# Public Infrastructure Investment in China: A Recursive Dynamic CGE Analysis

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## Abstract.

This paper employs a recursively dynamic two-sector CGE model incorporating public infrastructure as input and international trade in order to analyze impacts of tax policies that aims to enhance public infrastructure investment for China. We conduct two policy simulations: (1) Increasing household income tax rate by 10% while other variables remain at their base case level; (2) Increasing the household consumption tax rate by increasing the same amount of government revenue in the first period while the household income tax rate remains at its base case value. Results of both simulations suggest negative effects of adopting tax policies on volume of trade for the purpose of enhancing public infrastructure investment. The measure of welfare change suggests that households would suffer from the use of taxes to fund the increase in public infrastructure investment. Still, the sensitivity analysis results indicate that the conclusions are sensitive to the value of the output elasticity of public infrastructure.



*Key words: Public infrastructure investment; Transportation cost; Welfare effect; International trade.*

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## 1. Introduction.

During the past 30 years of economic reform and urbanization, China has established a proven trend of economic growth. According to the World Bank, in 2001, the year that China became a member of World Trade Organization (WTO), China's GDP only counted for 4.03% of the world GDP. However, in 2014, China's GDP was 13.3% of the world GDP. Admittedly, inspiring improvements on macro-data of China's economic growth brings a huge number of benefits to both the Chinese population and the world. However, there are still issues associated with China's rapid growth.

The wealth gap has been an issue for the Chinese government over the last several decades. Due to the geographical and historical reasons, the northwest area of China has been the poorest region.[1] To some extent, public infrastructure is one of the most crucial causes of this. For example, the National Development and Reform Commission (NDRC) found that, in 1999, there were less than 200 kilometers of traffic mileage on the highway of province Shaanxi and only 13 kilometers of highway in province Gansu. After the 10-year project dubbed "Western Development", in 2008, people in the northwest area of China were better off from the higher quality and more developed public infrastructure invested by the central government. For instance, data from National Bureau of Statistics of China (NBSC) suggest that the income per capita in the province of Sinkiang increased from 5645 Yuan in 2000 to 11432 Yuan in 2008. The improvement in the living standard for people in the northwest area of China is an indication that public investment on infrastructure can effectively reduce the poverty gap and stimulate economic growth in China. However, the report from NBSC indicates that, the Gini index in 2003 was 0.479 and in 2012 it reached 0.474. Although it is a reduction, the level of the Gini index implies that the gap of wealth in China is

[1] Source: Chinese Statistical Yearbook (2013).

continuously significant, which means the improvement in people's living standard is still insufficient.

Recently, the Asian Infrastructure Investment Bank (AIIB) emphasized the significance of infrastructure in the aspect of international trade.[2] According to its estimation, in order to maintain the economic growth rate in most Asian countries, the annual investment in public infrastructure should be around 8 trillion US dollars. In this case, the current investment in public infrastructure is not enough for Asian countries, including China.

From an economic perspective based on above information, investment in infrastructure, especially in public infrastructure, can improve not only the regional economic performance in China, but also the benefit from international trade. By definition, public infrastructure is a general concept that refers to a set of publicly owned institutions or facilities, which covers from tangible transportation infrastructure to intangible institutions such as legal processes, and the most important ones are transportation and communication infrastructures (Munnell, 1992). Because of adequate and developed public infrastructures, distances between regions even countries can be reduced and connections would be increased between different markets with low costs (Zhang *et al*, 2013). In other words, governments can increase the efficiency of trade between markets at a relatively lower cost.

Astonishingly, there is only a handful of studies focus on the role of public infrastructure in the stage of economic growth. Liu and Hu (2010) empirically tested the importance of transportation infrastructure in China's economic growth between regions. Their conclusion was positive: the development of and investment in transportation infrastructures is necessary in order to consistently spur growth in China. According to Zou *et al* (2008), the evidence from panel data

[2] Asian Infrastructure Investment Bank: Articles of Agreement

from 1994 to 2002 and time series data from 1978 to 2002 confirms the important role played by transportation infrastructure. Zou *et al* (2008) suggested that the most important reason for the high growth rate of the Central and East China is the investment in transportation infrastructures. Moreover, public investment in transportation infrastructures significantly accelerates growth in poor areas of China.

Most existing studies on public infrastructure are purely empirical in the sense that they look back to the past and derive conclusions from different perspectives. Studies on the role of transportation infrastructure in spurring international trade are scanty, making it even more important to pursue this information toward bettering economies through infrastructure investment. This paper employs a recursively dynamic CGE model incorporating public infrastructure capital to assess the impact of investment in public transportation infrastructure on the economy in the long-run in China. Specifically, this study assesses the welfare effect and the impact of public transportation infrastructure investment on international trade. Two simulations are conducted in order to compare different policies on economic performance.

The remainder of this paper is organized as follows. Section 2 reviews some major findings from previous studies regarding public transportation infrastructure investment and its impacts. Section 3 presents the theoretical setting of the CGE model employed in this paper. Section 4 and section 5 discuss the data, calibration and numerical results from our model. Finally, section 6 concludes major findings from this study. The appendix includes tables and figures.

## 2. Literature Review.

### 2.1. ***Transportation Cost.***

Transportation cost has received great attention in traditional trade theories as well as in new trade theories. In traditional trade theories, for example, Samuelson (1954) proposes the "iceberg" cost of transportation in a pure Ricardian world. The basic idea of transportation cost in Samuelson (1954) is that only a fraction of the aggregate value of exports from the domestic country that arrives in the country of destination. Specifically, the total value of exports that can arrive in the country of destination is $a_x X$, where $0 < a_x < 1$ and $X$ denotes the total value of exports before transportation. The transportation cost is therefore $(1 - a_x)X$. The "iceberg" cost of transportation has become a traditional way to measure transportation cost, for both traditional trade theories and new trade theories.

On the other side, the home-market effect from the new trade theories, which also highlights the importance of transportation cost in the international trade theory, is based on two assumptions other than in traditional trade theories: (i) increasing return-to-scale production technology, and (ii) monopolistic competition (Helpman and Krugman, 1985).[3] The home-market effect indicates that, under the characteristics of increasing return to scale technology and the presence of transportation cost, firms will locate themselves in the economy with the highest demand of final goods they specialize in. The rationale behind the home-market effect is simple. As discussed by Krugman (1980), it is optimal for a firm to locate in the country with the largest market in order to minimize transportation cost as well as to accomplish economies of scale by employing the "iceberg" type of transportation cost.[4] Moreover, by minimizing transportation cost, consumers are better off from the cheaper prices.

However, the limitation of the "iceberg" transportation cost is obvious: it cannot fully explain the negative relationship between transportation cost and distance from empirical studies.

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[3] Traditional trade theories such as Ricardian models and Heckscher-Ohlin-Samuelson (HOS) models assumes constant returns and perfect competition, which are unrealistic assumption because there is no real prefect competition in the world and sectors such as manufacturing is well known as increasing returns to scale.

[4] The general form of cost function in Krugman's model for good $i$ is $l_i = \alpha + \beta x_i$. Where $l_i$ is the labour input used in producing the $i^{th}$ good and $x_i$ is the total output of good $i$. It is obvious that $\alpha$ is the fixed cost and $\beta$ is the constant marginal cost. By concentrating in production the total cost will be reduced.

Because the transportation cost is related to many factors, for instance, geographical factors and infrastructures, so the simple "iceberg" cost of transportation is not as realistic as other more complex measures of transportation cost (Spies and Kleinert, 2011). Besides the "iceberg" type of transportation cost, Martin and Rogers (1995) presented another form of transportation cost called "infrastructure cost". This is more relevant to infrastructure which is a tax on consumers' budget constraints. Nevertheless, the tax Martin and Rogers (1995) used is a function of the quality of infrastructures, which is not a simple multiplier such as the "iceberg" transportation cost.[5] In their paper, Martin and Rogers demonstrated the effect of improvement in infrastructure and concluded the existence of a significantly nonlinear relationship between infrastructures and trade patterns. Additionally, Bergstrand (1985) treats transportation cost as a variable in the function of the price index of imported goods in a general equilibrium model for the purpose of analyzing the world trade flow, which is another way of modelling transportation cost.

In general, different modeling methods of transportation cost are used for different purposes of analyses, but transportation cost is undoubtedly a key factor that determines not only the firms' behaviour but also the decisions of consumers in the presence of trade between economies.

### 2.2. ***Transportation Infrastructure and Trade Volume.***

Infrastructure is commonly believed as a crucial factor for reducing transportation cost, thereby also for increasing firms' productivity and trade volume (Rioja, 1999). Therefore, many scholars have attempted to introduce transportation cost as well as infrastructures into trade models. Bougheas *et al* (1999) generated a modified Dornbusch-Fischer-Samuelson (DFS) model that is

[5] For all infrastructure cost $\tau$, $\tau = \tau(g)$, where $g$ is the quality of infrastructure, $\partial\tau/\partial g < 0$ implies that the investment on the quality of infrastructure decreases transport costs.

originally developed by Dornbusch *et al* (1977), which is a type of Ricardian two-country model, to analyze the impact of the introduction of transportation cost and the quality of infrastructure on trade volume. Following Samuelson (1954) and Krugman (1980), Bougheas *et al* (1999) employed the "iceberg" transportation cost and concluded that the introduction of transportation cost in the DFS model can lead to a decline of consumptions in all commodities as well as a negative relationship between transportation cost and trade volume.

Bougheas *et al* (1999) provides empirical evidence from European data. The augmented gravity specifications used are:

$$\begin{cases} ln\left(X_{ij,t}\right) = \beta_0 + \beta_1 \, ln\left(Y_{i,t}\right) + \beta_2 \, ln\left(Y_{j,t}\right) + \beta_3 \, ln\left(\frac{GG_{ij,t}}{D_{ij}}\right) + \varepsilon \\ ln\left(X_{ij,t}\right) = \tilde{\beta}_0 + \tilde{\beta}_1 \, ln\left(Y_{i,t}\right) + \tilde{\beta}_2 \, ln\left(Y_{j,t}\right) + \tilde{\beta}_3 \, ln\left(\frac{MM_{ij,t}}{D_{ij}}\right) + \tilde{\varepsilon} \end{cases},$$

where $X_{ij,t}$ is the volume of export from country *i* to country *j* at time *t*; $Y_{i,t}$ and $Y_{j,t}$ are GDPs of country *i* and country *j* at time *t*, respectively. $GG_{ij,t}$ is the variable measuring all infrastructures including transport-related infrastructures; $MM_{ij,t}$ is the variable that directly measures transportation infrastructures, which is the length of motorway between country *i* and *j*; and $D_{ij}$ is the distance between country *i* and *j*. A tilde is on the top of coefficients ($\tilde{\beta}$'s) for the second equation in order to distinguish it from the first equation.

Bougheas *et al* (1999) separately analyzed two datasets; one is the dataset including six European Union countries and the other one is a set including nine European countries (not necessarily in European Union). Results from both regressions indicated that their prediction is consistent with the data, which are positive signs on $\beta_3$ and $\tilde{\beta}_3$ in regressions stated above. In short, improvements on infrastructures can increase the volume of trade and this relationship is statistically significant.

There are similar results to Bougheas *et al* (1999) found in other papers. De (2006) found that transportation cost had significantly negative impacts on trade volume in Asia by utilizing a structural model with a cross-country dataset. Geraci and Prewo (1977) estimated elasticities of transportation cost on imports and exports for 18 countries, a 1% increase in transportation cost would averagely lead to a 1.15% decrease in import and export on average. As discussed in Bougheas *et al* (1999), transportation cost of a country to its trading partner might be potentially and majorly determined by the country's infrastructure system. It is then plausible to expect that transportation cost and infrastructures have a negative relationship.

The empirical framework used in Bougheas *et al* (1999) for the analysis of trade volume, the gravity model of trade, is a standard regression model dominated in empirical analyses of bilateral trade. The benchmark specification of the gravity model of trade uses the natural logarithm of trade volume between the two countries as the dependent variable, using natural logarithms of the two countries' GDPs and distance-related variables as independent variables. One study that cannot be neglected is Limão and Venables (2001), which directly investigates the relationship between infrastructure, transportation cost and trade volume. Limão and Venables analyzed two different data sources; the first one is a dataset of shipping quotes that includes a single commodity from different departure countries to a single country of destination. This dataset avoids the potential issue of heterogeneity as it controls for factors that would potentially generate biased estimations. The other dataset provides the measure of total imports from other countries, which is the type of data commonly used in most empirical studies.

Limão and Venables (2001)'s gravity model specification is

$$ln(M_{ij}) = \phi_0 + \phi_1 ln(Y_j) + \phi_2 ln(Y_i) + \psi'[distance\ related\ variables] + \eta_{ij},$$

where $M_{ij}$ denotes the trade volume between country $i$ and country $j$; $Y_j$ and $Y_i$ represent the GDPs of country $j$ and country $i$, respectively. $\psi'$ is the transpose of the vector of coefficients that corresponding to the vector of distance related variables (including measures of infrastructures); and $\eta_{ij}$ is the i.i.d error term.

Limão and Venables (2001) calculated an elasticity of trade volume with respect to transportation cost. By employing the same variables in the regression specifications for transportation cost and regression specifications for trade volume, the elasticity of trade volume with respect to transportation cost is -3 (significantly different from 0), which led them to conclude that the relationship between trade volume and transportation cost is actually negative. Importantly, improvements in infrastructures from the median to the top $25^{th}$ percentile is approximately equivalent to a 2358 kilometers decrease in physical distance between trading partners. Therefore, the deterioration in infrastructures increases transportation cost and reduces trade volume between trading partners. The conclusion from Limão and Venables (2001) confirms the finding of Bougheas *et al* (1999) that the relationship between transportation costs and trade volume is negative, but Limão and Venables (2001) emphasized the effects of infrastructures on the above relationship, which is a positive relationship between infrastructures and trade volume. The question implied from this study is how countries would cooperate in order to prevent the potential issue of deterioration in international infrastructures, or, how countries would decide to invest in their infrastructures to prevent potential deteriorations.

Bougheas *et al* (2003) empirically examined the question that how countries share costs of providing international transportation services and infrastructures, or equivalently, how countries invest in international transportation infrastructures. Precisely, Bougheas *et al* obtained a panel dataset spanning from 1987 to 1995 and covering 16 European countries. The log-linear regression specification is

$$ln(i)_{i,t} = \alpha_{i,t} + \beta_1 y_{i,t} + \beta_2 f y_{j,t} + \Lambda' X_{i,t} + \mu_{i,t},$$

where *i* is the infrastructure investment of the home country in per capita level, $y_{i,t}$ denotes the per capita income level of the home country, and $fy_{j,t}$ denotes the weighted per capita income of the rest countries.[6] In the above specification, $X_{i,t}$ is a set of explanatory variables and $\Lambda'$ is the transpose of the coefficient vector corresponding to $X$. Finally, $\mu_{i,t}$ is the error term.

