek economy.

Another important element of the banking sector that influences private investments is the rate of non-performing loans (NPL). Given the very high rate of non-performing loans, households and companies, that reached a level of almost 50% in 2016 (Foka, 2019), banks have decreased their lending rates, thus squeezing the private investments (Storm, 2017a). The increase in the level of non-performing loans is closely linked with the decrease in the income of households and the companies' profits. Their decrease since the beginning of the crisis led to an inability of repaying back the loans issued by the banks and that led to a decrease of the money supply from the banking sector. Thus, an increase in the level of profit and the income level of household, would lead to a decrease in the level of the non-performing loans and would allow for banks to supply more money to the real market and allow for more private investments. Despite that, a recovery of private investments can still be achieved without additional financing but it is likely to have a weaker growth rate (PwC, 2017).

Investments as a percentage of profit

Private investments are modeled as a percentage of the companies' profit. The rest of the profits are directed towards the repayment of shareholders and dividends to households. The dividends to the households are part of the households' income and are used for either private consumption or savings. Although this is generally a valid assumption, the variable of how much profit is directed towards investments is left exogenous. Thus, it is modelled as an uncertainty parameter during the run of the model and the analysis in EMA workbench. This approach removes the modelling difficulty of accurately endogenizing it but excludes the impact of the accelerator effect on private investments. The accelerator effect on private investments is connected with output (Naastepad, 2002). By specifying the accelerator effect, one could observe the two-way relation of the positive impact of an increase on investments in output and a positive impact of output on investments. The higher the magnitude of the accelerator effect, the higher is the impact of output's growth.

Capital transfers from and to the Rest of the World

The capital transfers from and to the RoW are assumed to be 0 as a sum for reasons of simplicity. That is a big assumption in the current model but does not deviate significantly from the reality. Looking at the past values for capital transfers however, it can be concluded that the governmental capital transfers receivable are slightly lower than the governmental capital transfers payable (ELSTAT, 2019a). A more accurate modelling for the capital transfers, would require a more detailed description of the economic dynamics for the global economy and thus it is assumed out of scope in the current research.

Inflation rate

Inflation rate is kept exogenous in the current model. As it was observed in the analysis on chapter 5, it is an important influential factor for the outcomes of interest. Inflation was also kept exogenous in the paper of Papadimitriou et al. (2013) that was as the basis for the System Dynamics model. An endogenous inflation rate would allow for a more precise forecast along the simulation time. This implies that the

inflation rate varies during the model run because of the change in other model variables, such as the unemployment rate and not as a constant during the whole run. Looking back at the statistics for Greece in the last 15-20 years we can observe that GDP deflator, that is influenced by inflation rate, is nothing but constant (ELSTAT 2019). Higher inflation leads to lower real values for the variables and vice versa. Since, the outcomes of interest are all defined in real terms, we can conclude that an endogenous inflation rate, would result in different real values for the outcomes of interest. An endogenous inflation rate is generally influenced by change in aggregate demand or a wage increase. A wage increase could be a policy lever from the government perspective to strengthen demand, but that would influence apart from inflation also the public budget balance.

Productivity growth factor

Productivity growth factor is also kept exogenous in the model and is investigated as an uncertainty parameter. Productivity is also modelled as a time trend determined exogenous parameter in Levy institute model of Papadimitriou et al., (2013). Endogenous productivity growth is influenced by investments on education, research and development and innovation (Storm, 2019). As these sectors are not treated separately in the current model, the productivity growth was chosen to remain exogenous. Endogenous labor productivity influences the growth of wages and the demand for labor, which consequently influences the unemployment rate. Although, a preliminary attempt was made to endogenize the relation of investments and productivity growth, the inaccuracy of proper variables and values, generated an unstable behavior in the model, and thus this attempt was abandoned.

Average real wage

Average real wage is aggregated in two levels. First, we do not make a distinction between the private and the public sector. This model choice was made because data for real wage are only available at national level and not per sector (OECD Data, 2019). For example, real income in Greece has fallen by 16% from 2008 until 2014 (Storm, 2017a), but a clear distinction on how much public sector and private sector have contributed in this fall cannot be made. It is important to notice that this has a direct influence for both the public sector expenditure, companies' expenditure and real disposable income. Consequently, it has implications on the outcomes of interest: Companies' profits, public budget balance and real disposable income. The Greek government has taken measures to reduce the public expenditures since 2008 and public sector' wages were almost immediately affected (Asteriou et al., 2011). This change cannot be captured in the model, as an increase (or decrease) in the wages is the same both in public and private sector. The process of determining the wage levels is also kept exogenous in the model of Papadimitriou et al. (2013) and thus a clear process for determining adequately the two sector difference could not be made.

Tax rate on personal income

The second meaning of average wage level concerns the aggregation of all levels of income and thus the tax rate on personal income. In the model, there is no clear distinction on the different wage levels, for example low wage earners or high wage earners and that influences the personal income tax rate. Personal income tax has four different rates in Greece, based on different levels of income (Foka, 2019).

As it was difficult and time consuming to define different level of personal income, it was chosen to have an average personal tax income rate. That immediately limits the policy options in the model. With 4 different tax rates, it would be possible to generate more policy combinations with a simultaneous increase or decrease of tax rates in different income groups and explore the government options for increasing or decreasing taxes in specific groups of tax payers, most likely the higher-level tax payers, and not the total population of tax payers.

Social benefits and Social contributions

Social benefits and social contributions are calculated as a percentage of the GDP, as specified in the OECD Data website. This directly leads to government expenses and revenue to depend from the growth of the GDP. Despite the fact, that this connection is not wrong, and not totally exogenous, it could be improved. Fully endogenous social benefits include connection to unemployment benefits, pensions, sickness, disabilities, survivors, family, housing social exclusion (ELSTAT, 2019b). Disaggregated data for the level of unemployment benefits and the average pension income were not available. For the rest of the categories on social benefits, an accurate data for the number of annuitants is not provided.

A connection of the two variables in the system would add more dynamic behavior and more accuracy in the model. With high unemployment generated by either policy in the model, the government expenditure would increase because more money would be directed towards unemployment benefits and thus public budget balance would decrease. Also, the population model could accurately assess the number of people that receive pension and define the pension expenses for the government. An additional policy that could be explored then would be a policy of increasing the average pension age.

Migration

The forecast for the population growth in the current research is very close to the UN forecast until 2050 for no migration. Migration is an important element in the population consistency in terms of labor force. Given the large number of Greek migrants, 250.000-350.000 people after the crisis begun (Labrianidis & Pratsinakis, 2014), and that most of them are in working age, it is safe to assume that available labor force will decrease if the migration outflow continues. It is difficult to forecast the percentage of those people that could actually find a job and thus move to employed status rather than just be a part of the labor force. If a large percentage remained unemployed, that would raise the unemployment levels. Given that available labor force at the beginning of 2017 was 4.7 Million people, more than 10 times higher the migration level, we can conclude with moderate certainty that migration flow cannot account for a big change in the final model outcomes.

Savings' rate

Private gross savings are determined by the savings' rate. Savings' rate is then dependent on the propensity of households to save and the real GDP value. In Neoclassical theory, if propensity to save increases with a given level of investments, it will first decrease the interest rate, which will lead to an increase of private investments and eventually to an increase of output. On the contrary, in Keynesian

theory, an increase in the propensity to save will not affect investments, since they are considered exogenous. Essentially in the Keynesian model, savings will just go out of the income flow and reduce private consumption (Naastepad, 2002). This is exactly what is assumed in the current model too. It is remarkable to mention, that from 2006 until 2011 savings rate as a ratio of GDP dropped from -0.5 % to -13%. (OECD DATA,2019).

6.3.2 Simulation limitations

Unemployment rate

As concluded in the analysis from Exploratory Modelling and Analysis, the unemployment rate values vary from very low up to very high levels. It is difficult the make a definite conclusion on which policy favors lower unemployment rates, since there is a big scattering of data from the results. However, it is important to notice that such high values of unemployment are unrealistic. The social unrest during the years of the Greek crisis, where unemployment exploded from almost 7% to 27% indicates that a level of unemployment higher than that is simply not viable for the economy and the society. The social benefits provided from the government would increase dramatically and lead to an inability from the government side to provide citizens with decent living standards. That could end up in governmental instability and crisis, as happened during the crisis' years where multiple elections and government' changes took place, due to the tremendous social unrest.

Uncertainties' range

As discussed in chapter 4, some of the ranges of the uncertainties cannot be precisely set. Setting a too tight range for values can exclude some plausible scenarios of interest. On the other hand, setting too broad ranges for the uncertainties can lead to rather unrealistic values for the outcomes of interest. Some behavior that was noticed in the visualization results, such as the long tails on KDE graphs for real GDP or gross capital formation of companies for example, can also be explained by the broad range of uncertainties. Of course, as the system dynamic model itself does not produce realistic values for the outcomes of interest in some cases, we cannot be certain how much is the effect of unrealistic ranges on the extreme values. Unrealistic for example could be considered the range for import and export elasticities. An initial value for their relative values on European GDP could not be established and would need to be calculated. It was then assumed, and that is a big assumption, that there is an '1-1' relation for the elasticities. This oversimplification led to setting a wider range for those values, in order to avoid discarding plausible values.

6.3.3 Further improvement

Concluding the current section, there are certain limitations of the current model that limit the research. The current research can be extended in some significant points. Firstly, the addition of the banking sector

would provide a more complete overview of the economy. Additionally, by making the inflation and productivity growth as endogenous variables in the model would enrich the analysis. Next, a connection of the private investments with the accelerator effect could be made. Additionally, a disaggregation of the income classes can be done in a system dynamics model by finding the relevant data and classify them through subscripts. Moreover, a migration sub-model could be added next to the population model. Finally, a more precise and realistic value of ranges could be given to the already existing uncertainties.

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Appendix A: Uncertainties full table

Most variables are defined as a standard deviation from initial values. The explanation for the precise choice of value range is presented on the table below.