In Bougheas *et al* (2003), they separately examined infrastructure investments in roads, maritime ports, rails and airports by employing the above log-linear specification. In general, results from the four sets of regressions confirm the hypothesis that one cannot analyze infrastructure investments by isolating incomes of the home country and rest of the world. This is because of the statistical significance of the estimated coefficients. In other words, investments in infrastructures are strategic decisions for a country that are, to some extent, determined by its partner's income level.

In conclusion of this sub-section, the relation between infrastructure and trade volume is clearly positive. Yet, it is still necessary to clarify whether private investment or public investment in infrastructures is better and feasible for implementation in policies.

### 2.3. *Public infrastructure and Welfare.*

Investment in public infrastructure improved the living standard for people who live in the northwest area in China during the "Western Development" project. Motivated by this success and

[6] In Bougheas *et al* (2003), $fy_{j,t} = \sum_{j=1}^{n} w_{i,j} y_{j,t}$, where $w_{i,j}$ is the weight corresponding to the national income of country *j* at time *t* and $w_{i,i} = 0$.

other relevant cases in other countries, some studies have attempted to examine the impact of public investment in infrastructure on welfare, using different methods.

Rioja (2001) developed a dynamic general equilibrium model and analyzed the impact of infrastructure investment on Brazil, Mexico and Peru. The simulation results in Rioja (2001) showed a positive effect of infrastructure investment on welfare. However, the model in Rioja (2001) indicates that there exists an optimal level of infrastructure investment and after this point there will be detrimental effects on macro-variables such as output, private capital investment and welfare.

Bougheas *et al* (1999) extend the DFS model discussed in subsection 2.2 and derived the welfare effect of infrastructure on welfare by maximizing the social welfare function with respect to endogenous transportation cost. As in Rioja (2001), the relationship between infrastructure and welfare is nonlinear; there is an optimal level of infrastructure that maximizes welfare.

Ferreira and Do Nascimento (2005) investigated financing schemes for public infrastructure investment that can benefit the Brazilian economy in the aspect of GDP, social welfare and growth. By analyzing a competitive general equilibrium model incorporating public infrastructure capital as an input of production, the most effective method of improving the welfare of Brazil was to reduce public consumption and increase public investment in infrastructures, while controlling other variables and parameters to be unchanged.

In short, although the effect of public infrastructure investment on welfare is still largely unexplored due to different constraints of data availability, especially for China, a handful of studies have provided tools and general conclusions on the relationship between public infrastructure investment and social welfare.

### 2.4. ***Public Infrastructure Investment and CGE Modeling.***

Effects of public infrastructure investment on economic performance have been emphasized in many studies. Summarized by Cohen and Paul (2004), previous estimations by Duffy-Deno (1988), Aschauer (1989) and Reich (1991) indicated that the economic return from public investment in infrastructures is much higher than from private investment in infrastructures. The result of those estimations implies that investment in infrastructures should be financed by the public sector of an economy, for example, the government. Lynde and Richmond (1993) suggested that public investment in infrastructure is significant in terms of its costs to the manufacturing sector based on evidence from U.K. data, which indicates infrastructure investment by government might directly influence the cost of production.

Most studies regarding public infrastructure investment, or more generally, public capital investment, focus on the effects on productivity of the production sector. Mikelbank and Jackson (2000) reviewed numerous studies that are important to this relationship and summarized them to one sentence: Public infrastructure capital is crucial as a type of input in the production. As a policy decision, public investment and other decisions related to trade made by the public sector usually be analyzed by applying computable-general-equilibrium (CGE) models and results from CGE models influence policy making procedure as well (Devarajan and Robinson, 2002).

CGE models convert theoretical general equilibrium theory to numerical representations via computer programs. According to Gilbert and Wahl (2002), CGE models can capture interactions between each economic agent when there is a shock (i.e. a new policy) introduced to an economy and policy makers can easily understand the numerical results computed by computer programs. Boccanfuso *et al* (2014) focused on the effects of public infrastructure investment on productivity for the province of Quebec in Canada by applying a recursively dynamic CGE model. In general, Boccanfuso *et al* (2014)'s results suggest that infrastructure investments by the public sector have positive contributions on productivity of private sectors, which are firms in the production sector. The best infrastructure funding options among household income tax and sales tax (consumption tax) is household income tax.

However, the effects of public infrastructure investment or provision on trade have been largely unexplored. The next section illustrates the theoretical model, which is used to analyze the relationship between public infrastructure investment and trade volume.

In summary of this section, all key theoretical papers regarding infrastructure and trade so far have only focused on one-time period. Precisely, they implicitly assumed that the contributions of investments on infrastructures would be realized quickly. Nevertheless, most empirical analyses used panel data sets to study the effect of infrastructure improvements on trade (i.e. Khadaroo and Seetanah, 2008; Mart ńez-Zarzoso *et al*, 2003; Iwanow and Kirkpatrick, 2007) or the effect of national income on infrastructure investments (i.e. Bougheas *et al*, 2003). This contrast between the theoretical and empirical studies implies that there is a need for models that could potentially take the time dimension into account in the analysis of the impact of transportation infrastructure on trade.

## 3. Description of the Model.[7]

This section presents the theoretical structure of our model, which demonstrates how the increase in public infrastructure investment funded by different types of taxes affects the domestic economy. Specifically, this model aims to simulate effects of the public infrastructure investment in the domestic economy and the volume of trade between the domestic economy and the rest of the world.

[7] Equations and variables as well as parameters are listed in the appendix.

Our model is a recursively dynamic CGE model. In this CGE model, trade is bilateral, namely, trade is assumed to happen between a domestic economy and the rest of the world. Following the tradition of CGE modeling, firms in the domestic economy have constant-return-to-scale production technologies. Because this CGE model uses the "representative" consumer assumption, it can only capture the macroeconomic effect of the policy. It cannot deal with heterogeneity across individuals.

### 3.1. ***The Representative Firms.***

There are two representative firms in the domestic economy. Firm 1 produces one representative tradable good named good 1 for export and domestic sales. It maximizes its profit using a constant-return-to-scale (CRS) Cobb-Douglas production function with two value-added inputs (labor and private capital) and one intermediate input (transportation service produced by the other firm). Mathematically, the production function of firm 1 can be written as

$$Y_t^1 = A^1 \left(K_t^{P,1}\right)^{\alpha_1} (L_t^1)^{\alpha_2} (D_t^{tr})^{\alpha_3}, \qquad (1)$$

where $Y_t^1$ is the output of good 1 produced by firm 1, and $K_t^{P,1}$ and $L_t^1$ are value-added inputs (private capital and labor, respectively) demanded by firm 1; finally, $D_t^{tr}$ is the intermediate input, which is transportation service produced by firm 2 and demanded by firm 1. The CRS technology assumption implies that $\alpha_1 + \alpha_2 + \alpha_3 = 1$. Because all markets in the world are assumed to be perfectly competitive, so the price of good 1 ($P_t^1$) is simply its marginal cost:

$$P_t^1 = \frac{1}{A^1} \left(\frac{r_t^P}{\alpha_1}\right)^{\alpha_1} \left(\frac{w_t}{\alpha_2}\right)^{\alpha_2} \left(\frac{P_t^{tr}}{\alpha_3}\right)^{\alpha_3}, \qquad (2)$$

where $r_t^P$, $w_t$ and $P_t^{tr}$ are rental price of private capital, wage rate and the price of transportation service, respectively. $A^1$ is total factor productivity (TFP) of firm 1, which is constant over time. The rationale behind this formulation of price is that, under the CRS production technology and perfect competition assumptions, break-even prices at equilibrium are the optimum for firms in the production sector (Shoven and Whalley, 1984). In short, profit-maximization and cost-minimization have the same result under the circumstance of CRS technology and perfect competition. At equilibrium, the output of good 1 is demanded by the rest of the world, consumption from the representative household and investments.

The other firm produces transportation service to supply the demand for intermediate input by firm 1. It maximizes its profit according to a standard CRS Cobb-Douglas production function with private capital and labor as inputs, implying that the sum of output elasticity of capital ($\beta_1$) and output elasticity of labor ($\beta_2$) is one (i.e. $\beta_1 + \beta_2 = 1$). The price of transportation service, which is also the transportation cost for firm 1, is the marginal cost of transportation service:

$$P_t^{tr} = \frac{1}{A_t^{tr}} \left(\frac{r_t^P}{\beta_1}\right)^{\beta_1} \left(\frac{w_t}{\beta_2}\right)^{\beta_2}, \tag{3}$$

where $P_t^{tr}$ is the price of transportation service, and $A_t^{tr}$ is the TFP with the following expression:

$$A_t^{tr} = \bar{A}(KG_t)^{\zeta} \text{ with } \zeta > 0, \tag{4}$$

is a function of public infrastructure, $KG_t$. As the public infrastructure capital is only used in the production of transportation service, it is explicitly assumed in this model that when there is more public infrastructure flowing into the economy, the cost of transportation for firm 1 will decrease, which is commonly believed and assumed by many studies as discussed in literature review (i.e. Boccanfuso *et al*, 2014).

### 3.2. ***<u>The Representative Household.</u>***

There is a typical representative household in the domestic economy that maximizes his utility while facing his budget constraint. This setting of our model implicitly assumes that the population growth rate is zero. The representative household purchases a composite commodity, constituting good 1 and a representative imported good from the rest of the world. Following Armington (1969), the imported good and good 1 are imperfect substitutes. Therefore, the composite commodity purchased by the representative household is assumed to be a CES function of the consumption of good 1 and the consumption of the imported good, where the elasticity of substitution is not one. The mathematical form of the aggregate consumption of the representative household ($C_t$) is written as

$$C_t = AC[\gamma(C_t^1)^{-\varphi} + (1-\gamma)(C_t^M)^{-\varphi}]^{-\frac{1}{\varphi}}, \tag{5}$$

where $C_t^1$ is the consumption of good 1 and $C_t^M$ is the consumption of the imported good. In the above equation, $\gamma$ denotes the share of consumption of good 1, $\varphi$ is the parameter of substitution and $AC$ is the shifting parameter of the consumption function. In this model, the imported good is entirely consumed by the representative household and there is no demand from firms in the production sector.

There are two types of proportional taxes facing the representative household; the first is the consumption tax ($\tau_C$) and the other is income tax ($\tau_H$). Income tax is imposed on the representative household's total income, namely, on their revenue from private capital and labor supply. The after-tax income or the disposable income of the representative household is saved and spent for consumption. The consumption tax is imposed on household aggregate consumption.

For a CES aggregate consumption function, it is possible to verify that a CES utility function is identical to the aggregate consumption function. Thus, the household problem is written as

$$\max\ U_t = C_t = AC[\gamma(C_t^1)^{-\varphi} + (1-\gamma)(C_t^M)^{-\varphi}]^{-\frac{1}{\varphi}}$$
$$s.t.\ \ (1+\tau_C)P_t^C C_t = P_t^1 C_t^1 + P_t^M C_t^M,$$

where $P_t^M$ is the price of the imported good determined by the exchange rate. The household consumption price index, $P_t^C$ is therefore solved as

$$(1+\tau_C)P_t^C = \frac{1}{AC}[\gamma^\sigma (P_t^1)^{1-\sigma} + (1-\gamma)^\sigma (P_t^M)^{1-\sigma}]^{\frac{1}{1-\sigma}}, \quad (6)$$

where $\sigma = \frac{1}{1+\varphi}$ is the elasticity of substitution for the representative household's consumption between good 1 and the imported good.

Since this model is recursively dynamic, saving of the representative household is determined by the exogenous saving rate and cannot be used to smooth consumption over time. However, according to Diao and Thurlow (2012), as long as the purpose of a model is not to find the steady-state equilibrium of an economy in the long-run, a recursively dynamic model is appropriate. For this study, because this model is to determine the impact of public infrastructure investment on the economy rather than to find the economy's steady state, so the setting of the model as a recursively dynamic model is reasonable. The saving of the representative household becomes part of the total saving in the economy that is used for investing on private capital.

### 3.3. ***The Representative Government.***

There is a representative government who collects income tax and consumption tax from the representative household as its budget. For the sake of simplicity, we assume that all government revenue is spent on public infrastructure:

$$GR_t = \tau_H YTH_t + \tau_C P_t^C C_t, \quad (7)$$

$$GR_t = P_t^1 INV_t^G. \quad (8)$$

In the equation (7) and (8), $GR_t$ is the total government tax revenue and $YTH_t$ is the household total income before tax, and $INV_t^G$ denotes the investment good of public infrastructure. As the investment good of public infrastructure is from the output of good 1, so the price of the investment good for public infrastructure is the price of good 1.

### 3.4. ***Saving and Private Investment.***

There are two types of saving in the domestic economy that determine the investment in private capital. The first component of total saving of the economy is foreign saving, and the second is household saving. The latter is in fixed proportion of household disposable income. Then, the sum of the two parts is used to purchase private investment good. Mathematically, we have

$$HSAV_t = sYD_t, \tag{9}$$

$$FSAV_t = PW_t^M C_t^M - \frac{P_t^1}{EXR_t} EX_t^1, \tag{10}$$

$$TOTSAV_t = HSAV_t + FSAV_t, \tag{11}$$

$$TOTSAV_t = P_t^1 INV_t^P. \tag{12}$$

In the above series of equations regarding saving and investment, $HSAV_t$ denotes the household saving and $YD_t$ is the disposable income of the representative household; $FSAV_t$ is the foreign saving and $TOTSAV_t$ denotes the level of total saving of the economy; finally, $INV_t^P$ denotes the investment of private capital, which is from the output of good 1.

### 3.5. ***Equilibrium Conditions.***

According to Diao and Thurlow (2012), the most significant difference between partial equilibrium models and general equilibrium models is that, in partial equilibrium models, prices are determined by exogenous sources or pre-defined functions, but in a general equilibrium model all prices are endogenously determined by equilibrium conditions. Thus corresponding markets determine all relative prices by equating the demand sides and supply sides.

In equilibrium, all markets clear. Firstly, in the factor market, total labor demand and total private capital demand are equal to their total supply:

$$KP_t^{TOT} = KP_t^1 + KP_t^{tr}. \tag{13}$$

$$L_t^{TOT} = L_t^1 + L_t^{tr}, \tag{14}$$

In equation (13) and (14), $L_t^{TOT}$ denotes the exogenous total labor supply from the representative household and $KP_t^{TOT}$ is the within period exogenous (i.e. at the beginning of one year) total private capital supply from the representative household. Here we assume that all primary factors are fully employed, mobile across production sectors and immobile across economies. Therefore, factor prices are fully endogenous. These two equations determine the wage rate and rental price of labor and private capital, respectively. Because public infrastructure capital ($KG_t$) is fully exogenous at time *t*, so there is no need to specify its equilibrium condition.