Table A-1: Uncertainties full table

Uncertainties	Sector	Initial Values	Value Range	Explanation
Capital depreciation rate	Companies, Government	0.1	0.075-0.125	Standard value for capital depreciation rate is 0.1. The bandwidth that was chosen reflects extreme values of almost 0 to 50% increase.
Propensity to save	Households	0.075	0.05-0.1	Initial propensity in the model is 0.075. Again, extreme values of 0 up to 50% is chosen
Interest rate	Public sector	0.031	0.01-0.05	Lower value is close to interest of Germany and 0.03 is close to current value
Growth rate GDP EU	Import-Exports	0.01	0.01-0.03	Lower value is the average growth rate in the period 2008-2017 and upper boundary is the GDP of 2007 before the crisis
GDP deflator EU	Imports-Exports	1.091	1-1.2	Initial deflator is 1.091. We choose a deviation of 10%
Export elasticity	Import-Exports	1	1-2	Lower boundary is an 1-1 relation. Upper boundary is an extreme value
Import elasticity	Import-Exports	1	1-2	Lower boundary is an 1-1 relation. Upper boundary is an extreme value
Average fertility per woman	Population	1.3	1.2-2.1	Initial value is 1.4. Lower boundary reflects a further decrease and upper boundary reflects the minimum value for increase in the population
Average hiring time for new workforce	Employment	0.5	0.5-1	Minimum of 6 months and maximum of 1 year
Average firing time workforce	Employment	1	1-1.5	Minimum of 1 months and maximum of 1.5 year. Assumed that firing time is higher than hiring time due to labor regulations.
Labour force participation rate	Employment	0.683	0.6-0.8	Initial value is 0.683. A deviation of 0.1 is chosen
Percentage public employees	Employment	0.18	0.1-0.2	Initial value of 0.18. Lower boundary of 10% implies a small government. Upper boundary does not deviate much from the initial value due to the commitments of

				Greek governments to reduce expenses.
Annual growth rate inflation	Wages	0.02	0-0.03	Current value for Greece is 0.2%. Assuming that deflation will not return 0 is the lower limit. 2 % is the limit of ECB. We choose a slightly higher level
Productivity growth factor	Wages	0	-0.01-0.03	Labor productivity values deviating from the almost 0 % current growth of productivity to the almost 3% that had in 2008
Investments as a percentage of profit	Companies	0.3	0.2-0.5	Since it is a parameter set in the model, a real-life value is not found. Thus, a wide range of uncertainty is set

Appendix B: Exogenous variables

In the table below, the exogenous variables of the model are presented. These are the values that remain constant during the whole time of the simulations.

Table B-1: Exogenous variables' table

Constants	Sector	Value	Units	Source
Capital-output ratio	Companies	1/3	Dimensionless	
Other capital expenditure	Companies	-0.7	Billion euros	AMECO Data
Other taxes on production	Companies	4.7	Billion euros	AMECO Data
Net property income companies	Companies	-1.1	Billion euros	AMECO Data
Net current transfers received	Companies	-1.3	Billion euros	AMECO Data
Other subsidies on production	Companies	0.8	Billion euros	AMECO Data
Net property income households	Households	4.4	Billion euros	AMECO Data
Gross capital formation households	Households	4.2	Billion euros	AMECO Data
Property tax as percentage of GDP	Public Sector	0.032	Dimensionless	OECD Data
Social benefits as percentage of GDP	Public Sector	0.213	Dimensionless	OECD Data
Subsidies as percentage of GDP	Public sector	0.00926	Dimensionless	OECD Data
Goods and services	Public sector	14.173	Billion euros	ELSTAT DATA
Capital transfers as percentage of GDP	Public Sector	0.035	Dimensionless	OECD Data
Price deflator exports of goods and services EU	Imports-Exports	1.061	Dimensionless	AMECO Data
Price deflator exports of goods and services Greece	Imports-Exports	0.995	Dimensionless	AMECO Data
Price export elasticity	Imports-Exports	1	Dimensionless	Original values for price elasticity from (Papadimitriou,2013) are relative to Germany exports only
Price deflator imports of goods and services EU	Imports-Exports	1.044	Dimensionless	AMECO Data
Price deflator imports of goods and services Greece	Imports-Exports	0.946	Dimensionless	AMECO Data
Years in fertile age	Population	30	Years	Modelling assumption
Relative share women in fertile age	Population	0.5	Dimensionless	Modelling assumption

Appendix C: Sub-models' additional equations

The SD model and the full python script can be found on:

https://github.com/antonioskarampekios/Master-Thesis-Antonios-Karampekios

Government

Table C-1: Government sub-model equations

Variables*	Equations
Revenue from Social contribution	Constant
Revenue from property tax	property tax as percentage of the GDP* nominal GDP
Revenue from corporate tax	profit * corporate profit tax rate
Revenue from value added tax	value added tax rate * private consumption
Revenue from personal income tax	tax rate on personal income* total real income
Compensation of employees	number of public employees* average nominal wage level
Social benefits	social benefits as percentage of GDP* nominal GDP
Goods and Services	Constant
Subsidies	subsidies as percentage of GDP*nominal GDP
Capital transfers paid	capital transfers as percentage of GDP* nominal GDP
Interest payments	interest rate as percentage of GDP* nominal GDP

Corporate Sector

Table C-2: Corporate sector sub-model equations

Variables	**Equation**
Corporate profit tax	Profit * corporate tax profit rate
Compensation of private employees	number private employees * average nominal wage level
Other capital expenditure	Constant
Other taxes on production	Constant
Gross value added	nominal GDP-gross capital formation government-compensation of public employees
Net current transfers received	Constant
Net property income companies	Constant
Other subsidies on production	Constant
Profit share	profit/Total Revenue Companies
Profit rate	cumulative profit/net capital stock

Capacity utilization	MIN (1, profit rate/profit share * capital-output ratio)

Households

Table C-3: Household sub-model equations

Variables	Equation
Compensation of employees	Compensation of private employees + compensation of public employees + dividends to households
Dividends to households	dividends to households as percentage of profits * profit
Private consumption	real disposable income - private gross savings

Unemployment

Table C-4: Unemployment sub-model equations

Variables	Equation
Relative change working population per group	(Deaths[LaborForce]+Ageing[LaborForce]) / Population[LaborForce]
Relative difference between potential and actual workforce	(Total Demand for labor - SUM (Workforce[LaborForce!])) / SUM (Workforce[LaborForce!])
Available Labor force	Population[LaborForce]*labor force participation rate
Unemployment rate	(SUM(Available Labor Force[Youth!])-SUM(Workforce[Youth!])) / SUM(Available Labor Force[Youth!])
Youth unemployment rate	(SUM(Available Labor Force[Youth!])-SUM(Workforce[Youth!])) / SUM(Available Labor Force[Youth!])
Total demand for labor	real GDP*/labour productivity

Appendix D: Full description of model validation

Model consistency with prior macroeconomic theory

Is the model consistent with prior macroeconomic theory?

The current model is built on the basis of a traditional macroeconomic model (Papadimitriou et al., 2013). Apart from the equations used in this macroeconomic model, additional equations from AMECO database and ELSTAT definitions were used, where necessary, to expand the SD model. It can be concluded then that the model is consistent with prior macroeconomic theory.

Model Aggregation

Is the level of aggregation appropriate for the purpose of the research?

The purpose of the current research is to explore the economy in a macroeconomic level. All the components of the system and the outcomes of interest, such as the real GDP, unemployment rate or public budget balance are macroeconomic values in the aggregate level of a national economy. The research choice then to keep all the values in a national macroeconomic level seems to serve the purpose of the research analysis.

However, it cannot be concluded for sure that an analysis in a more disaggregated level would also provide useful insight. For example, an analysis that would be in the level of separate economy sectors, such as agriculture, real-estate or manufacturing, could provide a useful insight on which of these industries are lacking more investments and which of them have the potential to grow and create more job opportunities if investments are increased. That would provide the government with useful insight for targeted policies on public investments.

Finally, population is also measured not only in an aggregated level of total population, but also in a more disaggregated level of 5 years' cohorts. This choice was made, since it would provide more evidence about not only the total increase or decrease of the population but also if the population is ageing. An aggregation of the population in such level, provides also the opportunity to monitor the workforce in cohorts of 5 years. That way, we can measure not only the total unemployment, but also the youth unemployment too.

It can be concluded then, that the level of aggregation is appropriate for the purposes of the current analysis.

Exogenous parameters' assessment

Do exogenous parameters respond to reality?

Almost all exogenous parameters have accurate real-world values. Most data are retrieved from reliable sources, such as AMECO website, ELSTAT website and EU KLEMS.

The main exogenous parameters that do not have real-world values, are public investments as a ratio of public budget balance and private investments as percentage of profit. These variables are as with 0.5 as

a default value. In macroeconomic terms, that means that both government and companies spend half of their budget surplus and profits for investments. There is not a clear-cut reasoning for that, as there are only for investments as a percentage of the GDP. However, the purpose of the model is to show how private and public investments can be increased when government and companies use their own finance.

It should be kept in mind, that the model does not include a banking sector. Thus, external financing is not available in the model. This is contradictory to the reality. In real economy, both companies and governments can finance investments even if they have public deficit or profit losses. The high rate of public debt and the companies' non-performing loans though, makes additional financing costlier. A healthy growth is based on low net borrowing, which in return increases the confidence of investors for future growth.

In chapter 5, public investments as a ratio of public budget balance are used as a policy lever for the model. The purpose is to explore the policies' performance compared to the original performance of the model with the default values. It is then concluded, that the use of those variables is important, although they do not necessarily match real-world values.

System Boundary

Is the System boundary adequate for the purposes of the analysis?

Most of the economy's components are modelled as endogenous variables. The most important variables of an economy are the components of the GDP. Private consumption, public expenditure, private investments, public investments and net trade balance are all endogenous variables in the model. The purpose is to explore the evolution of the GDP over the course of 33 years. Of course, when we refer to such a long-term economic period, there are other important parameters that could influence the system, such as external financial shocks, natural disasters, wars. This are not included in the model, but their forecasting is very difficult at least. That does not weaken the argument that the system boundary is not adequate for exploring policies.

Another important substance of the model is that private investments are endogenized in the model. That provides a more insightful angle on the role of private investments in the economy and the role of government investments upon the evolution of private investments.

Finally, endogenizing the population with a separate sub-model, extends our model boundary to an important economic element that is often ignored. A country's population evolution plays an important role in macroeconomic terms, as a decrease in the population makes an economic recovery or growth more challenging. This is an issue, that traditional macroeconomic models fail to capture, as they consider population as an exogenous constant. As mentioned before in the current document, migration is not part of the population model as it is out of scope for the current research.

On the other hand, there are exogenous parameters that could be endogenized in the future to make the system boundary more sufficient. The most important parameters are the inflation and the labor productivity growth. Labor productivity growth is closely connected with the evolution of the labor demand. Inflation in the Neoclassical approach is linked to unemployment and interest rates. If unemployment goes lower than a certain level, interest rate should increase, in order to increase inflation and restore the "equilibrium unemployment rate". Such mechanism is not included in the model. However, it can be argued that at some extent, inflation is indeed exogenous in a European economy,

since the mandate of ECB dictates that inflation should be kept below the limit of 2%. Thus, including the inflation in the model as an exogenous parameter, does not decrease the boundary adequacy of the model.