Secondly, in the commodity market, outputs equal to their corresponding demands:

$$Y_t^1 = EX_t^1 + DS_t^1, \tag{15}$$

$$DS_t^1 = C_t^1 + INV_t^P + INV_t^G, \tag{16}$$

$$Y_t^{tr} = D_t^{tr}. \tag{17}$$

Equation (15), (16) and (17) describe the equilibrium conditions that must be satisfied in the good and service market, where $DS_t^1$ is the aggregate level of domestic sales of good 1. The demand function for export of good 1 by the foreign economy has the following specification:

$$EX_t^1 = AX\left(\frac{P_t^{EX}}{P_t^1}\right)^{\epsilon_{EX}} FGDP_t, \tag{18}$$

where $FGDP_t$ is the measure of GDP of the foreign economy and $P_t^{EX}$ is the world price of export. In equation (18), $\epsilon_{EX}$ is the constant elasticity of substitution between good 1 and good produced abroad.

Thirdly, in general equilibrium models, household income is endogenously determined by his labor and private capital revenue rather than in partial equilibrium models household income is exogenous:

$$YTH_t = r_t^P KP_t^{TOT} + w_t L_t^{TOT}, \tag{19}$$

where $YTH_t$ is the total before-tax income of the representative household. Equation (19) implicitly assumed that all value-added factors are owned by the representative household.

Last, for the external account, the export price and import price as well as exchange rate are endogenously determined by equation (20) and (21):

$$P_t^{EX} = PW_t^{EX} EXR_t, \tag{20}$$

$$P_t^{M} = PW_t^{M} EXR_t, \tag{21}$$

$P_t^{EX,W}$ denotes the exogenous world price of export and $P_t^{M,W}$ denotes the exogenous world price of the imported good. For general equilibrium models, at equilibrium, the value of total export must equal to the value of total import, so this condition determines the endogenous exchange rate.

### 3.6. ***Recursive Dynamics.***

The static (within-period) part of the model has been descripted in previous sub-sections; this sub-section presents the dynamic (between-period) part of the model. In the between-period part, all exogenous variables in the within-period are updated externally by their relevant factors or results from previous periods, and all parameters are fixed over time.

Total private capital and total public capital in the between-period part is determined by previous results:

$$KP_{t+1}^{TOT} = (1-\delta) KP_t^{TOT} + INV_t^P, \tag{22}$$

$$KG_{t+1} = (1-\delta) KG_t + INV_t^G, \tag{23}$$

where $\delta$ is the capital depreciation rate. Equation (22) and (23) are also called the standard capital (private and public) accumulation equations, which are determined by results of private and public investment from the within-period part.

As discussed in the sub-section of the representative household, the population is implicitly assumed to be constant over time. Thus there is no population growth in the between-period part of the model. Since the population is the labor supply, the labor supply does not grow over time.

The TFP of firm 1 is a constant parameter as we consider the time period is based on one-year, which means the technology implemented by firm 1 cannot improve during this short of time. For the firm that produces transportation service, its TFP improves according to the availability of public infrastructure based on the public capital accumulation equation.

## 4. Data and Calibration.

### 4.1. ***The Input-Output Table and Social Accounting Matrix.***

The calibration procedure of this model is based on a social accounting matrix (SAM). According to Dissou (2005), there is a reference situation called the business-as-usual (BAU) case in a CGE model. We then assume that the BAU situation is the initial equilibrium represented by the SAM, which is also assumed to be the initial state of the economy. Our SAM is built using the input-output (I-O) table, which is mainly constructed using the average shares derived from national accounts of China's GDPs between 2000 and 2013. The GDP at factor cost and GDP at market prices are obtained from the National Bureau of Statistics of China (NBSC) for consistent monetary measurement over the 13-year period. The I-O table is calculated by multiplying the two GDPs with shares of components of the table that are obtained from the World Bank database. This calculation method of the I-O table avoids inconsistent measurement of different cells. The data in the SAM and the I-O table are mainly from the China Statistical Yearbook (2000–2013).

The SAM for this study is constructed in two steps. The first step is to build a balanced I-O table for the economy. The construction of the I-O table is based on the data of GDP at market prices and GDP at factor cost. Specifically, the GDP at market prices is adjusted to be 1000 and all other data are adjusted by GDP at market prices, multiplied by 1000. By definition, GDP at factor cost is the overall value of the two value-added production factors used by the production sector; GDP at market prices is the overall value of final consumption expenditures: $Y = C + I + G + (EX - M)$, where $Y$ denotes the GDP at market prices, $I$ is the value of private investment, $G$ is the government spending (in this model it represents public investment) and $(EX - M)$ represents the net export of the domestic economy. Therefore, since we do not consider any indirect taxes paid by firms, the difference between GDP at market prices and GDP at factor cost is the consumption tax paid by the representative household. In the above equation, each component's share of GDP at market prices is obtained from the Word Bank database and all shares are adjusted to the average level from 2000 to 2013 except for private investment. However, the share of private investment can be calculated by subtracting all other shares from 1, and the resulted share is thus the average level from 2000 to 2013.

With only two value-added production factors in this model, as long as there is share for either labor or private capital, the other's share can be calculated without further information. It is usually easier to find data on labor rather than private capital due to the problem of defining private capital. Thus we found the data on the number of employed people in China and the average wage for those people from NBSC, and the product of them is the total remuneration of labor. Then, we calculate the remuneration of private capital by subtracting the labor remuneration from GDP at factor cost. Similarly, the data on employed people in the transportation sector from 2000 to 2013 are obtained from NBSC. Finally, by assuming the tradable industry is the rest of the production sector, the labor and private capital remuneration from firm 1 is the difference between total labor and private capital remuneration and labor and private capital remuneration from the transportation sector. After the calculation of each firm's figures on labor and private capital, there is no complex calculation procedure in the construction of the I-O table. Table 4.1 describes the structure of our I-O table.

After completing the I-O table construction, the SAM can be built by extending the I-O table to a more detailed structure. The household income tax paid by the representative household to the representative government is calculated by subtracting the household consumption tax revenue from the government total spending (equivalent to public investment). As a square matrix, the SAM has the same number of rows and columns, wherein the total of each row must equal the total of the corresponding column in order to represent the initial equilibrium. Table 4.2 shows details of the SAM.

## 4.2. ***Exogenous Data and Parameters.***

Most parameters in this CGE model can be calibrated using the information provided by the SAM; however, elasticities in CES functions cannot be calibrated as the SAM does not have enough information in order to calibrate these values. Thus there are some parameters used in this paper from previous studies. The elasticity of demand for export of domestically produced goods was estimated by Lin and Li (2003), the elasticity of public infrastructure on productivity was estimated by Ma and Li (2001) and the elasticity of substitution for Chinese consumers between domestic produced goods and imported goods was estimated by Tang (2003). Additionally, the capital depreciation rate, which is assumed to be the same for private and public capital, is estimated by Chow and Li (2002). Table 4.3 presents all values of parameters estimated by previous literatures.

In this model, demand for exported good 1 by the rest of the world is assumed to depend on the level of its aggregate GDP at market price. The world GDP at market price is obtained from the World Bank database and the aggregate GDP at market price for ROW is calculated by subtracting China's GDP at market price by the world GDP at market price. The final rate for the GDP of ROW is adjusted by exchange rate obtained from Bloomberg.

**4.3. *Calibration Results.***

For solving the calibration procedure as well as the following simulations, we use the advanced modeling program GAMS. Table 4.5 presents the calibrated values of parameters from the BAU situation of the economy described by the SAM. Since the economy is assumed to be at its initial steady state, the total volumes of private capital and public infrastructure are calibrated by dividing their values in the SAM by the exogenous capital depreciation rate. Therefore, the rental price of private capital is calculated by dividing the nominal value of total private capital in the SAM by the calibrated volume of total private capital, which is different from 1. All other prices are assumed to be 1 in the calibration procedure.

The calibration results of share parameters for the three inputs in firm 1's production function indicate that good 1 is labor intensive as the share of labor is 0.675, which is more than a half. The calibration results of share parameters for the value-added production factors indicate that transportation service is capital intensive as the share of private capital in the production function is 0.882. The calibration result for the shift parameter in the TFP of firm 2 indicates that the efficiency of using public infrastructure is low, as the value is only 0.001.

On the other hand, the representative household saves slightly more than half of his disposable income and hence spends less than half of his disposable on consumption. This result of saving rate indicates that China is a high saving country, which is consistent with results from previous literatures (i.e. Li and Yin, 2007; Kuijs, 2005; Kraay, 2000).

## 5. Simulations.

In order to capture the dynamic effect of public infrastructure investment on the economy presented by our model, we conduct two simulations focusing on the two tax rates for the representative household. This is because, in our model, the two tax rates directly affect the public infrastructure investment. The first simulation is designed to increase the household income tax rate by 10% permanently and fix the household consumption tax rate at its BAU level. Hence, the calibrated income tax rate has been changed from 0.135 to 0.1485 in this simulation. The objective of this experiment is to measure the impact of the enhancement of public infrastructure investment from the household income tax on the economy. The second simulation is to permanently increase the household consumption tax rate such that the amount of tax revenue generated by the policy is equal to the amount of tax revenue generated by the increase of household income tax in simulation 1, while no change in the household income tax rate in the second experiment. All simulation results of endogenous variables are presented as percentage deviations from their BAU values.

### 5.1. ***Results of Simulation 1.***

In this experiment, the policy of a 10% permanent increase of household income tax rate is simulated in order to analyze effects of increasing public infrastructure investment on the economy. We separate the analysis on the simulation result into three steps. First, we discuss the impact of the policy on endogenous variables at the first period. Then we move forward to analyze the short-run and long-run effects of this permanent policy on the economy.

Table 5.1 presents the percentage deviation of each endogenous variable with respect to its BAU level in the first period. As a recursive dynamic model, the effect from the public infrastructure investment and private investment on firms cannot be reflected in the first period due to capital accumulation, in this case, we can only capture the demand effects from the representative household in the analysis of the first period.

At the first period, the government tax revenue jumps 11.51% from its BAU level directly by the increase of household income tax revenue, and the investment in public infrastructure that financed by the government tax revenue thereby jumps 9.87% with respect to its BAU value. According to the transmission mechanism described by our model, the jump of the demand for public infrastructure investment drives the demand for domestic sale up, and the increase of the domestic sale demand overcomes the drop in export demanded by ROW. Finally, the increasing demand for good 1 drives up its price in the first period as the output level of good 1 does not change in this period.

The 10% increase of the household income tax rate decreases household disposable income, total consumption expenditure and his saving level by 0.09% all at once. Since the representative household only takes account the current situation in consideration, the decrease of his disposable income induces him to reduce his consumption. Particularly, the consumption of good 1 decreases by 1.16% and the consumption of the imported good declines by 0.43% in comparison with their BAU levels. Because of the decline in disposable income, the representative household has to decrease his saving level as his saving is determined by the exogenous saving rate. In this way, the decline of household saving level combines with the exogenously fixed level of foreign saving results in a drop in the demand level of private capital investment.

On the other hand, the increase of household income tax drives up all prices in the first period. The wage rate and rental price of private capital both jump 1.50% from their BAU values, which benefit the total income of the representative household by the same percentage points. This is the reason why the 10% increase of household income tax rate does not decrease the household disposable income by the same percentage points. The reason for the increase in the wage rate and the rental price of private capital is that, as the price of good 1 is just the marginal cost of firm 1, an increase in the price of good 1 means an increase in the marginal cost of production for firm 1. By adjustment, since the demand for all production factors by firm 1 and the firm producing transportation service do not change at all and the level of total supply is fixed as an exogenous variable, prices of the three production factors evenly jumps 1.50% due to the CRS assumption.

In the context of international trade, the policy decreases the volumes of both export and import in the first period. Specially, the demand for export of good 1 drops 1.84% and the demand for imported good by the representative household drops by 0.43% form their BAU values. As discussed above, the decline in the demand for imported good is due to the reduction of the household disposable income. The demand for export of good 1 by ROW decreases because of the jump of the price of good 1. In this case, the policy of increasing household income tax rate by 10% fails to enhance the total volume of trade in the first period.

In short, the policy of a 10% increase in household income tax rate diverges the economy from its BAU situation, which is the initial steady state of the economy. Figure 1 illustrates the short-run and the long-run effect of the 10% increase of household income tax rate for 150 periods. An important result is that, although initially the transportation cost for firm 1 jumps 1.50%, it starts to decrease after the jump and finally to be the same as its BAU value at the $10^{th}$ period due to the increased TFP of firm 2. After the $10^{th}$ period from the reference year, the transportation cost of firm 1, or the price of transportation service, starts to fall with respect to its BAU level since the level of firm 2's TFP is permanently higher than its BAU level in the long-run.

In contrast, the rental price of private capital continues to increase after the jump in time 1. Since the total demand and total supply of private capital both decline in the short-run, the only reason for the increase of rental price of private capital is the larger amount of decrease in total private capital supply. Because of this relationship, the rental price of private capital becomes permanently higher than its BAU level in the long-run. In the short-run, the declining transportation cost drives up the demand for transportation service while decreases the demand for private capital in the production of good 1. The increase of demand for transportation service and decline of demand for private capital indicate that private capital and transportation service are substitutes in the production of good 1.

After the jump at the first period, the government revenue starts to fall in the short-run until it reaches its new steady-state level in the long-run. However, the new steady-state level of government revenue maintains at 11.49% higher than its BAU level. Then, the decrease of government revenue directly drives down the volume of public infrastructure investment in the short-run, which makes the total volume of public infrastructure to evolve at a diminishing rate until it achieves its new steady-state level.

The increase of public infrastructure permanently increases the TFP of firm 2 and therefore drives the output level of transportation service up. Meanwhile, since private capital and public infrastructure are substitutes in this simulation, the decline of transportation cost results the demand for private capital permanently lower than its BAU level, and the demand for transportation service by firm 1 increases in the long-run. The demand for transportation service by firm 1 is permanently higher than its BAU level and the demand for private capital is permanently lower than its BAU value due to the substitute relationship in this simulation.

For firm 2, the increase in TFP induced by the higher investment in public infrastructure results in less demand for private capital in its production. The decline of total demand for private capital combines its negative growth rate for investment drives the total supply of private capital down in the short-run, and it becomes lower than its BAU level at its new steady-state level in the long-run.

As the demand for labor by the two firms changes only negligibly, so by adjustment, the wage rate starts to fall after its jump at the first period. The lower level of household saving and the fixed level of foreign saving lower the level of total saving in the economy, this is the reason why investment in private capital decreases in the long-run.

In summary, the policy of increasing the household income tax rate by 10% to fund an increase in public investment does not enhance the volume of trade. Particularly, both export and import decreased permanently. Regarding the welfare effect of the policy, since the utility level of the representative household is just the level of aggregate consumption, the permanent decrease in the aggregate consumption also represents a permanently lower utility level for the economy. More specifically, we calculate the compensating variation and the equivalent variation. According to Hicks (1939), the compensating variation (CV) is the monetary measure of welfare that reflects the amount of additional money an agent need in order to maintain his or her initial utility level in terms of the new prices and income. In this case, the calculation is simple as the utility function is just the aggregate consumption function. Therefore, in order to get his old utility after the change in income tax rate, the representative household needs 4.103 additional units of money, which means the new utility level is lower than the BAU level. Another measure of welfare change, the equivalent variation (EV) represents the money needed for the representative household to meet his new utility level, given the BAU prices and income (Hicks, 1939). Thus, assuming the representative household is at his BAU situation, he has to give up 3.311 units of his wealth to achieve the new utility level, which is a sad news for him. Therefore, by looking directly at the utility level and CV and EV, the economy is getting worse off after implementing this policy. In conclusion, the policy to increase the household income tax rate in order to increase the public infrastructure investment is not a good option for policy makers.

### 5.2. ***Results of Simulation 2.***

In this experiment, the household income tax rate retains its BAU value, but the household consumption tax rate increases such that the tax revenue generated by this increase of household consumption tax rate at the first period is equivalent to the government revenue generated by the policy in simulation 1. Following the steps in the analysis of simulation 1, this subsection firstly discusses the impact of the increase in household consumption tax rate at the first period, and then analyzes the short-run and long-run impacts of this policy.

Table 5.2 displays the percentage deviation of endogenous variables from their BAU level in the first period. As in table 5.1, the increase of household consumption tax rate results in an 11.51% jump in government revenue, 8.63% higher infrastructure investment than its BAU level. The jump of demand for public infrastructure investment and private investment drives up the demand for domestic sales and overcomes the decline of export demand. As the productivity effect for firms cannot be reflected in the first period and the increase in household consumption tax rate does not affect firms' decisions in the first period, both demand for production factors and output levels remain the same. Increased demand for good 1 and unchanged supply therefore leads the price of good 1 to increase 2.66% higher than its BAU level. Since we are in a perfectly competitive market, the increase of the marginal cost of firm 1, namely the price of good 1, drives up production factor prices in the first period. The total income of the representative household must then increase by 2.66% as well.

Thanks to the increase in total income of the representative household, household disposable income increases by the same percentage points from its BAU level, which leads to a higher level of expenditure available for consumption and a higher level of household saving. The increase of household saving level directly drives up the total saving of the economy, and results in an increase of private investment in the first period.

On the other hand, since the price of good 1 increases, the household consumption price index also increases. Thus, although household nominal income increases, the extra tax on household consumption tax rate leads to a lower level of aggregate consumption for the representative household.

Regarding international trade, the increase of household consumption tax rate and household consumption price index lower the import demand by the representative household. Moreover, the increase in the price of good 1 reduces the demand for export by the rest of the world. In this case, the policy to increase the household consumption tax rate does not stimulate either export or import in the first period, which is the same result as in simulation 1.

In the long-run, all variables move to their new steady-state level after the introduction of the permanent increase in household consumption tax rate. Figure 2 illustrates the short-run and long-run effects of the permanent increased household consumption tax rate. The short-run paths for all variables are due to capital accumulation. As both private investment and public infrastructure investment increased in the first period, the total volume of private capital and public infrastructure increase in the following period. Since the rental price of private capital decreases in the short-run and becomes permanently lower than its BAU level in the long-run, we can infer that the amount of increase in total demand for private capital in the short-run is less than the amount of increase in total supply of private capital. This relationship continues in the short-run and finally results in a permanent decrease in the rental price of private capital and higher level in the long-run.

By looking at the short-run path of the total income of the representative household, the decrease of rental price of private capital does not make the total household income decreased since the wage rate for labor increases in the short-run and becomes higher than its BAU level in the long-run. As the BAU level of wage rate is higher than the BAU level of rental price of private capital, the increase of wage rate leads to an increase of the total income of the representative household.

Because of the increase in household total income, the disposable income and money available for the representative household to consume increases in the short-run. Additionally, benefit from the increase of household disposable income in the short-run, the level of total saving in the economy goes up in the short-run and it drives up the private capital investment.

As the total volume of public infrastructure increases in the short-run, the TFP of firm 2 increases as well, which results in a higher level of output and lower level of price of transportation service in the short-run. Furthermore, the decrease of transportation cost drives up the demand for transportation service by firm 1. Similarly, as the rental price of private capital decreases in the short-run, the demand for private capital also goes up, which means that private capital and transportation service are not substitutes for firm 1 in this simulation.

Benefit from the decrease of transportation cost and rental price of private capital, the output level of good 1 increases and the price decreases in the short-run, which drives the demand for good 1 up. However, total demand for good 1 stays to be lower than its BAU level but higher than its level in the first period in the long-run.

The decrease of good 1's price in the short-run lowers the consumption price index for the representative household, leading to a lower level of this price index in the long-run than in the first period. Thus, the demand for consumption in the short-run directly goes up due to the decrease in the consumption price index, which results in a higher level of aggregate consumption in the long-run than in the first period but permanently lower than its BAU value.

For international trade, the volumes of both export and import decrease permanently. The volume of export decreases in the long-run due to the permanently higher level of price of good 1, however, because of the lower price level of good 1 than in the first period, the volume of export increases after its drop in the first period. On the other hand, the volume of import follows the same path of export due to the lower level of price index and higher level of money available for expenditure in the long-run than in the first period.

In summary of this simulation, the policy to increase household consumption tax rate fails to enhance the total volume of trade, with a lower level of trade volume than in simulation 1. However, this policy raises the demand level from domestic market, which is a higher level of domestic sales than the BAU level and the long-run level in simulation 1. The utility level of the representative household, namely the level of aggregate consumption, decreases a little more than in simulation 1, which results in a CV of 4.878 and an EV of -4.829. By definition (Hicks, 1939), the representative household needs 4.878 units of money in order to back to his original utility level after the change in policy. To move from the BAU situation to the new utility level, the representative household must give up 4.829 units of money. By comparison, the policy of increasing the household consumption tax rate is worse than the policy to increase the household income tax rate in order to increase the public infrastructure investment.

### 5.3. ***Sensitivity Analysis.***

According to Bretschger *et al* (2011), different choices of parameters would distinctly influence simulation results. Surprisingly, the two tax policies simulated in this paper have same conclusions, which is the increase in public infrastructure investment funded by increasing household income tax or household consumption tax would lead to reductions in trade volume and welfare. Thus we perform sensitivity analyses for the elasticity of public infrastructure capital ($\zeta$), the elasticity of export demand ($\epsilon_{EX}$) and the Armington elasticity ($\sigma$) to check the robustness of our conclusions. These elasticities are allowed to be halved and increased by 50% from their BAU levels (calibrated in section 4). Variations of elasticities are done separately (i.e. one elasticity changes for each time). Results for the sensitivity analysis are presented in table 5.3 and 5.4. Sensitivities are interpreted as percentage deviations from base simulations (i.e. based on simulation 1 and simulation 2).

The results in table 5.3 and 5.4 suggest that, for both policies, the increase in $\zeta$ improves welfare (i.e. the aggregate consumption level of the representative household) mostly in comparison with results of changes in other elasticities. The increase in $\zeta$ also confers the largest positive effect on the total volume of trade (i.e. the sum of export and import). Our results indicate that our simulation results are very robust with respect to changes in $\epsilon_{EX}$ as the variations in all crucial variables are in the interval between -2% and 2%, which is defined as the minimal impact interval based on Bretschger *et al* (2011).

However, changes in $\zeta$ fluctuate the simulation results most intensely as variations in most variables are very large. Precisely, the increase in $\zeta$ drives up the household aggregate consumption level, which is also the welfare of the representative household, by about 8.44% in the long-run in comparison with the result of simulation 1. Moreover, the increase in $\zeta$ raises the volumes of export and import with a larger increase in import based on results of simulation 1. In this case, a higher level of $\zeta$ would improve welfare and trade volume, implying that at certain level of $\zeta$ that is higher enough than the value chosen in simulation 1, the results from our simulation would be reversed. Same implications apply for results of simulation 2.

According to table 5.3 and 5.4, the increase of $\sigma$ raises the trade volume but lowers the welfare in both simulations. These changes in welfare and import are in the minimal impact interval and the change in export is slightly beyond this interval. By comparison, changes in the elasticity of public infrastructure capital affects our conclusions most largely.

## 6. Conclusions.

This paper develops a simple recursively dynamic CGE model to analyze the potential impact of public investment in infrastructure on China's economy incorporating international trade. There are two policy scenarios conducted for the purpose of comparing the results from changes in different type of taxes. In general, results from the two simulations both suggest a negative outcome for welfare and volume of trade in the long-run.

In simulation 1, we increase the public infrastructure investment by increasing 10% of the household income tax rate. In both short-run and long-run, export demand from the rest of the world and the demand of imported good by the representative household decreased. The rapid reduction of transportation cost for firm 1 neither enhances its output level nor reduces the price of good 1. For welfare effect, because we assume the economy only has one representative household, so the aggregate consumption function of the representative household is identical to the social welfare function, which is the utility function of the economy. The simulation result suggests a continuous decrease in the short-run and eventually a permanent reduction in the utility level of the representative household in the long-run. Additionally, by computing the CV and EV of this simulation result, the representative household is worse off in the long-run from this policy.

In simulation 2, we increase the fund for public investment in infrastructure by increasing the same amount of government tax revenue via an increase in household consumption tax rate since in our model the tax revenue of the representative government is directly used in public infrastructure investment. By looking at the simulation results, although the export demand from the rest of the world and the import demand from the representative household increase slightly after their drops in the first period, they become permanently lower than the BAU level in the long-run, and their decline are larger than in simulation 1. For firm 1, although the reduction of transportation cost lowers the price of good 1 from its level in the first period, the price becomes permanently higher than in the BAU case. The long-run results in the figures show that, although the utility level of the representative household increases from its first period level in the short-run, it is still lower than its BAU level in the long-run due to the permanently higher tax rate on consumption. According to CV and EV, the representative household suffers a worse decline in welfare than in simulation 1.

In the sensitivity analysis of our simulation results, the change in the elasticity of public infrastructure capital affects our simulation results most significantly, indicating that our conclusions would be reversed when there is a much higher value of this elasticity than our original selection. Unfortunately, there is no direct support from previous literatures for our simulation results. Our uniform consumption tax environment is a much simpler setting than many studies. However, our results are consistent with the general conclusion by Conrad (1997), which is a theoretical CGE framework for European transportation infrastructure investment. Precisely, if infrastructure investment is financed by taxations, there could be a negative effect on the economy's welfare level, as well as a negative externality.

In conclusion, constrained by our data availability, our CGE model is simple as we assume potentially heterogeneous individuals are identical. Thus, we cannot report different effects from the two policies on individuals in various groups. Moreover, the government in our model only invests in public infrastructures and does not take into account the welfare of the representative household. This results in a worse off welfare level in the two policy simulations. For future works, more researches are required to extend the results in this paper to different regions except China. Also, there are many other methods to enhance public infrastructure investment such as FDI.

**References.**


Armington, Paul S. "A Theory of Demand for Products Distinguished by Place of Production." Staff Papers-International Monetary Fund (1969): 159-178.

Aschauer, David Alan. "Is public expenditure productive?" *Journal of monetary economics* 23, no. 2 (1989): 177-200.

Bergstrand, Jeffrey H. "The gravity equation in international trade: some microeconomic foundations and empirical evidence." *The review of economics and statistics* (1985): 474-481.

Boccanfuso, Dorothée, Marcelin Joanis, Patrick Richard, and Luc Savard. "A comparative analysis of funding schemes for public infrastructure spending in Quebec." *Applied Economics* 46, no. 22 (2014): 2653-2664.

Bougheas, Spiros, Panicos O. Demetriades, and Edgar LW Morgenroth. "Infrastructure, transportation costs and trade." *Journal of International Economics* 47, no. 1 (1999): 169-189.

Bougheas, Spiros, Panicos O. Demetriades, and Edgar LW Morgenroth. "International aspects of public infrastructure investment." *Canadian Journal of Economics/Revue canadienne d'économique* 36, no. 4 (2003): 884-910.

Bretschger, Lucas, Roger Ramer, and Florentine Schwark. "Growth effects of carbon policies: applying a fully dynamic CGE model with heterogeneous capital." *Resource and Energy Economics* 33, no. 4 (2011): 963-980.

Chow, Gregory C., and Kui-Wai Li. "China's Economic Growth: 1952–2010." *Economic Development and Cultural Change* 51, no. 1 (2002): 247-256.

Cohen, Jeffrey P., and Catherine J. Morrison Paul. "Public infrastructure investment, interstate spatial spillovers, and manufacturing costs." *Review of Economics and Statistics* 86, no. 2 (2004): 551-560.

Conrad, Klaus. "Traffic, transportation, infrastructure and externalities A theoretical framework for a CGE analysis." *The Annals of Regional Science* 31, no. 4 (1997): 369-389.

De, Prabir. "Trade, infrastructure and transaction costs: the imperatives for Asian economic cooperation." *Journal of Economic Integration* (2006): 708-735.

Devarajan, Shantayanan, and Sherman Robinson. "The influence of computable general equilibrium models on policy." No. 98. *International Food Policy Research Institute (IFPRI)*, 2002.

Diao, Xinshen, and James Thurlow. "A recursive dynamic computable general equilibrium model." In *Strategies and Priorities for African Agriculture: Economywide Perspectives from Country Studies* (2012): 17-50.

Dissou, Yazid. "Cost-effectiveness of the performance standard system to reduce CO 2 emissions in Canada: a general equilibrium analysis." *Resource and Energy Economics* 27, no. 3 (2005): 187-207.

Dornbusch, Rudiger, Stanley Fischer, and Paul Anthony Samuelson. “Comparative advantage, trade, and payments in a Ricardian model with a continuum of goods.” *The American Economic Review* (1977): 823-839.

Duffy-Deno, Kevin T., and Randall W. Eberts. “Public infrastructure and regional economic development: a simultaneous equations approach.” *Journal of urban economics* 30, no. 3 (1991): 329-343.

Ferreira, Pedro Cavalcanti, and Leandro Goncalves Do Nascimento. Welfare and growth effects of alternative fiscal rules for infrastructure investment in Brazil. Funda ção Getulio Vargas, 2005.