Model behavior under extreme scenarios

i. EU recession

One of the examined scenarios is a long-term recession in the EU countries. Assuming that the aggregate GDP of European Union decreases with a rate of 2% for the whole duration of the model run. That is a rather unrealistic scenario, given that the run of the model extends for 33 years. Despite that we want to explore how the model behaves and if the behavior follows a normal trend. EU GDP is connected with the country's exports and a decrease in the EU GDP growth rate is expected to lead to a decrease of Greece's exports. Consequently, a decrease in the exports, will lead to a decrease of the country's net balance and GDP. We compare this scenario with the basic scenario for the SD model. The results are presented below. Since exports are closely related with the growth of the European GDP, a decrease of its growth rate, is only natural to cause a decrease at the exports of the Greek economy. Net trade balance is lower than in the basic scenario and the difference occurs from the drop in the country's exports. Real GDP is dropping in a faster rate than in the basic scenario, as the impact of exports' decrease is pushing down economic growth.

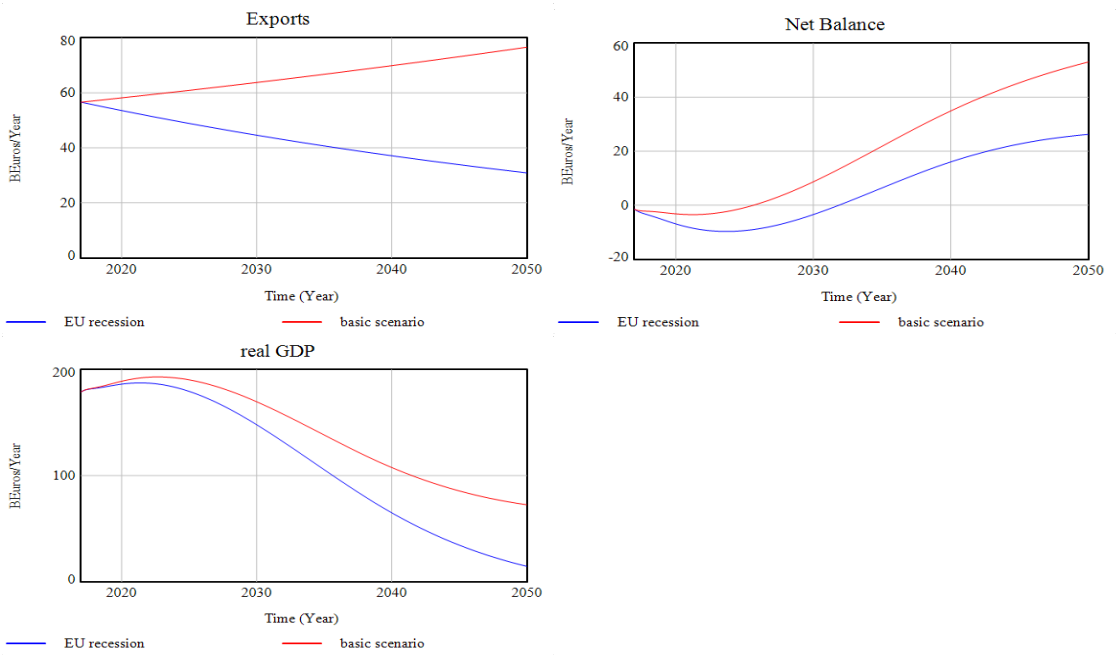


Figure D.1: EU recession impacts

ii. Extreme inflation

Second scenario that is explored is an extreme inflation in the economy. Assuming that inflation rate is 10% in the economy, we expect real values to drop. We investigate the impact on real GDP, public budget balance and real imports. The results are presented below. Real GDP and imports present the same behavior in that scenario. The extremely high inflation rate leads to a rapid decrease of the real GDP and the Greeks imports from the beginning of the model. The economy instead of growing is shrinking rapidly. The inflation rate is growing in a much faster rate than the nominal GDP and the nominal value of imports and as a result, their real values shrink quite fast. Given that a devaluation of the currency is not possible, since Greek government after the adoption of the Euro does not have the option of a currency devaluation. The lower value of real GDP leads to a decline of the public budget balance and eventually to a public deficit after 2020. The low values of the real GDP create a persistent public deficit. From a macroeconomic point of view, real GDP could only increase in case that the growth rate of nominal GDP is higher than 10%. Such a high value of GDP growth has never been achieved in the Greek economy, even in periods of high growth rate of GDP. Despite that, the fact that the imports lose almost two thirds of their value in almost 10 years, seems rather unrealistic. This implies, that imports and real GDP are quite sensitive to the change of the values of interest rate.

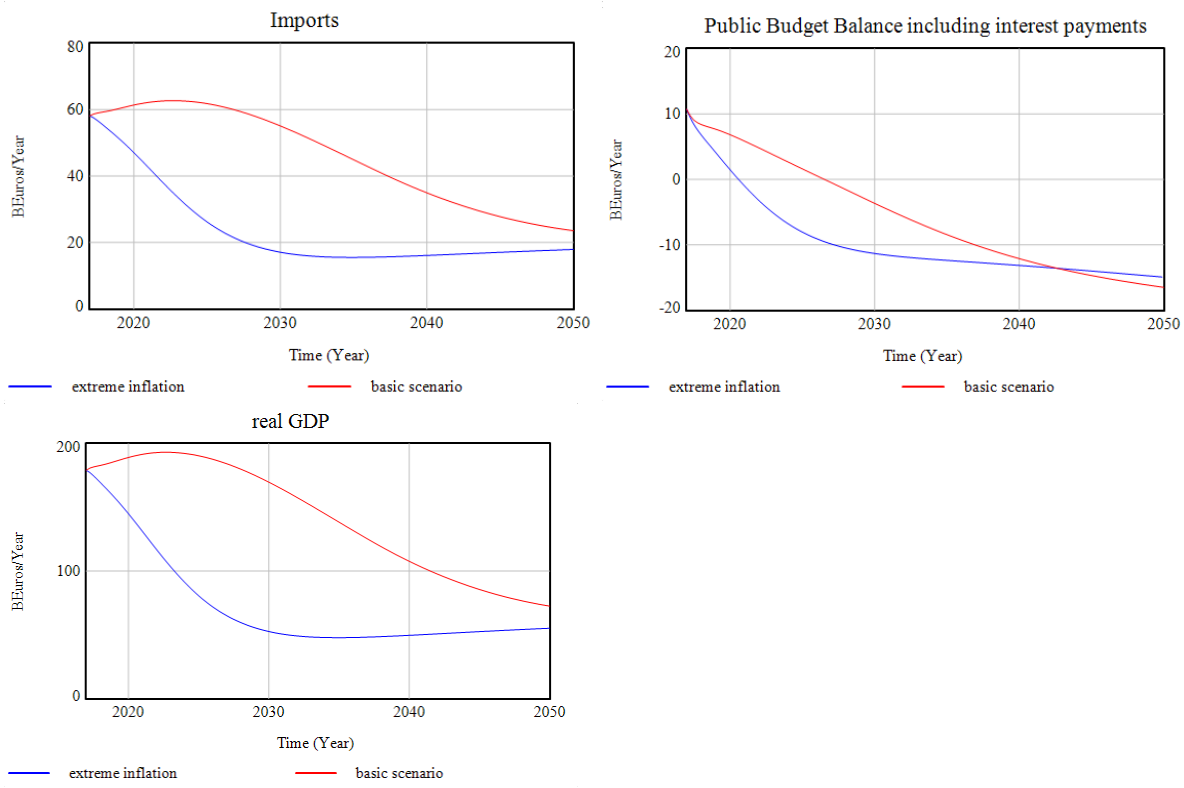


Figure D.2: Extreme inflation impacts

iii. Exceptional interest payments

In that scenario it is assumed that due to a loss of confidence from the investors, Greek government has to borrow in an exceptional rate of interest, 10%, and thus the interest payments are increasing. We are expecting total expenditures to increase, public budget balance to decrease and real GDP to drop. The results are presented below. Real GDP graph presents an expected behavior for such a high increase in the interest rate. As the expenses of the government increase and has to borrow in a much higher interest rate, real GDP value drops in a faster rate. For the total government expenditure graph, the difference at the initial values can be explained, as the increase in expenditures from the higher interest rates is assumed from the beginning of the model. The behavior though is expected from macroeconomic theory, where expenditures remain higher than in the basic scenario. The public budget balance has a logical behavior, as its value is lower than the one in the basic scenario, where the interest rate is at 3.1 % of the real GDP.

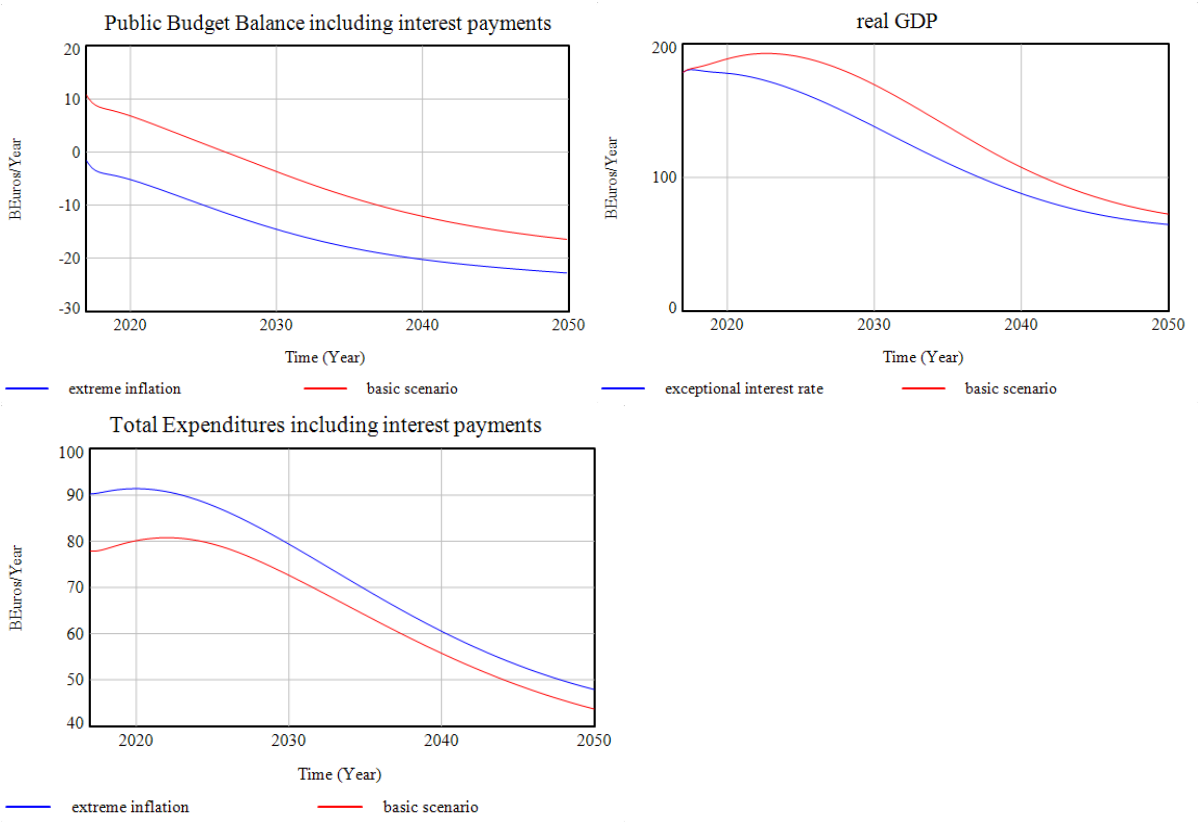


Figure D.3: Exceptional interest rate impacts

Appendix E: Jupyter notebook

Visualizations

Below the rest of the visualization results for the rest of the outcomes of interest are presented.