Geraci, Vincent J., and Wilfried Prewo. “Bilateral trade flows and transportation costs.” *The Review of Economics and Statistics* (1977): 67-74.

Gilbert, John, and Thomas Wahl. “Applied General Equilibrium Assessments of Trade Liberalization in China.” The World Economy 25, no. 5 (2002): 697-731.

Helpman, Elhanan, and Paul R. Krugman. *Market structure and foreign trade: Increasing returns, imperfect competition, and the international economy*. MIT press, 1985.

Hicks, John R. “The foundations of welfare economics.” *The Economic Journal* (1939): 696-712.

Iwanow, Tomasz, and Colin Kirkpatrick. “Trade facilitation, regulatory quality and export performance.” *Journal of International Development* 19, no. 6 (2007): 735-753.

Khadaroo, Jameel, and Boopen Seetanah. “The role of transport infrastructure in international tourism development: A gravity model approach.” *Tourism management* 29, no. 5 (2008): 831-840.

Kleinert, Joern, and Julia Spies. “Transportation Costs in International Trade.” (2011).

Kraay, Aart. “Household saving in China.” *The World Bank Economic Review* 14, no. 3 (2000): 545-570.

Krugman, Paul. “Scale economies, product differentiation, and the pattern of trade.” *The American Economic Review* (1980): 950-959.

Kuijs, Louis. “Investment and saving in China.” *World Bank Policy Research Paper Series* 3633 (2005).

Li, Yang, Jianfeng YIN, and Hongbo CHEN. “China's High Saving, High Investment, and High Growth.” *Finance & Trade Economics* 1 (2007): 006.

Lim ão, Nuno, and Anthony J. Venables. “Infrastructure, geographical disadvantage, transportation costs, and trade.” *The World Bank Economic Review* 15, no. 3 (2001): 451-479.

Lin, Justin Yifu, and Yongjun Li. “Export and economic growth in China: a demand-oriented analysis.” *China Economic Quarterly* 2 (2003): 779-794.

Liu, Sheng-long, and An-gang Hu. “Transport Infrastructure and Economic Growth: Perspective from China’s Regional Disparities.” *China Industrial Economics* 4 (2010): 14-23.

Lynde, Catherine, and James Richmond. “Public capital and long-run costs in UK manufacturing.” *The Economic Journal* (1993): 880-893.

Martin, Philippe, and Carol Ann Rogers. “Industrial location and public infrastructure.” *Journal of International Economics* 39, no. 3 (1995): 335-351.

Mart ńez-Zarzoso, Inmaculada, and Felicitas Nowak-Lehmann. “Augmented gravity model: An empirical application to Mercosur-European Union trade flows.” *Journal of applied economics* 6, no. 2 (2003): 291-316.

Mikelbank, Brian A., and Randall W. Jackson. “The role of space in public capital research.” *International Regional Science Review* 23, no. 3 (2000): 235-258.

Munnell, Alicia H. “Policy watch: infrastructure investment and economic growth.” *The Journal of Economic Perspectives* (1992): 189-198.

Reich, R., “The Real Economy,” *The Atlantic Monthly* 267:2 (1991), 35–52.

Rioja, Felix K. “Productiveness and welfare implications of public infrastructure: a dynamic two-sector general equilibrium analysis.” *Journal of Development Economics* 58, no. 2 (1999): 387-404.

Rioja, Felix K. “Productiveness and welfare implications of public infrastructure: a dynamic two-sector general equilibrium analysis.” *Journal of Development Economics* 58, no. 2 (1999): 387-404.

Samuelson, Paul A. “The transfer problem and transportation costs, II: Analysis of effects of trade impediments.” *The Economic Journal* (1954): 264-289.

Shoven, John B., and John Whalley. “Applied general-equilibrium models of taxation and international trade: an introduction and survey.” *Journal of Economic Literature* (1984): 1007-1051.

Tang, Tuck Cheong. “An empirical analysis of China's aggregate import demand function.” *China Economic Review* 14, no. 2 (2003): 142-163.

Zhang, Yumei, Xinxin Wang, and Kevin Chen. “Growth and distributive effects of public infrastructure investments in China.” In Infrastructure and Economic Growth in Asia, pp. 87-116. Springer International Publishing, 2013.

Zou, Wei, Fen Zhang, Ziyin Zhuang, and Hairong Song. “Transport Infrastructure, Growth and Poverty Alleviation: Empirical Analysis of China.” *Annals of economics and finance* 2 (2008).

## Appendix: Tables and Figures.

**Table 3.1: List of Variables and Parameters (time subscript: t)**

| | Notation | Variable Name | Equation of Determination |
|---|---|---|---|
| *Endogenous Variables:* | | | |
| 1. | $P_t^1$ | Price of good 1 | Equation (A1) |
| 2. | $r_t^P$ | Rent of private capital | Equation (A26) |
| 3. | $w_t$ | Wage rate of labor | Equation (A27) |
| 4. | $KP_t^1$ | Demand for private capital by firm 1 | Equation (A2) |
| 5. | $L_t^1$ | Demand for labor by firm 1 | Equation (A3) |
| 6. | $D_t^{tr}$ | Demand for transportation service by firm 1 | Equation (A4) |
| 7. | $Y_t^1$ | Output of good 1 produced by firm 1 | Equation (A5) |
| 8. | $DS_t^1$ | Domestic sale of good 1 | Equation (A6) |
| 9. | $EX_t^1$ | Demand for export of good 1 | Equation (A7) |
| 10. | $P_t^{tr}$ | Price of transportation service produced by firm 2 | Equation (A8) |
| 11. | $A_t^{tr}$ | TFP of firm 2 | Equation (A9) |
| 12. | $KP_t^{tr}$ | Demand for private capital by firm 2 | Equation (A10) |
| 13. | $L_t^{tr}$ | Demand for labor by firm 2 | Equation (A11) |
| 14. | $Y_t^{tr}$ | Output of transportation service | Equation (A12) |
| 15. | $YTH_t$ | Household total income before tax | Equation (A13) |
| 16. | $YD_t$ | Household disposable income | Equation (A14) |
| 17. | $HC_t$ | Household total consumption | Equation (A15) |
| 18. | $P_t^C$ | Price index of household consumption | Equation (A17) |
| 19 | $C_t$ | Household aggregate consumption | Equation (A16) |
| 20. | $C_t^1$ | Consumption demand for good 1 | Equation (A18) |
| 21. | $C_t^M$ | Consumption demand for imported good | Equation (A19) |
| 22. | $HSAV_t$ | Household saving | Equation (A20) |
| 23. | $GR_t$ | Government revenue | Equation (A21) |
| 24. | $INV_t^{KG}$ | Demand for public infrastructure investment | Equation (A22) |
| 25. | $INV_t^{KP}$ | Demand for private capital investment | Equation (A25) |
| 26. | $FSAV_t$ | Foreign saving | Equation (A23) |
| 27. | $TOTSAV_t$ | Total saving of the economy | Equation (A24) |
| 28. | $EXR_t$ | Exchange rate (numeraire) | Equation (A30) |

| | | | |
|---|---|---|---|
| 29. | $P_t^{EX}$ | Export price | Equation (A28) |
| 30. | $P_t^M$ | Import price | Equation (A29) |
| 31. | $WALRAS$ | Walras law (check variable) | |

| *Exogenous Variables:* | | |
|---|---|---|
| 1. | $PW^{EX}$ | World price of export |
| 2. | $PW^M$ | World price of import |
| 3. | $FGDP$ | Measure of GDP of the rest of the world |
| 4. | $KG_t$ | Public infrastructure |
| 5. | $KP_t^{TOT}$ | Total private capital supply |
| 6. | $L_t^{TOT}$ | Total labor supply |
| 7. | $OMEGA$ | 10 |

| *Parameters:* | | |
|---|---|---|
| 1. | $A^1$ | TFP of firm 1's production function |
| 2. | $AX$ | Shifting parameter for foreign demand of export |
| 3. | $\bar{A}$ | Constant parameter for $A_t^{tr}$ |
| 4. | $AC$ | Shifting parameter for household consumption |
| 5. | $\alpha_1$ | Output elasticity of private capital for firm 1's production |
| 6. | $\alpha_2$ | Output elasticity of labor for firm 1's production |
| 7. | $\alpha_3$ | Output elasticity of transportation service for firm 1's production |
| 8. | $\epsilon_{EX}$ | Output elasticity of demand for export of good 1 |
| 9. | $\beta_1$ | Output elasticity of private capital for firm 2's production |
| 10. | $\beta_2$ | Output elasticity of labor for firm 2's production |
| 11. | $\zeta$ | Elasticity of public infrastructure for firm 2's TFP |
| 12. | $\delta$ | Capital depreciation rate |
| 13. | $s$ | Household saving rate |
| 14. | $\tau_H$ | Household income tax rate |
| 15. | $\tau_C$ | Household consumption tax rate |
| 16. | $\varphi$ | Substitution parameter of consumption function |
| 17. | $\sigma$ | Substitution elasticity of consumption |
| 18. | $\gamma$ | Share of consumption on good 1 for the representative household |

**Table 3.2: List of Equations**

$$P_t^1 = \frac{1}{A^1}\left(\frac{r_t^P}{\alpha_1}\right)^{\alpha_1}\left(\frac{w_t}{\alpha_2}\right)^{\alpha_2}\left(\frac{P_t^{tr}}{\alpha_3}\right)^{\alpha_3} \quad \text{(A1)}$$

$$r_t^P KP_t^1 = \alpha_1 P_t^1 Y_t^1 \quad \text{(A2)}$$

$$wL_t^1 = \alpha_2 P_t^1 Y_t^1 \quad \text{(A3)}$$

$$P_t^{tr} D_t^{tr} = \alpha_3 P_t^1 Y_t^1 \quad \text{(A4)}$$

$$Y_t^1 = EX_t^1 + DS_t^1 \quad \text{(A5)}$$

$$DS_t^1 = C_t^1 + INV_t^{KP} + INV_t^{KG} \quad \text{(A6)}$$

$$EX_t^1 = AX\left(\frac{P_t^{EX}}{P_t^1}\right)^{\epsilon_{EX}} FGDP_t \quad \text{(A7)}$$

$$P_t^{tr} = \frac{1}{A_t^{tr}}\left(\frac{r_t^P}{\beta_1}\right)^{\beta_1}\left(\frac{w_t}{\beta_2}\right)^{\beta_2} \quad \text{(A8)}$$

$$A_t^{tr} = \bar{A}(KG_t)^{\zeta} \quad \text{(A9)}$$

$$r_t^P KP_t^{tr} = \beta_1 P_t^{tr} Y_t^{tr} \quad \text{(A10)}$$

$$w_t L_t^{tr} = \beta_2 P_t^{tr} Y_t^{tr} \quad \text{(A11)}$$

$$Y_t^{tr} = D_t^{tr} + WALRAS \quad \text{(A12)}$$

$$YTH_t = r_t^P KTOT_t^P + w_t LTOT_t \quad \text{(A13)}$$

$$YD_t = (1 - \tau_H)YTH_t \quad \text{(A14)}$$

$$HC_t = (1 - s)YD_t \quad \text{(A15)}$$

$$HC_t = P_t^C C_t (1 + \tau_C) \quad \text{(A16)}$$

$$(1 + \tau_C)P_t^C = \frac{1}{AC}[\gamma^{\sigma}(P_t^1)^{1-\sigma} + (1-\gamma)^{\sigma}(P_t^M)^{1-\sigma}]^{\frac{1}{1-\sigma}} \quad \text{(A17)}$$

$$C_t^1 = AC^{\sigma-1}\left[\frac{\gamma(1+\tau_C)P_t^C}{P_t^1}\right]^{\sigma} C_t \quad \text{(A18)}$$

$$C_t^M = AC^{\sigma-1}\left[\frac{(1-\gamma)(1+\tau_C)P_t^C}{P_t^M}\right]^{\sigma} C_t \tag{A19}$$

$$HSAV_t = sYD_t \tag{A20}$$

$$GR_t = \tau_H YTH_t + \tau_C P_t^C C_t \tag{A21}$$

$$GR_t = P_t^1 INV_t^{KG} \tag{A22}$$

$$FSAV_t = P_t^M C_t^M - \frac{P_t^1}{EXR_t} EX_t^1 \tag{A23}$$

$$TOTSAV_t = HSAV_t + FSAV_t \tag{A24}$$

$$TOTSAV_t = P_t^1 INV_t^{KP} \tag{A25}$$

$$KP_t^{TOT} = KP_t^1 + KP_t^{tr} \tag{A26}$$

$$L_t^{TOT} = L_t^1 + L_t^{tr} \tag{A27}$$

$$P_t^{EX} = PW^{EX} EXR_t \tag{A28}$$

$$P_t^M = PW^M EXR_t \tag{A29}$$

$$OMEGA = 10 \tag{A30}$$

*Dynamic Equations:*

$$KP_{t+1}^{TOT} = (1-\delta)KP_t^{TOT} + INV_t^P \tag{A31}$$

$$KG_{t+1} = (1-\delta)KG_t + INV_t^G \tag{A32}$$

| | Good 1 | Transportation service | Household | Export | Import | Private investment | Public investment (government spending) | Total |
|---|---|---|---|---|---|---|---|---|
| **Good 1** | | | 429.33 | 268.66 | -233.13 | 397.25 | 136.34 | 998.46 |
| **Transportation service** | 49.72 | | | | | | | 49.72 |
| **Indirect Tax** | | | 1.54 | | | | | 1.54 |
| **Labor remuneration** | 674.00 | 5.86 | | | | | | 679.86 |
| **Private capital remuneration** | 274.74 | 43.86 | | | | | | 318.60 |
| **Total** | 998.46 | 49.72 | 430.87 | 268.66 | -233.13 | 397.25 | 136.34 | |

**Table 4.1: Structure and Data of the Input-Output Table.**

**EXPENDITURES**

| RECEIPTS | Good 1 | Transportation service | Labor | Private capital | Representative household | Government | Indirect taxes | Direct taxes | Private investment | ROW | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Good 1** | | | | | 429.32607 | 136.34402 | | | 397.25449 | 268.66430 | 1231.58889 |
| **Transportation service** | 49.7179 | | | | | | | | | | 49.71786 |
| **Labor** | 673.9997 | 5.85929 | | | | | | | | | 679.85900 |
| **Private capital** | 274.7401 | 43.85857 | | | | | | | | | 318.59870 |
| **Representative household** | | | 679.85900 | 318.59870 | | | | | | | 998.45770 |
| **Government** | | | | | | | 1.54230 | 134.80172 | | | 136.34402 |
| **Indirect taxes** | | | | | 1.54230 | | | | | | 1.54230 |
| **Direct taxes** | | | | | 134.80172 | | | | | | 134.80172 |
| **Savings** | | | | | 432.78761 | | | | | -35.53311 | 397.25449 |
| **ROW** | 233.1312 | | | | | | | | | | 233.13119 |
| **Total** | 1231.5882 | 49.71786113 | 679.8589956 | 318.5987031 | 998.4576987 | 136.3440165 | 1.542301286 | 134.8017152 | 397.2544943 | 233.131191 | |

**Table 4.2: Structure and Data of SAM.**

**Table 4.3: Data Description.**

| Data | Unit | Source |
|---|---|---|
| GDP at factor cost | Hundred Million Yuan | National Baueau of Statistics of China (NBSC) |
| GDP at market price | Hundred Million Yuan | National Baueau of Statistics of China (NBSC) |
| Output of transportation service | % of GDP at factor cost | National Baueau of Statistics of China (NBSC) |
| Household final consumption expenditure | % of GDP at market price | World Development indicators from the World Bank |
| Total value of export | % of GDP at market price | World Development indicators from the World Bank |
| Total value of import | % of GDP at market price | World Development indicators from the World Bank |
| General government final consumption expenditure (public investment) | % of GDP at market price | World Development indicators from the World Bank |
| Labor force | person | World Development indicators from the World Bank |
| Unemployment | % of labor force | World Development indicators from the World Bank |
| Average wage for employed people | Yuan | National Baueau of Statistics of China (NBSC) |
| Employed people in transportation sector | person | National Baueau of Statistics of China (NBSC) |
| GDP of rest of the world (GDP of ROW) | Hundred Million Yuan | World Development indicators from the World Bank |

**Table 4.4: Values of Exogenous Parameters.**

| Notation | Definition of parameter | Parameter value | Reference |
|---|---|---|---|
| $\epsilon_{EX}$ | Elasticity of demand for export of good 1 with respect to relative price of good 1 for rest of the world | 1.25 | Lin and Li (2003) |
| $\zeta$ | Elasticity of public infrastructure capital for firm 2's TFP | 0.55 | Ma and Li (2001) |
| $\delta$ | Capital depreciation rate | 0.054 | Chow and Li (2002) |
| $\sigma$ | Elasticity of substitution for the representative household's consumption between good 1 and the imported good | 0.5 | Tang (2003) |

**Table 4.5: Calibration Result of the Static Model (BAU situation).**

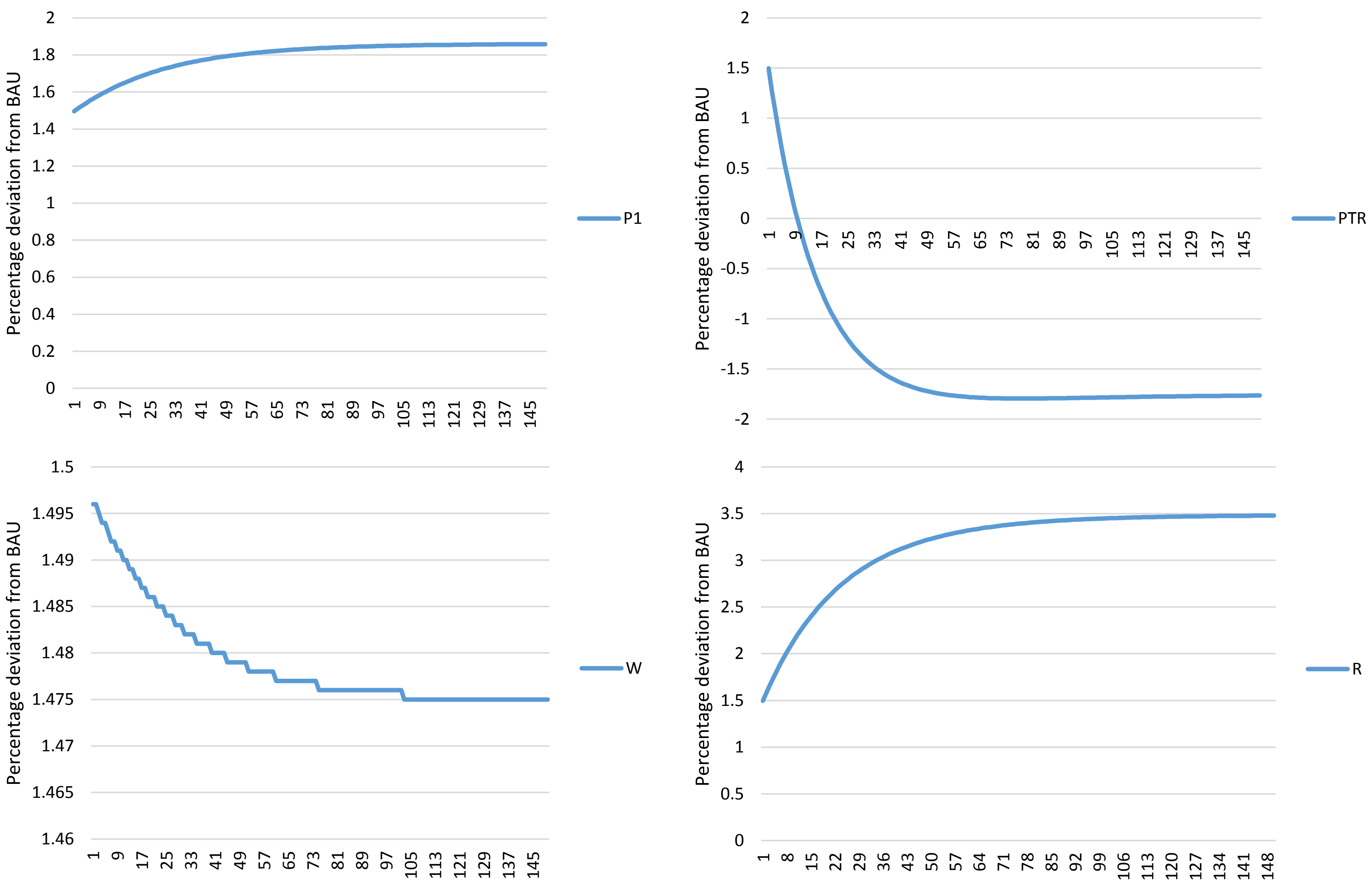
| Variable Name | Label in GAMS | Calibration Result |
|---|---|---|
| Household saving rate | s | 0.501 |
| Price of good 1 | P_1 | 1.000 |
| Price of transportation service | P_tr | 1.000 |
| Wage rate | w | 1.000 |
| Rental price of private capital | r_KP | 1.000 |
| Price of export | P_EX | 1.000 |
| Price of import | P_M | 1.000 |
| Elasticity of private capital in firm 1 | alpha_1 | 0.223 |
| Elasticity of labor in firm 1 | alpha_2 | 0.547 |
| Elasticity of transportation service | alpha_3 | 0.040 |
| TFP of firm 1 | A1 | 2.213 |
| Scale coefficient on export demand function | AX | 0.021 |
| Elasticity of private capital in firm 2 | beta_1 | 0.882 |
| Elasticity of labor in firm 2 | beta_2 | 0.118 |
| Public infrastructure capital | KG | 2524.889 |
| TFP of firm 2 | A0_tr | 1.437 |
| Scale coefficient on firm 2's TFP | Abar | 0.019 |
| Household income tax rate | tao_H | 0.135 |
| Household consumption tax rate | tao_C | 0.004 |
| Scale coefficient on household aggregate consumption | AC | 1.905 |
| Private capital used by firm 1 | KP_1 | 274.740 |
| Labor used by firm 1 | L_1 | 674.000 |
| Transportation service used by firm 1 | D_tr | 49.718 |
| Private capital used by firm 2 | KP_tr | 43.859 |
| Labor used by firm 2 | L_tr | 5.859 |
| Output of good 1 | Y_1 | 1231.589 |
| Output of transportation service | Y_tr | 49.718 |
| Household total income | YTH | 998.458 |
| Household disposable income | YD | 863.656 |
| Household aggregate consumption expenditure | HC | 430.868 |
| Household aggregate consumption | C | 429.326 |

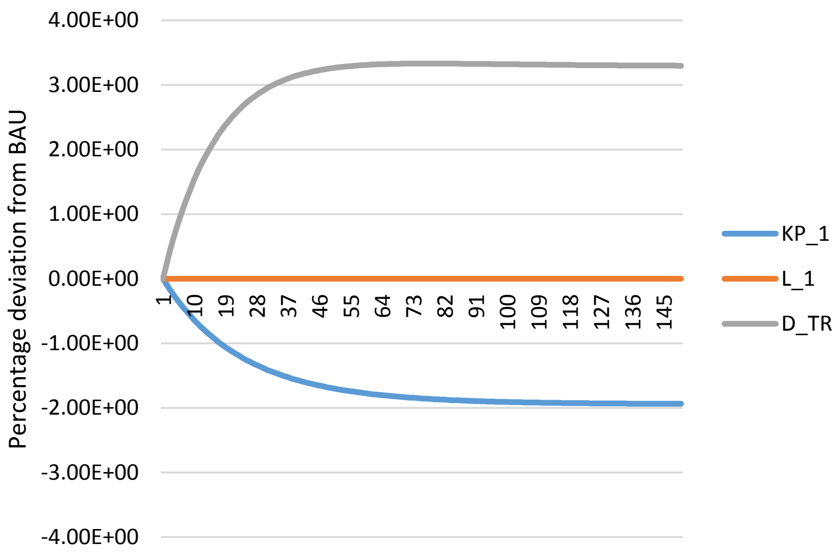
| | | |
|---|---|---|
| Household consumption on good 1 | C_1 | 196.195 |
| Household consumption on imported good | C_M | 233.131 |
| Household saving | HSAV | 432.788 |
| Government tax revenue | GR | 136.344 |
| Investment on private capital | INV_KP | 397.254 |
| Investment on public capital | INV_KG | 136.344 |
| Foreign saving | FSAV | -35.533 |
| Total saving | TOTSAV | 397.254 |
| Total supply of private capital | TOT_KP | 318.599 |
| Total supply of labor | TOT_L | 679.859 |

**Table 5.1: Percentage Deviation at Time 1 with respect to BAU Situation (simulation 1)**

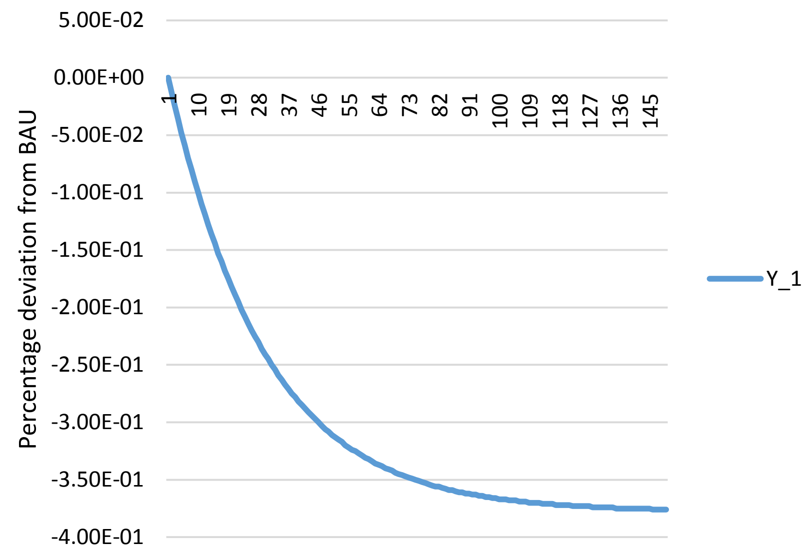
| Label in GAMS | Percentage Deviation |
|---|---|
| P1 | 1.496 |
| PTR | 1.496 |
| W | 1.496 |
| R | 1.496 |
| KP_1 | 0.000 |
| L_1 | 0.000 |
| D_TR | 0.000 |
| Y_1 | 0.000 |
| DS_1 | 0.677 |
| EX_1 | -1.839 |
| A_TR | 0.000 |
| KP_TR | 0.000 |
| L_TR | 0.000 |
| Y_TR | 0.000 |
| YTH | 1.496 |
| YD | -0.088 |
| HC | -0.088 |
| P_C | 0.682 |
| C | -0.765 |
| C_1 | -1.164 |
| C_M | -0.427 |
| HSAV | -0.088 |
| GR | 11.513 |
| INV_KP | -1.569 |
| INV_KG | 9.869 |
| TOTSAV | -0.096 |

**Figure 1: Long-run Results for Simulation 1:**

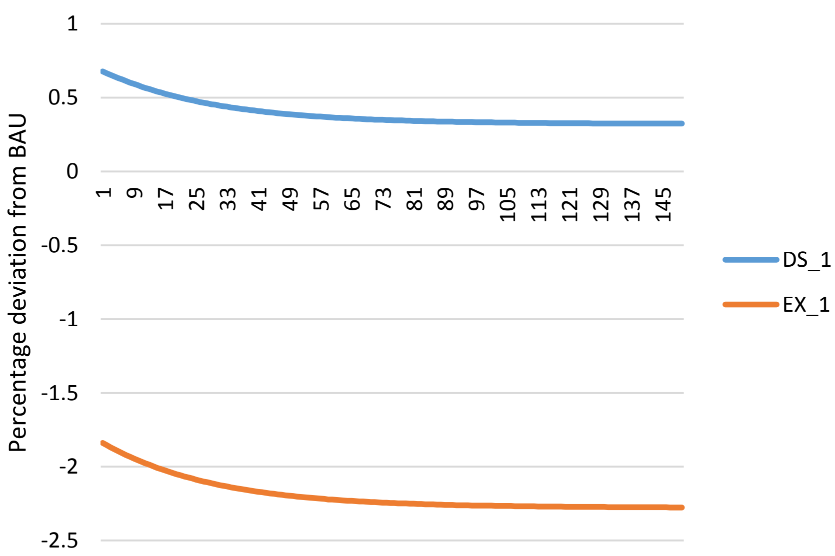




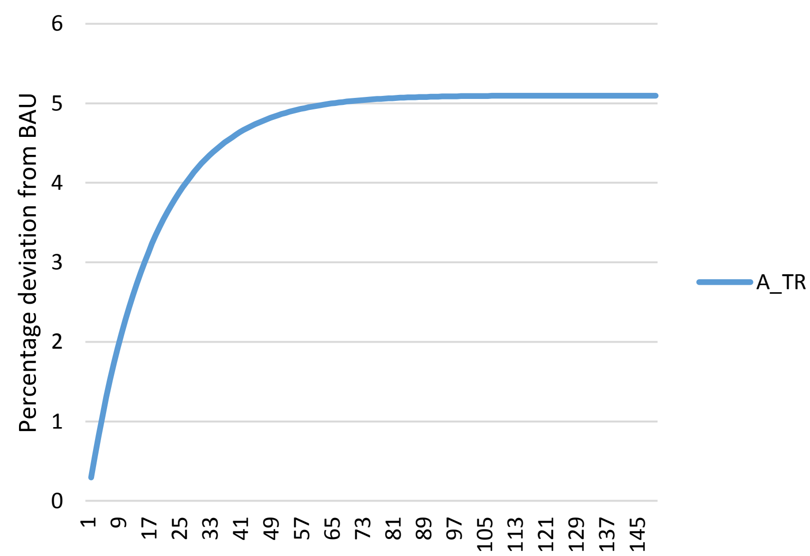
Percentage deviation from BAU
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
-1.00E+00
-2.00E+00
-3.00E+00
-4.00E+00
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
KP_1
L_1
D_TR