Profits perform better in the lower taxes' policy compared with the high taxes policy.

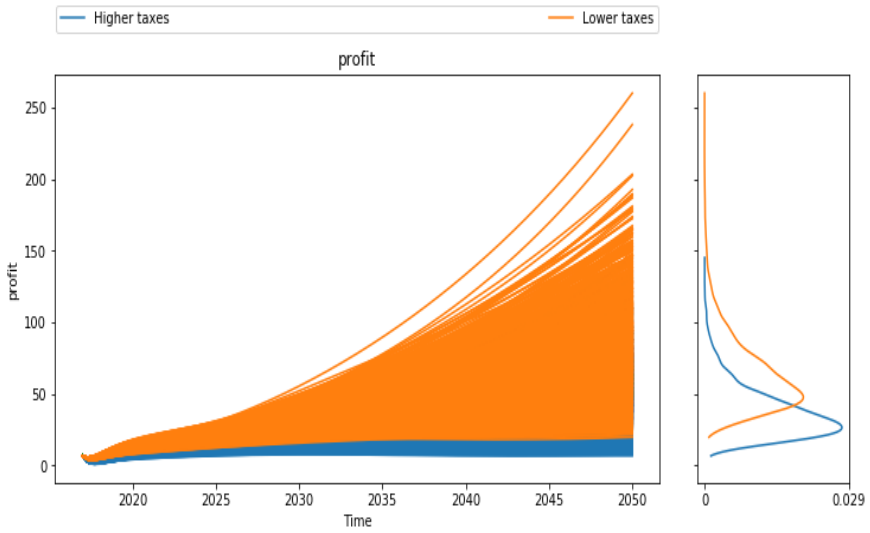


Figure E.1: Profit visualization

Real disposable income has higher values for the lower taxes policy both in terms of extreme high values and the density concentration.

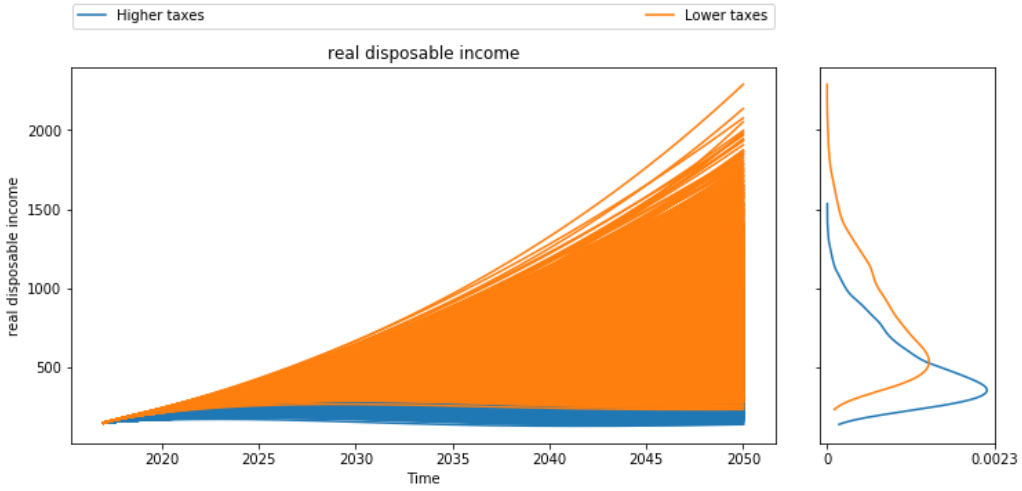


Figure E.2: Real disposable income visualization

Gross capital formation of the government has higher values for the higher taxes' policy both in terms of extreme high values and the density concentration.

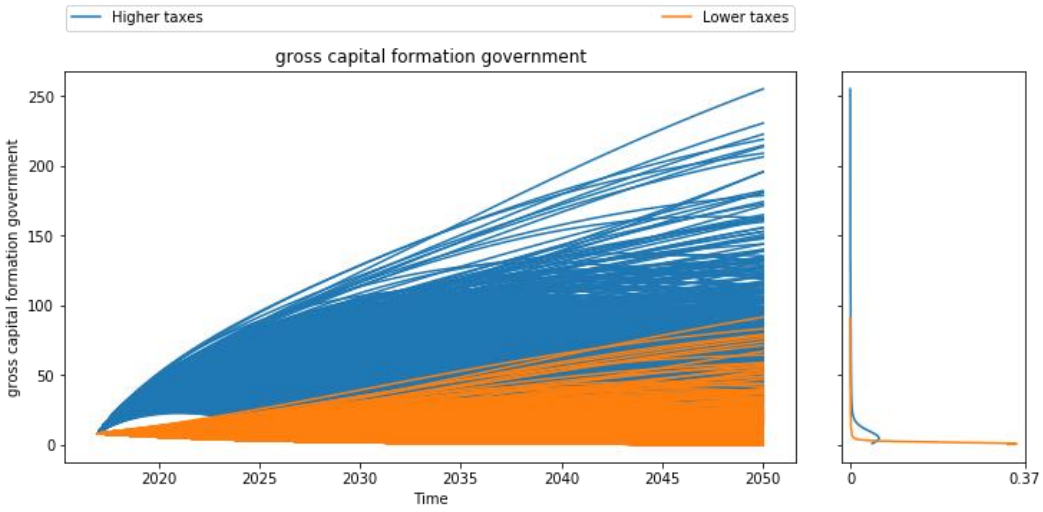


Figure E.3: Gross capital formation government visualization

In the table below, the scores for the values of outcomes of interest at the end of the run (2050) are presented.

Table E-1: Outcomes' scores in 2050

Real GDP		Unemployment rate	
Low taxes	High taxes	Low taxes	High taxes
count 5000.000000 mean 288.540320 std 152.016328 min 64.498680 25% 176.350855 50% 251.080330 75% 361.796388 max 1314.416600	count 5000.000000 mean 200.971240 std 103.805743 min 50.876015 25% 124.344610 50% 175.222010 75% 251.226165 max 903.664550	count 5000.000000 mean 0.281267 std 0.171608 min 0.021911 25% 0.137405 50% 0.243410 75% 0.400726 max 0.825865	count 5000.000000 mean 0.393400 std 0.190847 min 0.040055 25% 0.230556 50% 0.383315 75% 0.541341 max 0.862171
Public budget balance		Real disposable income	
Low taxes	High taxes	Low taxes	High taxes
count 5000.000000 mean -23.999388 std 12.034727 min -80.299225 25% -30.535736 50% -23.585062 75% -17.544052 max 24.584290	count 5000.000000 mean -14.411407 std 11.287160 min -53.644780 25% -20.970758 50% -15.797211 75% -8.858203 max 34.440720	count 5000.000000 mean 788.403799 std 329.458701 min 235.327090 25% 527.919960 50% 720.353580 75% 997.978167 max 2288.462400	count 5000.000000 mean 512.395825 std 225.564869 min 140.818770 25% 340.075645 50% 458.439870 75% 647.570287 max 1534.753800
Profit		Gross capital formation companies	
Low taxes	High taxes	Low taxes	High taxes

count 5000.000000 mean 63.634750 std 25.839260 min 19.768976 25% 45.139427 50% 57.934376 75% 76.071165 max 260.226350	count 5000.000000 mean 37.046975 std 17.800568 min 6.708580 25% 24.133697 50% 33.175761 75% 45.926327 max 145.206530	count 5000.000000 mean 162.656378 std 78.294524 min 36.380890 25% 106.430113 50% 146.467340 75% 201.263220 max 707.261900	count 5000.000000 mean 91.485988 std 46.479530 min 16.112116 25% 58.028703 50% 81.630417 75% 113.313673 max 405.559420
Gross capital formation government			
Low taxes	High taxes		
count 5000.000000 mean 1.474059 std 5.431921 min 0.127712 25% 0.250831 50% 0.421198 75% 0.690535 max 91.480700	count 5000.000000 mean 13.751065 std 24.943764 min 0.707305 25% 3.040896 50% 5.099920 75% 10.285163 max 255.253110		

Below the envelopes for all the outcomes of interest and the two different policies are presented. With the use of the envelopes, we observe the higher and lower values per outcome and policy. We can observe that the maximum value of the lower taxes policy is higher for real GDP, companies' profits, real disposable income, companies' gross capital formation. On the contrary, the maximum value of higher taxes policy is higher in the case of governments' gross capital formation, public budget balance and unemployment rate.

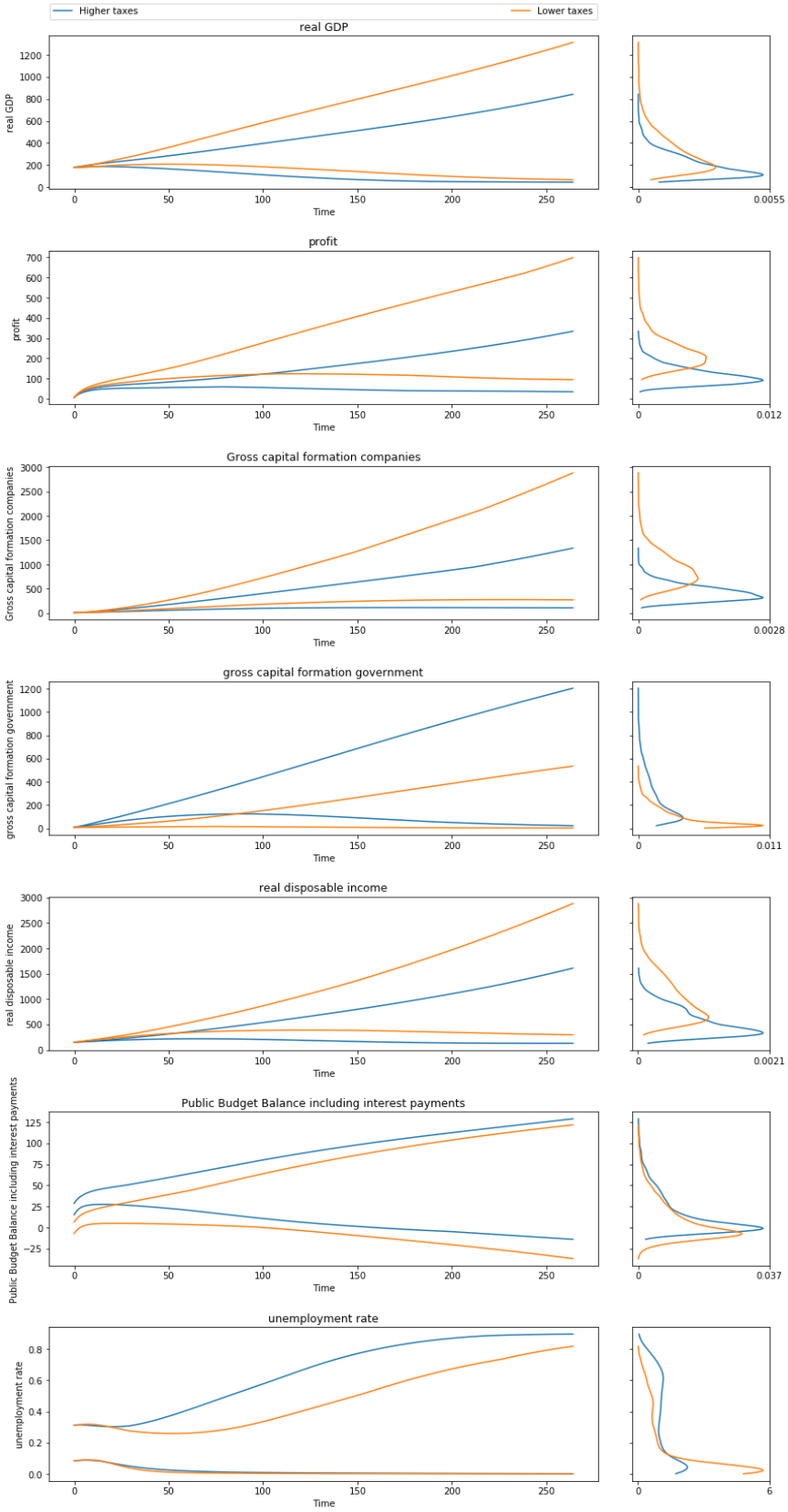


Figure E.4: Outcomes of interest envelopes

The scatter plot with all the outcomes of interest without being grouped by policy. Although this graph is useful for exploring the correlation of the outcomes, it does not provide much info on the different correlations of the outcomes amongst the two different policies. Thus, in the next scatterplot we explore the correlations by grouping the data points by policy.

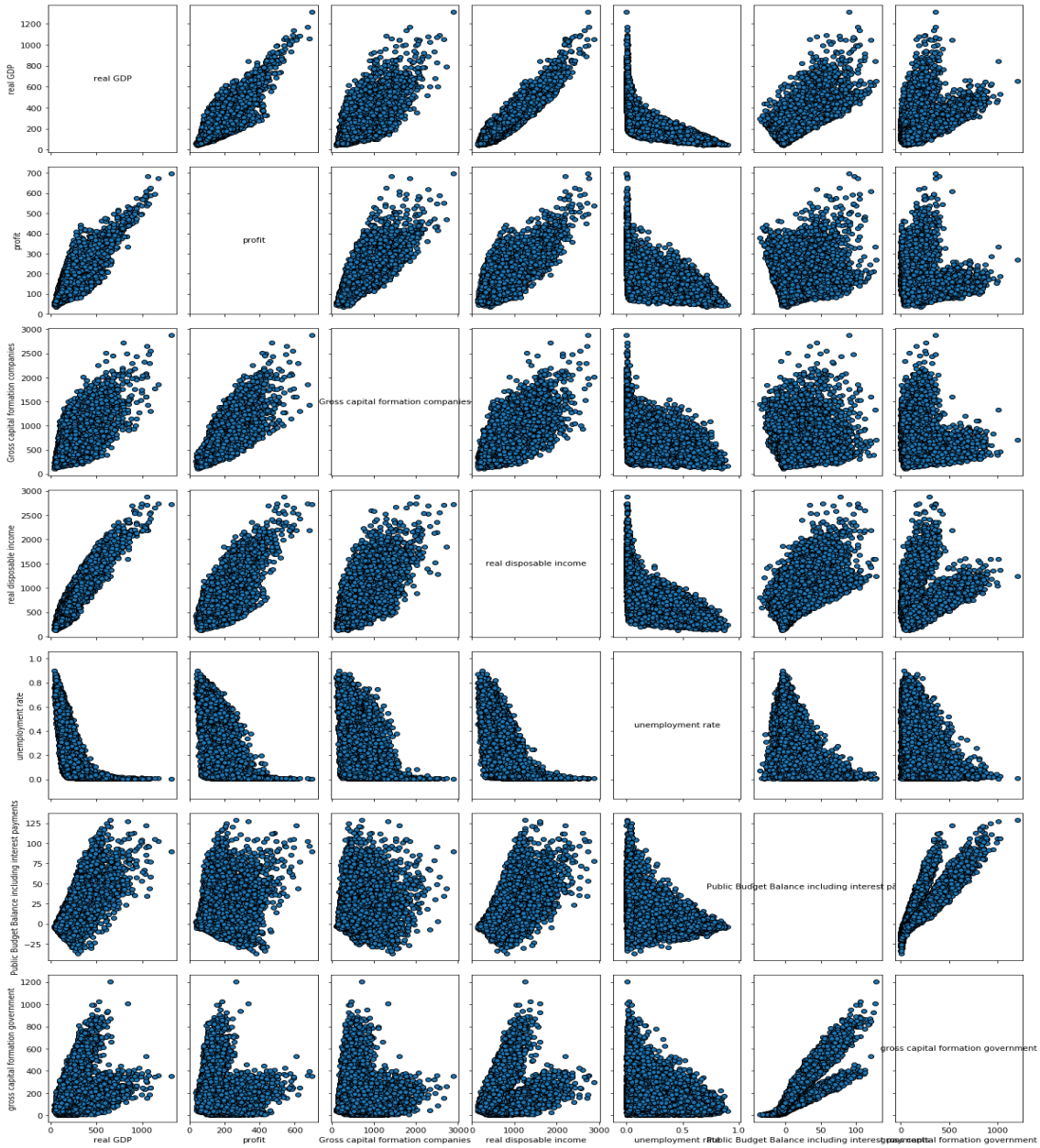


Figure E.5: 7 Outcomes scatterplot

Afterwards, the same scatterplot is presented with the data grouped by policy. The outcomes of interest are presented diagonally from top left to bottom right and then they are plotted against each other to observe their correlation. Not all relations are clear from this plot, but some useful observations can be made.

The higher the value of real GDP, the higher is the value of companies' gross capital formation. Especially in the lower taxes' policy this correlation seems to be stronger. Also, the higher the real GDP is, the higher the public budget balance is. That observation can be made for both policies, but in the case of lower taxes, we observe some higher values for public budget balance, but this is logical, since lower taxes' policy give in general higher values for real GDP.

Interesting is also the relation of public budget balance and unemployment rate. Although the scattering of data points is big, it can be seen that for higher values of public budget balance, unemployment rate is lower. That relation is stronger in the case of the higher taxes' policy too. Lastly, what is of great interest is to observe the correlation of the gross capital formation of companies and the gross capital formation of the government. It appears, that government investments have a rather weak correlation with the private investments. Especially in the policy of higher taxes, even very high values of governmental' gross capital formation do not produce high values for the gross capital formation of companies.