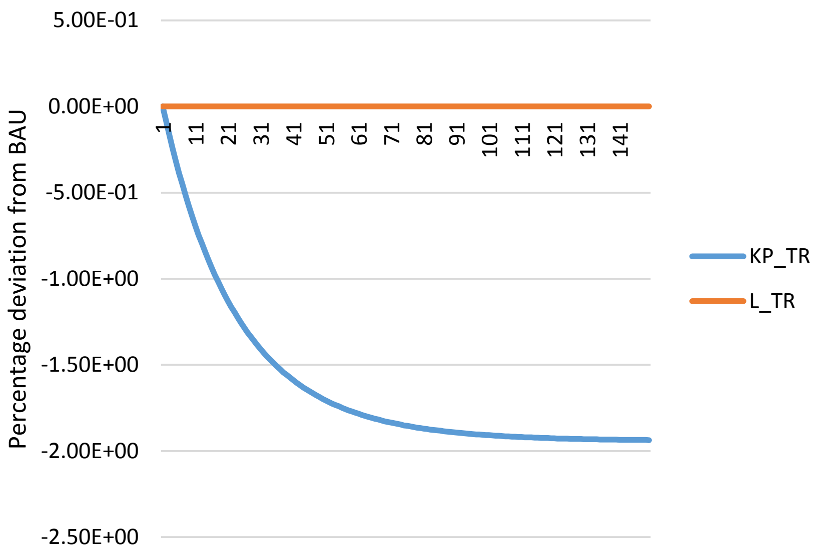
Percentage deviation from BAU
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
-2.50E-01
-3.00E-01
-3.50E-01
-4.00E-01
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
Y_1

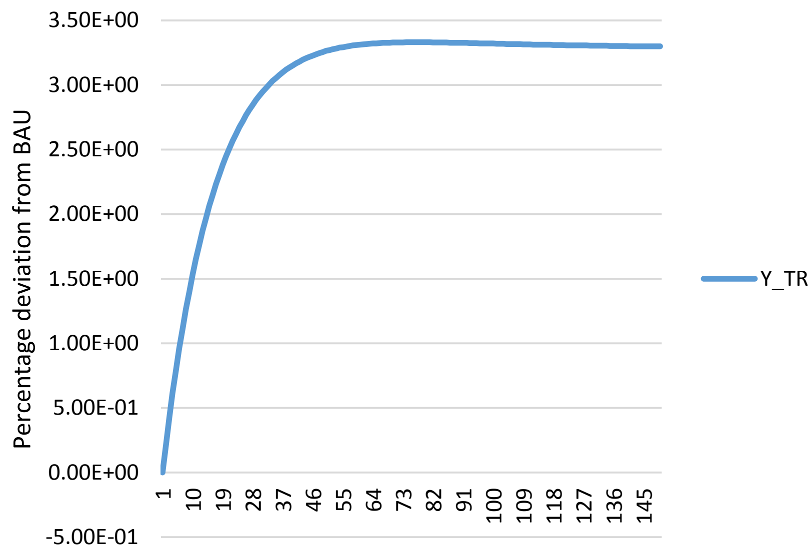



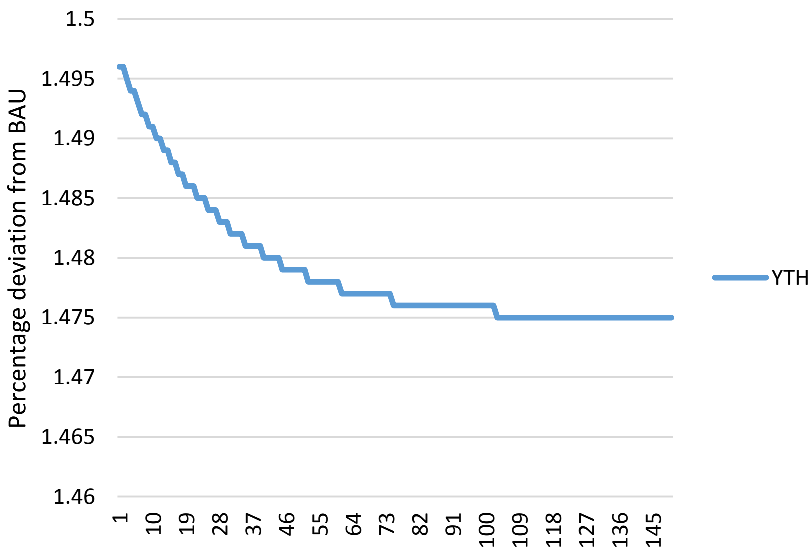
Percentage deviation from BAU
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
DS_1
EX_1

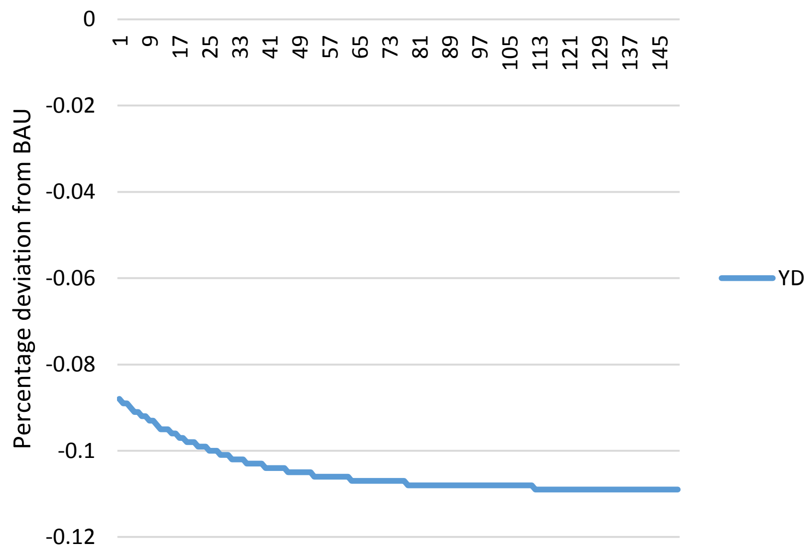



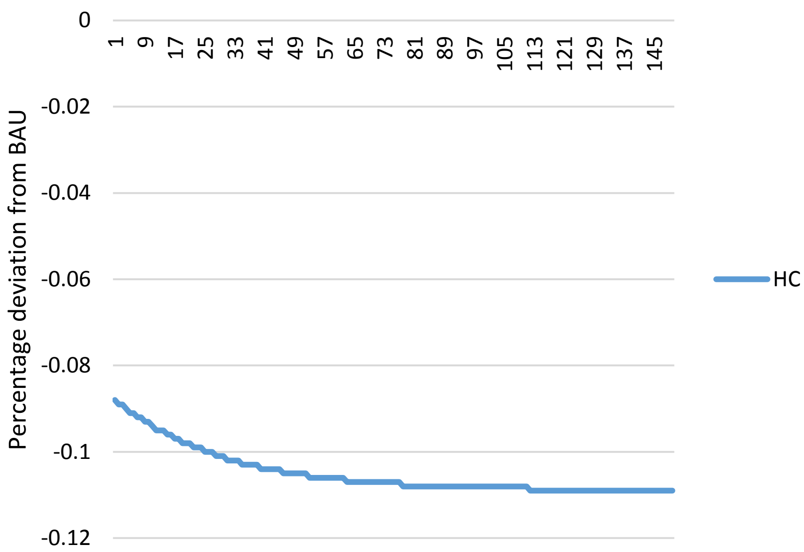
Percentage deviation from BAU
6
5
4
3
2
1
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
A_TR


Percentage deviation from BAU
5.00E-01
0.00E+00
-5.00E-01
-1.00E+00
-1.50E+00
-2.00E+00
-2.50E+00
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141
KP_TR
L_TR

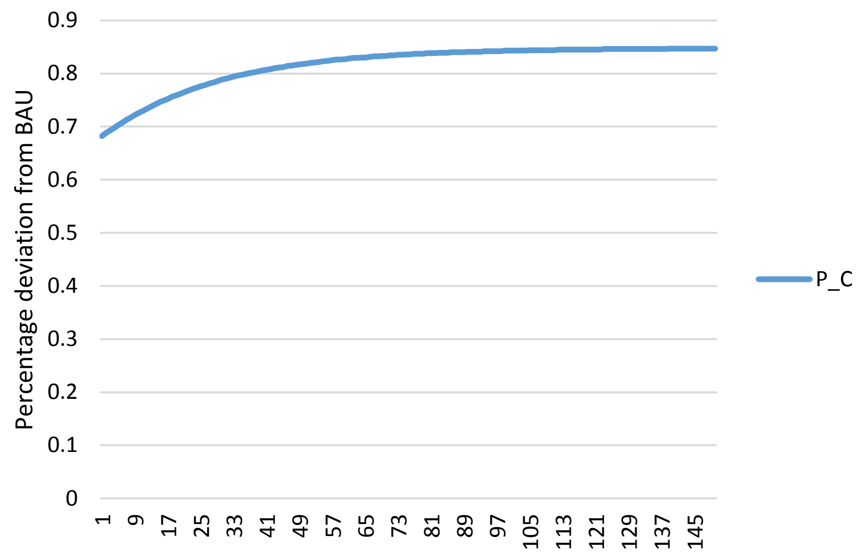

Percentage deviation from BAU
3.50E+00
3.00E+00
2.50E+00
2.00E+00
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-5.00E-01
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
Y_TR


Percentage deviation from BAU
1.5
1.495
1.49
1.485
1.48
1.475
1.47
1.465
1.46
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
YTH

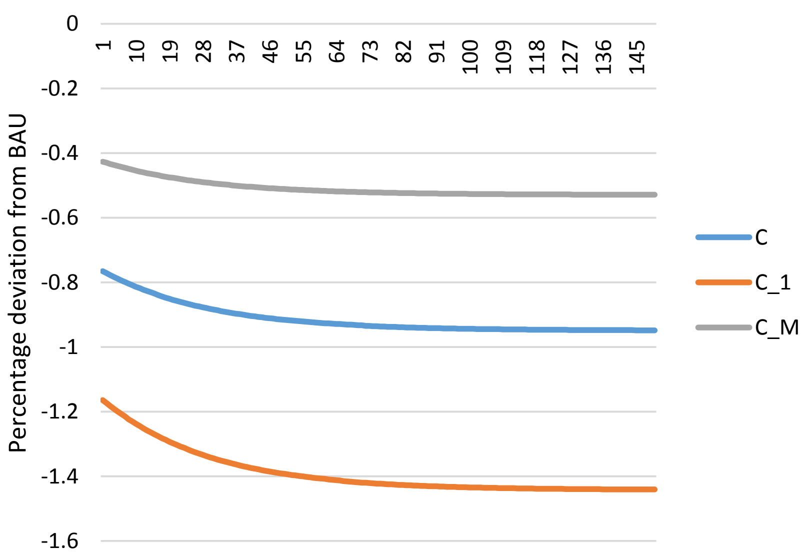

Percentage deviation from BAU
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
YD



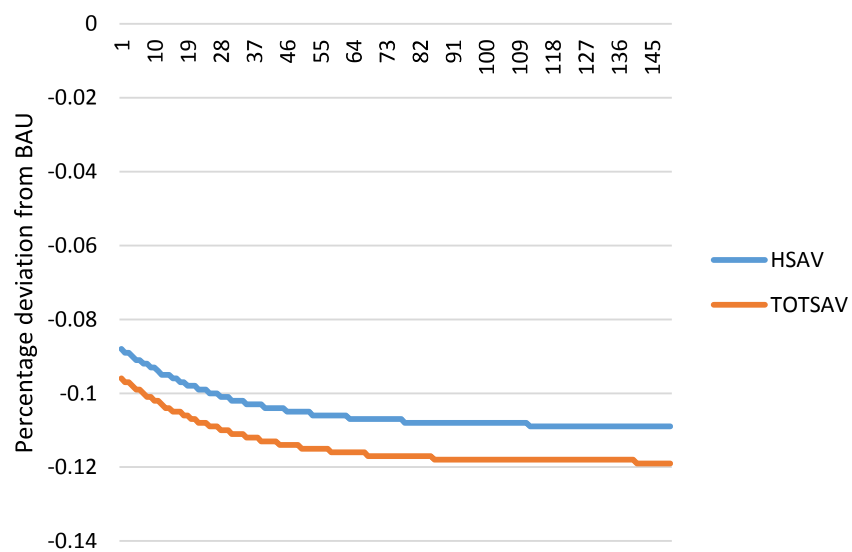
Percentage deviation from BAU
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
HC

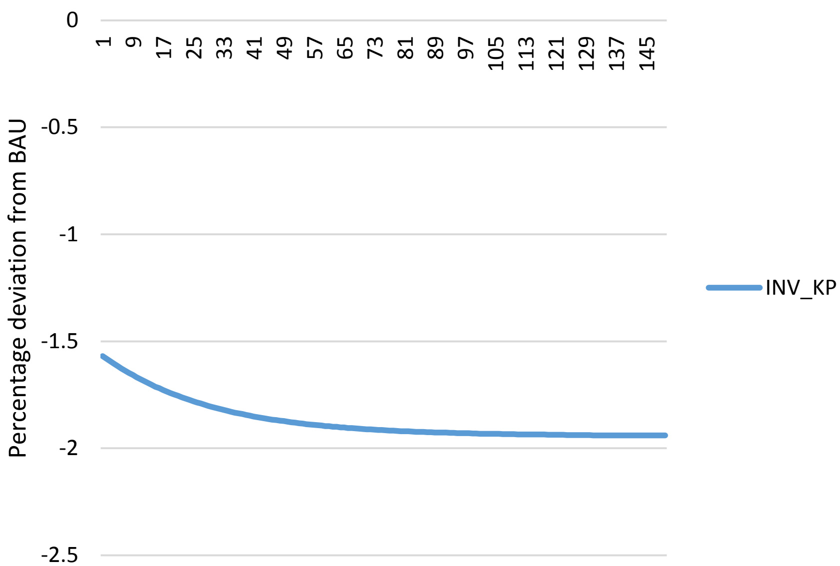
Percentage deviation from BAU
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
P_C