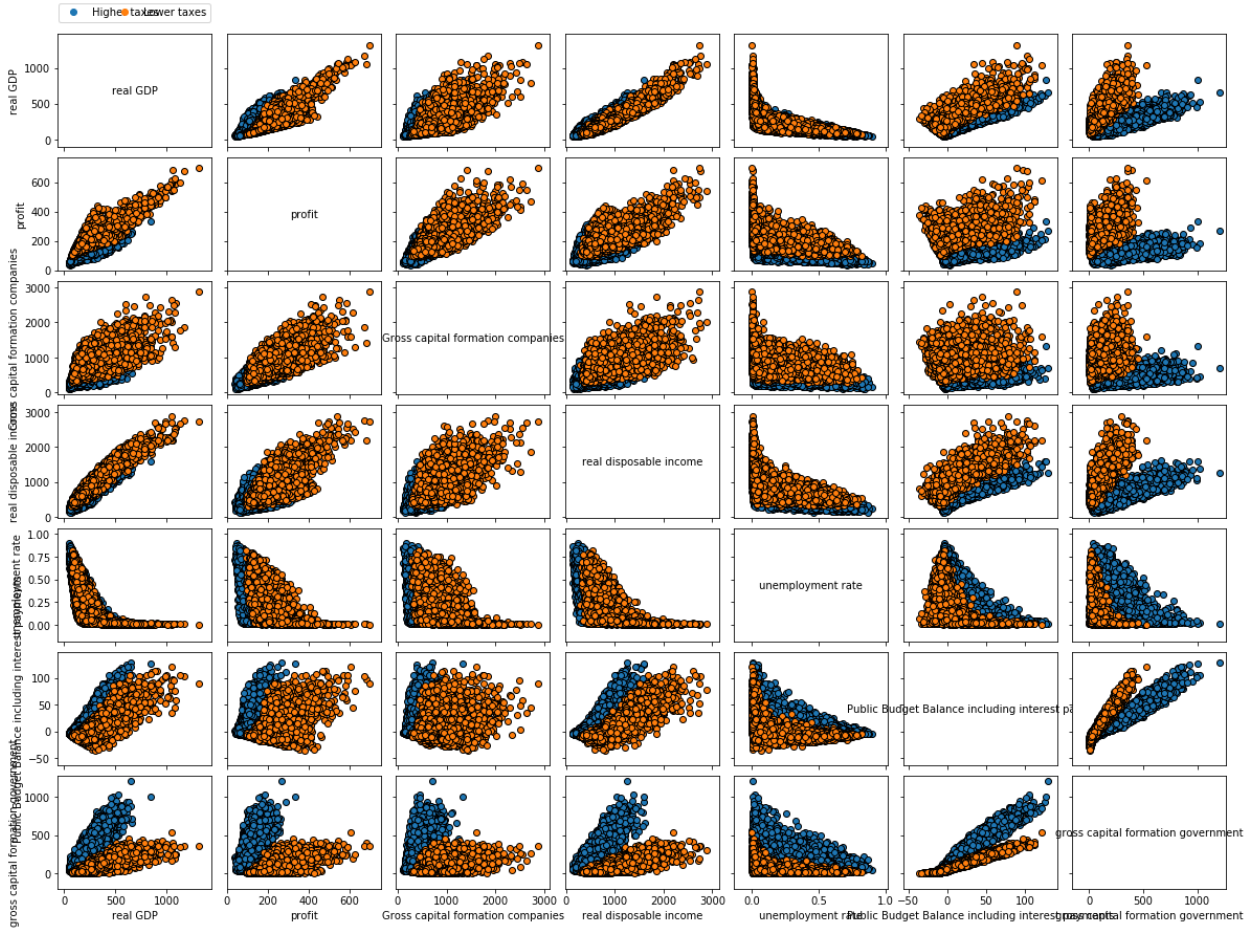


Figure E.6: 7 outcomes scatterplot with 2 policies

SOBOL Results

Global Sensitivity analysis can rank input parameters and help policy makers identify the most important as well as the least important parameters during the optimization process (Song, Zhou, Wang, Kucherenko, & Lu, 2019). Compared to local sensitivity analysis, global SA has two main differences. First, the space of the input factors is explored within a finite (or infinite) region. Second, the variation of the output induced by a factor is taken globally, meaning that it is averaged over the variation of all factors. Local SA examines how small variations in the input variables affect the quantities of interest, while global SA deals with possible large variation of the input variables (Schöbi & Sudret, 2019).

Typically, global sensitivity analysis methods are developed in the context of probability theory, for example the uncertainty in the input variables is modelled by probability distributions. Such a model can be used to explore uncertainties that are linked with lack of existing knowledge and can be reduced with the collection of more data or with uncertainties that are related with the variance of the input parameters and it cannot be mitigated (Schöbi & Sudret, 2019). Global sensitivity analysis focuses on the output uncertainty over the entire range of values of the input parameters. Within this setting uncertainty parameters, different in principle for each parameter, are the input for the analysis. These ranges are valuable because they represent our knowledge or lack of it. Global sensitivity then should not be solely considered as a method for exploring the model specified solution rather than the mathematical model itself (Sobol & Kucherenko, 2007).

Variance-based importance measure indices were first proposed by the Russian mathematician Sobol (1993) and are still the main important measure system trend for the positive link between variance and function decompositions. Variance decomposition refers to the total variance of the outcome of interest added by each uncertain input parameter. In the SOBOL indices, we observe the first order effect S1, that represents the single influence of each parameter and the total effect ST, which contains also the interaction effects between the parameters. The equations for the two effects are presented below.

$$S_i = \frac{Var(\mathbb{E}(Y|X_i))}{Var(Y)}$$

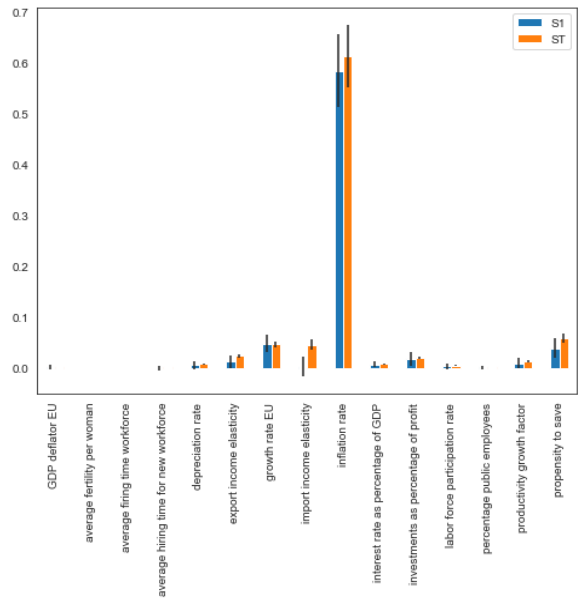
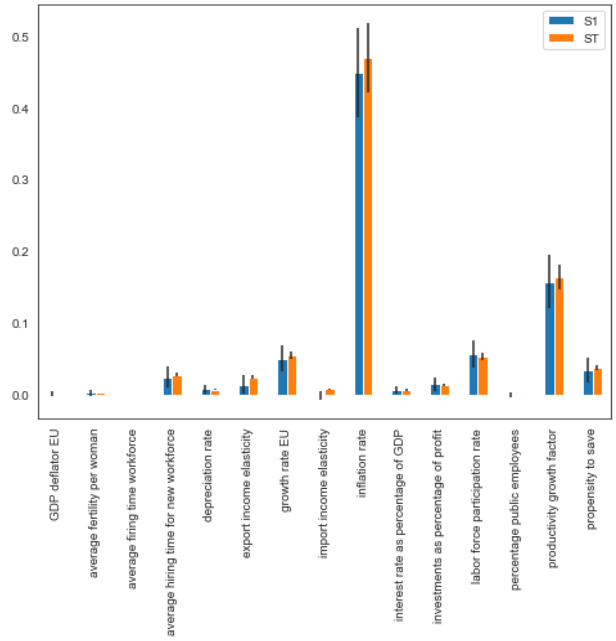
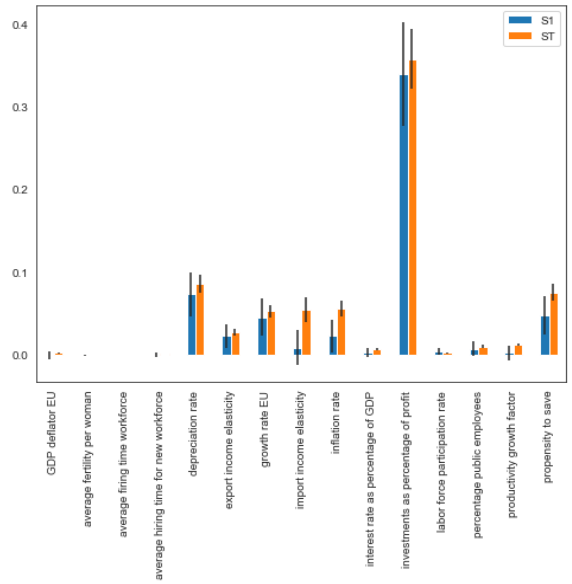
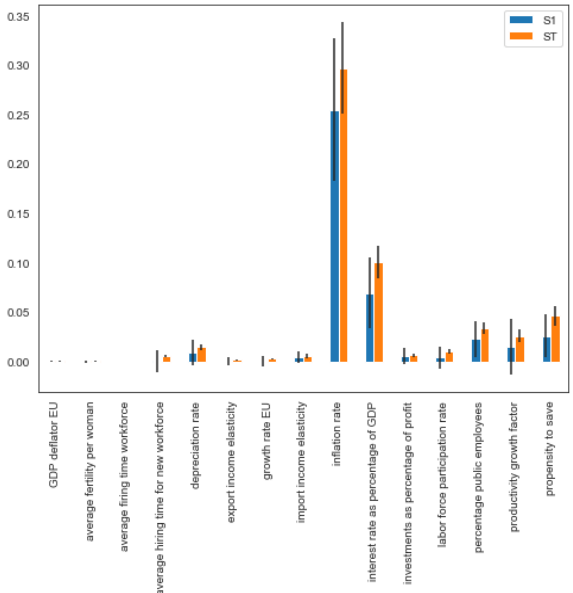
$$S_{T_i} = \frac{\mathbb{E}(Var(Y|\mathbf{X}_{\sim i}))}{Var(Y)} = 1 - \frac{Var(\mathbb{E}(Y|\mathbf{X}_{\sim i}))}{Var(Y)}$$

Figure E.7: First order and total effect equations

In the equations above, Var(Y) is the unconditional variance and $E(Y|X_i)$ and $E(Y|X_{\sim i})$ describe the conditional expected values (Steiner, Bourinet, & Lahmer, 2019).

In the tables below we can observe the graphical representation of the global sensitivity analysis and the numerical estimation of the results that are based on the above equations. The maximum value for every uncertainty input parameter is 1. A value of 1 implies that this parameter is solely responsible for the behavior of the outcome of interest. We are then interested in observing the parameters with the highest value both from the graphs and the tables of scores.

Table E-2: Sobol results for all outcomes of interest

Real GDP	Unemployment rate
	
Gross capital formation companies	**Gross capital formation government**
	

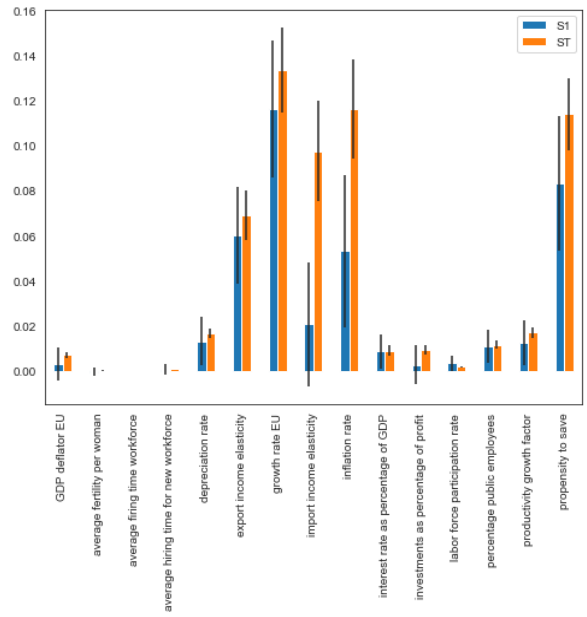
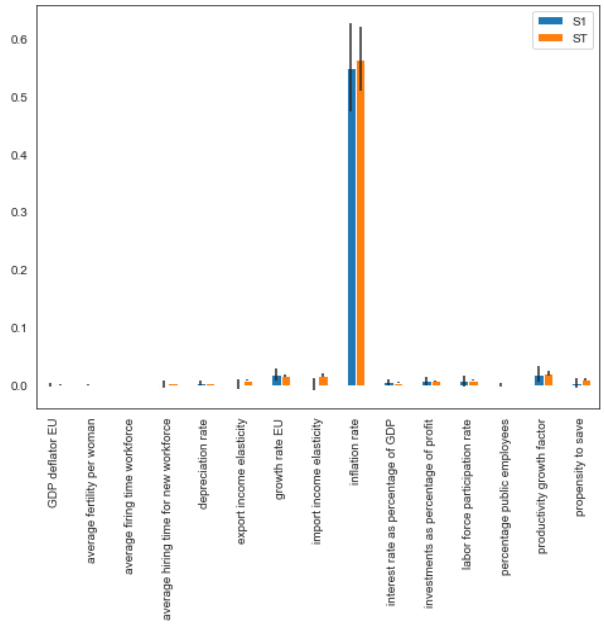
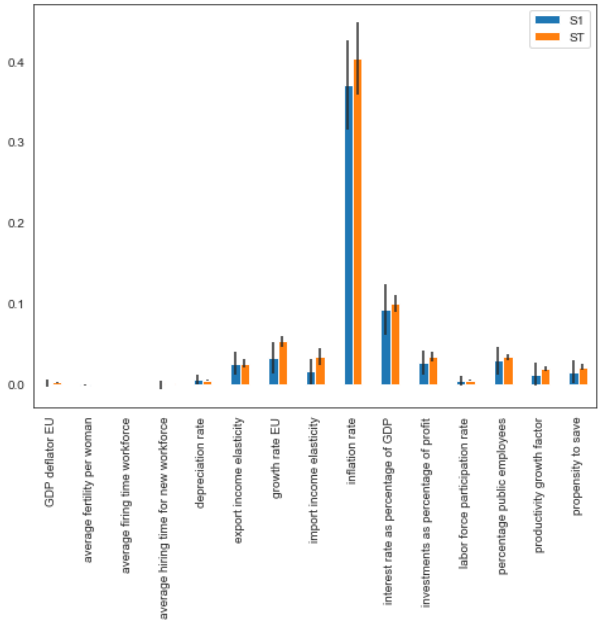
Profit	Real disposable income
	
Public budget balance	
	

Table E-3: Scores for the total effect (ST) of the input uncertainty parameters on the outcomes of interest

Real GDP

0	GDP deflator EU	0.002366
1	average fertility per woman	0.000073
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001984
4	depreciation rate	0.007874
5	export income elasticity	0.024250
6	growth rate EU	0.047072
7	import income elasticity	0.046036
8	inflation rate	0.613791
9	interest rate as percentage of GDP	0.008132
10	investments as percentage of profit	0.019990
11	labor force participation rate	0.004831
12	percentage public employees	0.001718
13	productivity growth factor	0.012998
14	propensity to save	0.059707

Unemployment rate

0	GDP deflator EU	0.001931
1	average fertility per woman	0.002731
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.027750
4	depreciation rate	0.006873
5	export income elasticity	0.024826
6	growth rate EU	0.055457
7	import income elasticity	0.008054
8	inflation rate	0.469742
9	interest rate as percentage of GDP	0.006772
10	investments as percentage of profit	0.013392
11	labor force participation rate	0.053840
12	percentage public employees	0.001107
13	productivity growth factor	0.164911
14	propensity to save	0.037961

Gross capital formation companies

0	GDP deflator EU	0.002509
1	average fertility per woman	0.000142
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001082
4	depreciation rate	0.085772
5	export income elasticity	0.027443
6	growth rate EU	0.052685
7	import income elasticity	0.054908
8	inflation rate	0.056182
9	interest rate as percentage of GDP	0.006392
10	investments as percentage of profit	0.358297
11	labor force participation rate	0.002338
12	percentage public employees	0.010096
13	productivity growth factor	0.012355
14	propensity to save	0.075761

Gross capital formation government

0	GDP deflator EU	0.000147
1	average fertility per woman	0.000150
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.005398
4	depreciation rate	0.014432
5	export income elasticity	0.001400
6	growth rate EU	0.002701
7	import income elasticity	0.005412
8	inflation rate	0.297085
9	interest rate as percentage of GDP	0.100528
10	investments as percentage of profit	0.006041
11	labor force participation rate	0.010373
12	percentage public employees	0.033766
13	productivity growth factor	0.025858
14	propensity to save	0.046121

Profit

Real disposable income

0	GDP deflator EU	0.007164
1	average fertility per woman	0.000326
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.001028
4	depreciation rate	0.017015
5	export income elasticity	0.069074
6	growth rate EU	0.133558
7	import income elasticity	0.097721
8	inflation rate	0.116311
9	interest rate as percentage of GDP	0.009243
10	investments as percentage of profit	0.009421
11	labor force participation rate	0.001974
12	percentage public employees	0.011734
13	productivity growth factor	0.017292
14	propensity to save	0.114036

0	GDP deflator EU	0.000729
1	average fertility per woman	0.000117
2	average firing time workforce	0.000000
3	average hiring time for new workforce	0.003439
4	depreciation rate	0.003293
5	export income elasticity	0.007964
6	growth rate EU	0.015959
7	import income elasticity	0.016530
8	inflation rate	0.565075
9	interest rate as percentage of GDP	0.004720
10	investments as percentage of profit	0.007716
11	labor force participation rate	0.008417
12	percentage public employees	0.001170
13	productivity growth factor	0.020328
14	propensity to save	0.010000

Public budget balance

0	GDP deflator EU	2.661625e-03
1	average fertility per woman	1.815236e-04
2	average firing time workforce	1.781289e-18
3	average hiring time for new workforce	2.147229e-03
4	depreciation rate	5.473847e-03
5	export income elasticity	2.641433e-02
6	growth rate EU	5.380930e-02
7	import income elasticity	3.495380e-02
8	inflation rate	4.032875e-01
9	interest rate as percentage of GDP	1.003666e-01
10	investments as percentage of profit	3.498340e-02
11	labor force participation rate	5.446877e-03
12	percentage public employees	3.403510e-02
13	productivity growth factor	1.982934e-02
14	propensity to save	2.171512e-02

PRIM Results

Table E-4: Scores for outcomes mean values

Real GDP	Unemployment rate	Gross capital formation companies	Gross capital formation government
count 10000.000000 mean 224.363051 std 75.173506 min 100.536266 25% 166.465501 50% 208.054804 90% 330.804080 max 633.800744	count 10000.000000 mean 0.202196 std 0.142377 min 0.021185 25% 0.077335 50% 0.159924 75% 0.310832 max 0.631188	count 10000.000000 mean 48.833754 std 25.221934 min 8.821328 25% 30.364558 50% 43.009259 max 231.362215	count 10000.000000 mean 24.589814 std 25.904288 min 1.892366 25% 3.296107 50% 17.920707 max 180.149399
Public budget balance	**Real disposable income**	**Profit**	
count 10000.000000 mean -1.770847 std 7.823992 min -29.118525 25% -7.271052 50% -2.700207 max 34.401102	count 10000.000000 mean 451.749133 std 155.673715 min 178.770097 25% 332.708280 50% 429.068714 max 1059.904069	count 10000.000000 mean 21.691608 std 10.320261 min 4.772636 25% 13.510609 50% 20.173648 max 87.954469	

PRIM BOXES

PRIM algorithm is using hill-climbing optimization procedure (J. H. Kwakkel & Cunningham, 2016). PRIM starts from the whole uncertain input space and searches in the boxes for the desirable outcomes of interest. To reach the desired regions, the space (starting box) is sliced in each side (top-down, left-right) and the PRIM algorithm choses the space that optimizes the outcomes of interest. The remaining space is now smaller but has a higher concentration of points of interest. Higher concentration of points means that the density is higher. Thus, in that specific box there is high number of scenarios that produce the desirable outcomes of interest. The algorithm continues the process until the condition that is set by the PRIM user is reached. Below there is a visual representation of how the PRIM algorithm works based on (Kwakkel & Cunningham, 2016).

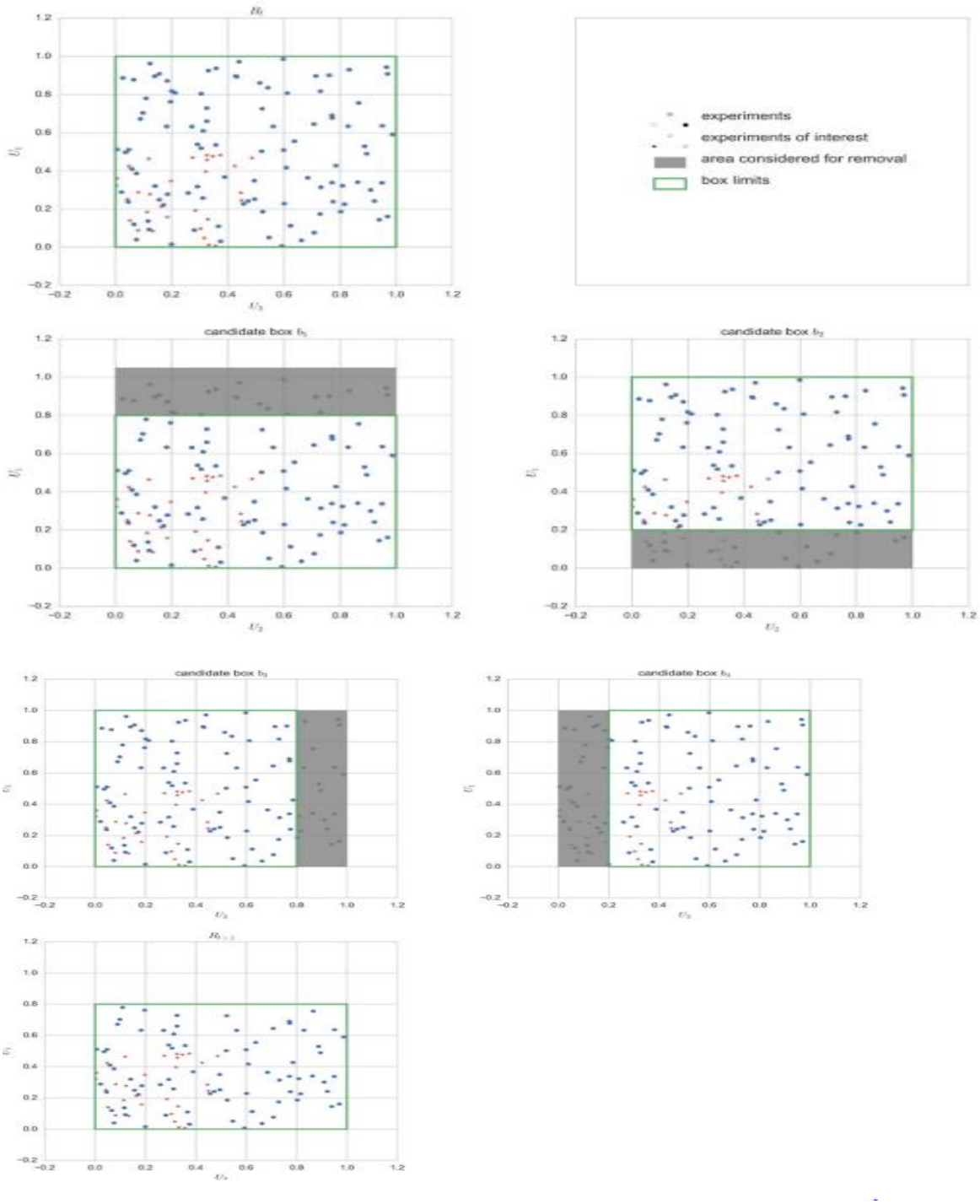


Figure E.8: Visual explanation of PRIM boxes slicing (source: Kwakkel & Cunningham, 2016)

For the current research, PRIM boxes were chosen based on the values of the two criteria of density and coverage. Goal is to find the boxes that have as high as possible values both for density and coverage. Below the PRIM boxes for all the outcomes of interest are presented.

Real GDP

```
coverage    0.635576
density     0.607256
id                13
mass            0.2536
mean        0.607256
res_dim            2
Name: 13, dtype: object
```

	box 13		
	min	max	qp values
growth rate EU	0.010003	0.022984	[-1.0, 7.522940558370013e-29]
inflation rate	0.018401	0.029994	[2.5766231702099278e-216, -1.0]

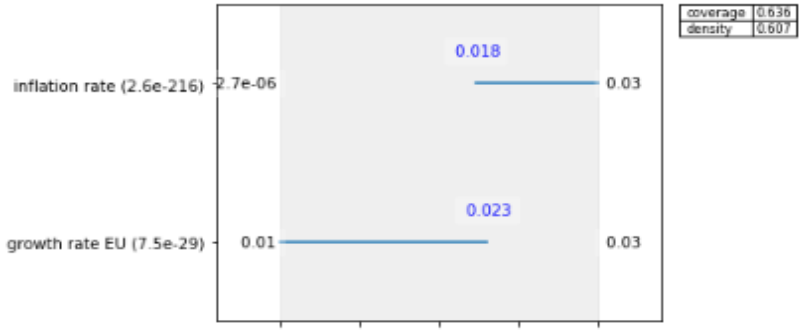


Figure E.9: Real GDP PRIM box

Profit

```
coverage    0.609566
density      0.60523
id                 7
mass             0.478
mean         0.60523
res_dim            3
Name: 7, dtype: object
```

	box 7		
	min	max	qp values
growth rate EU	0.010003	0.023144	[-1.0, 1.3394029526691402e-29]
propensity to save	0.059783	0.099994	[5.735857806328924e-06, -1.0]
inflation rate	0.002969	0.029994	[0.005085407225167938, -1.0]

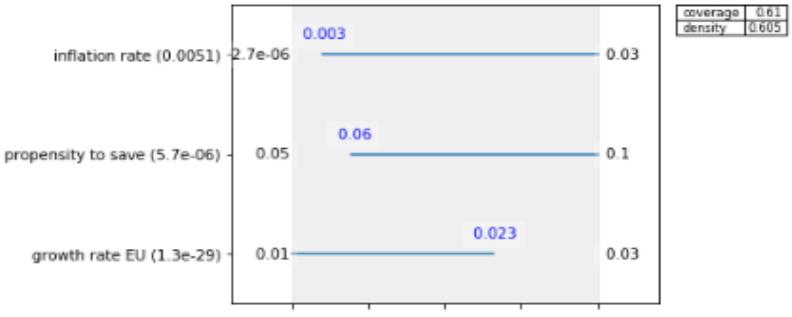


Figure E.10: Profit PRIM box

Gross capital formation companies

```
coverage     0.60243
density     0.510291
id                12
mass          0.2818
mean        0.510291
res_dim            2
Name: 12, dtype: object
```

	box 12	
	min	max
investments as percentage of profit	0.200019	0.304277
depreciation rate	0.084504	0.124995

	qp values
investments as percentage of profit	[-1.0, 8.742455489953378e-164]
depreciation rate	[4.551066495290105e-06, -1.0]

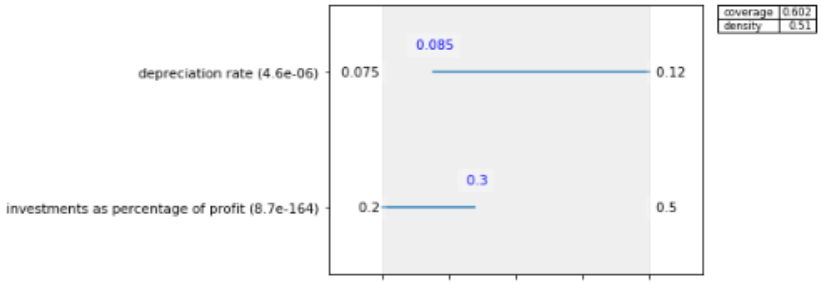


Figure E.11:Gross capital formation companies' PRIM box

Gross capital formation government

```
coverage    0.583981
density     0.594315
id                 6
mass          0.5312
mean        0.594315
res_dim            2
Name: 6, dtype: object
```

	box 6	
	min	max
inflation rate	0.007951	0.029994
interest rate as percentage of GDP	0.020763	0.049996

	qp values
inflation rate	[1.07936088127738e-05, -1.0]
interest rate as percentage of GDP	[6.574646196392659e-05, -1.0]

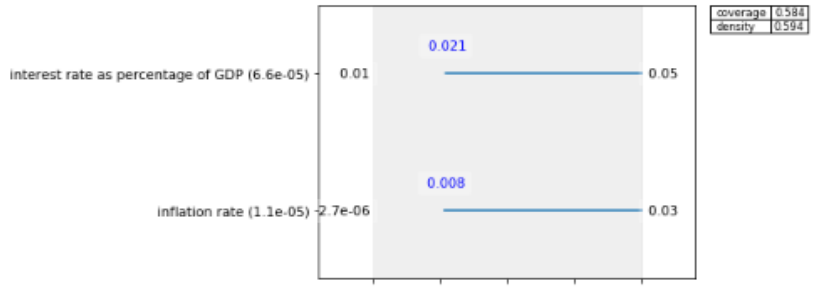


Figure E.12: Gross capital formation government PRIM box

Public budget balance

```
coverage    0.682036
density     0.714854
id                 7
mass           0.478
mean        0.714854
res_dim            2
Name: 7, dtype: object
```

```
                                    box 7            \
                                      min       max
inflation rate                   0.014063  0.029994
interest rate as percentage of GDP  0.013782  0.049996

                                                    qp values
inflation rate                   [4.937635262094964e-166, -1.0]
interest rate as percentage of GDP   [0.0004152501488185453, -1.0]
```

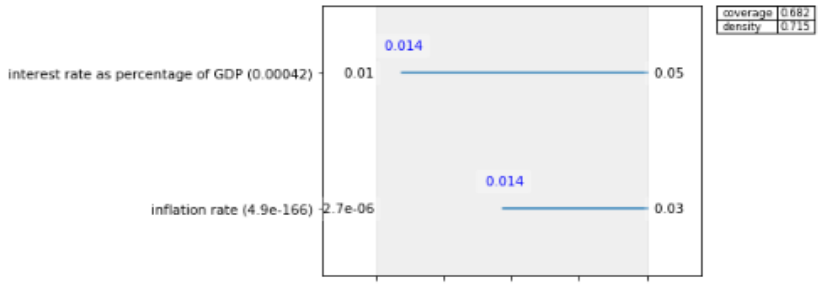


Figure E.13: Public budget balance PRIM box

Real disposable income

```
coverage    0.721841
density     0.513498
id                10
mass          0.3482
mean        0.513498
res_dim            1
Name: 10, dtype: object
```

```
                  box 10
                     min       max                          qp values
inflation rate  0.019552  0.029994  [2.4027375643357115e-247, -1.0]
```

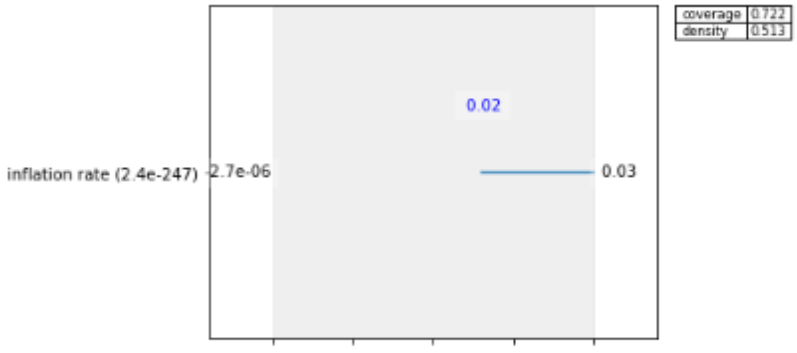


Figure E.14: Real disposable income PRIM box

Unemployment rate

```
coverage    0.710199
density      0.60249
id                11
mass           0.3132
mean          0.60249
res_dim             2
Name: 11, dtype: object

                                box 11            \
                                   min       max
inflation rate                0.015701  0.029994
productivity growth factor    0.003990  0.029999

                                                 qp values
inflation rate                [2.5675660525480713e-183, -1.0]
productivity growth factor      [2.942454275410686e-49, -1.0]
```

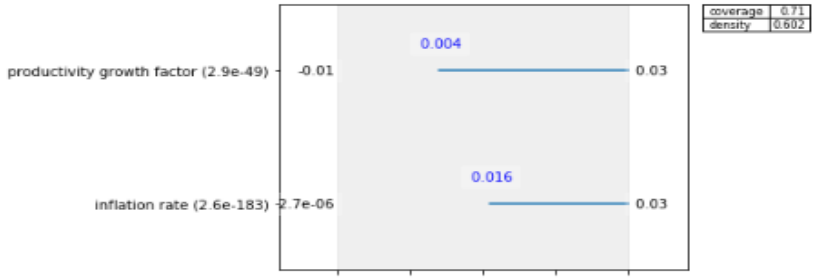


Figure E.15: Unemployment rate PRIM box