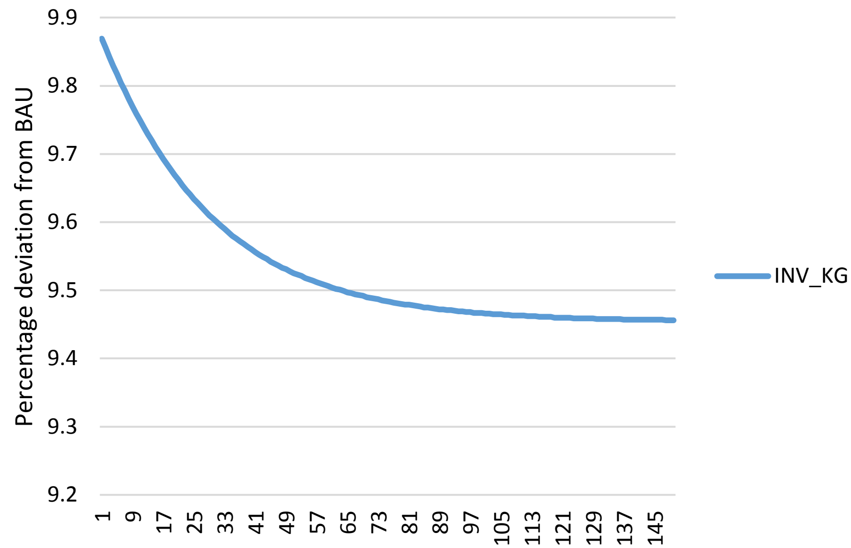



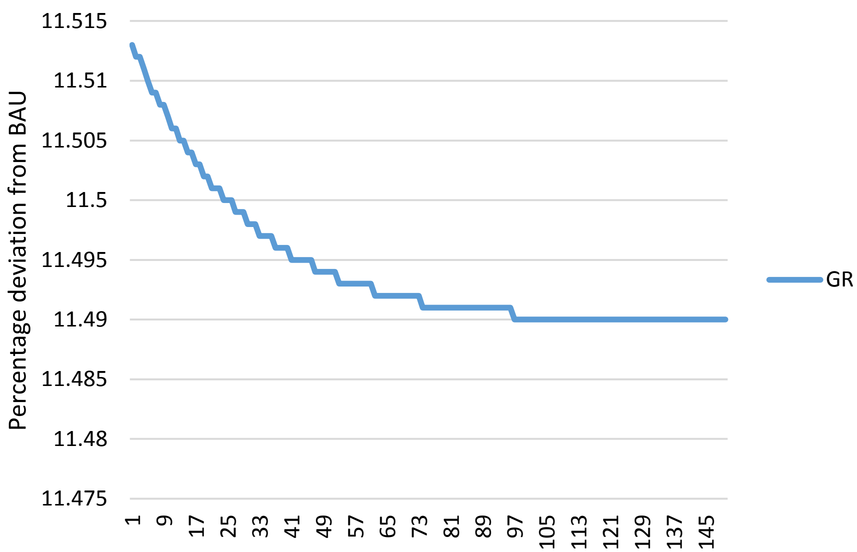
Percentage deviation from BAU
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
C
C_1
C_M

Percentage deviation from BAU
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
HSAV
TOTSAV


Percentage deviation from BAU
INV_KP


Percentage deviation from BAU
INV_KG


Percentage deviation from BAU
GR

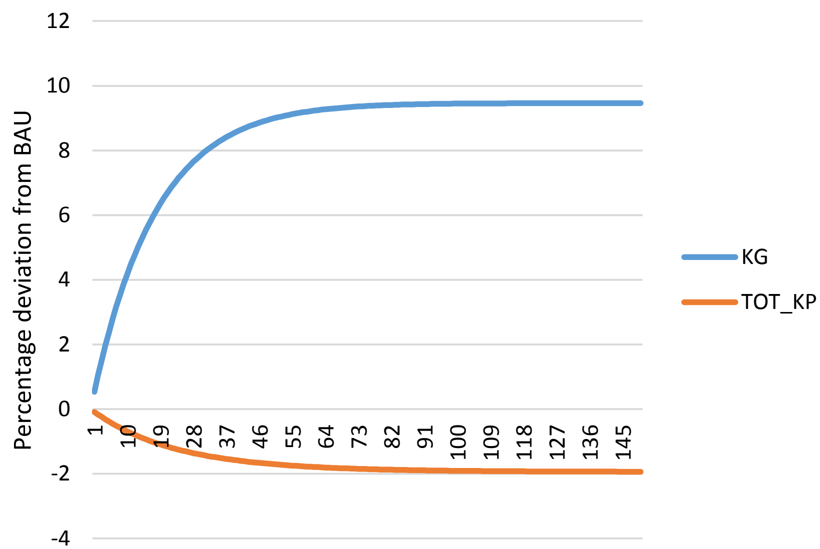
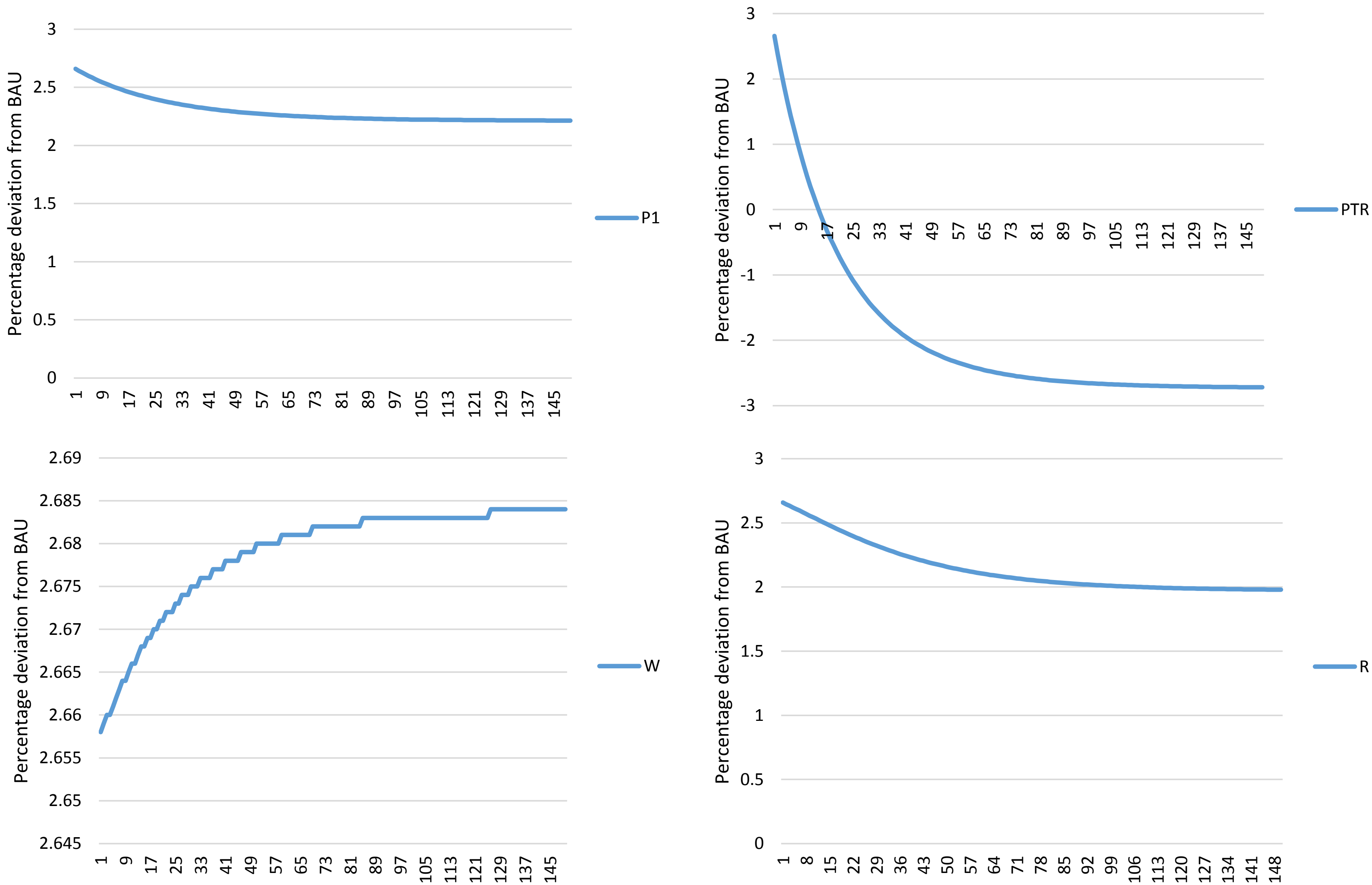
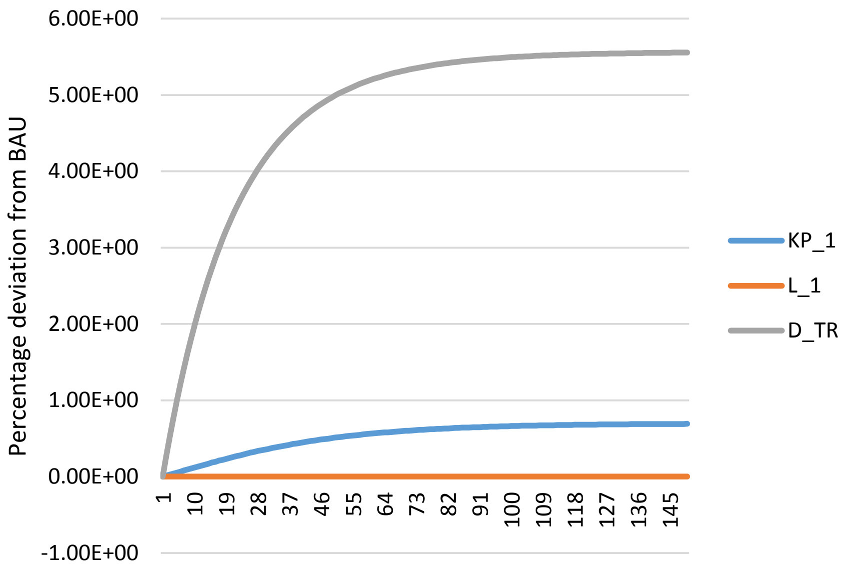

Percentage deviation from BAU
KG
TOT_KP

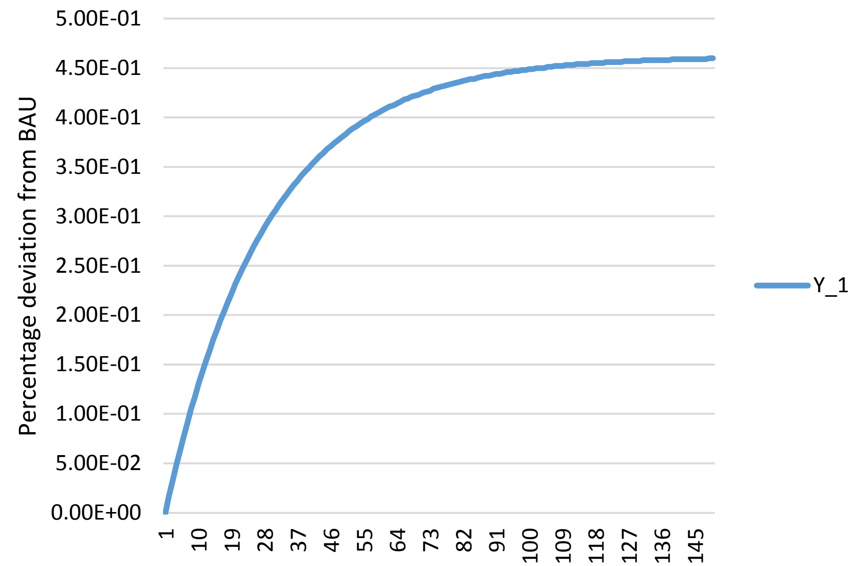
**Table 5.2: Percentage Deviation at Time 1 with respect to BAU Situation (simulation 2)**

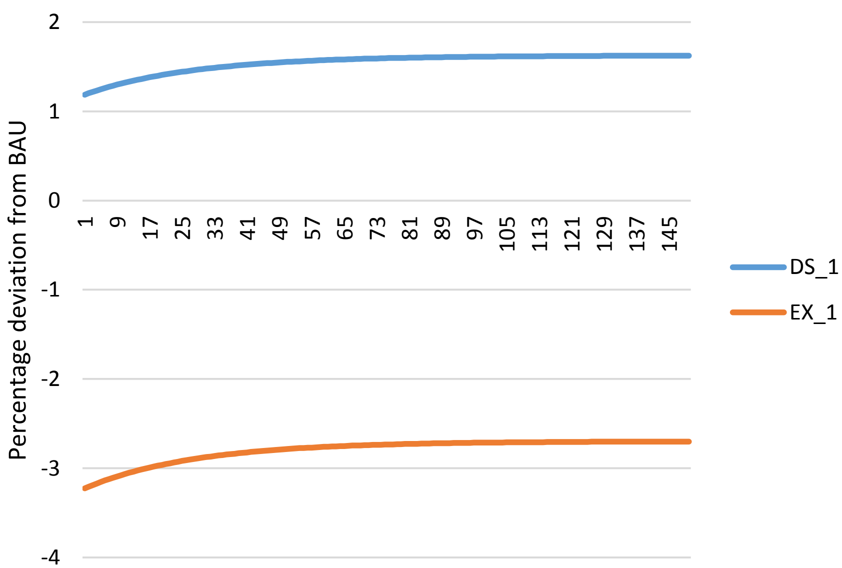
| Label in GAMS | Percentage Deviation |
|---|---|
| P1 | 2.658 |
| PTR | 2.658 |
| W | 2.658 |
| R | 2.658 |
| KP_1 | 0.000 |
| L_1 | 0.000 |
| D_TR | 0.000 |
| Y_1 | 0.000 |
| DS_1 | 1.187 |
| EX_1 | -3.226 |
| A_TR | 0.000 |
| KP_TR | 0.000 |
| L_TR | 0.000 |
| Y_TR | 0.000 |
| YTH | 2.658 |
| YD | 2.658 |
| HC | 2.658 |
| P_C | 1.210 |
| C | -1.348 |
| C_1 | -2.046 |
| C_M | -0.753 |
| HSAV | 2.658 |
| TOTSAV | 2.895 |
| INV_KP | 0.232 |
| INV_KG | 8.626 |
| GR | 11.513 |

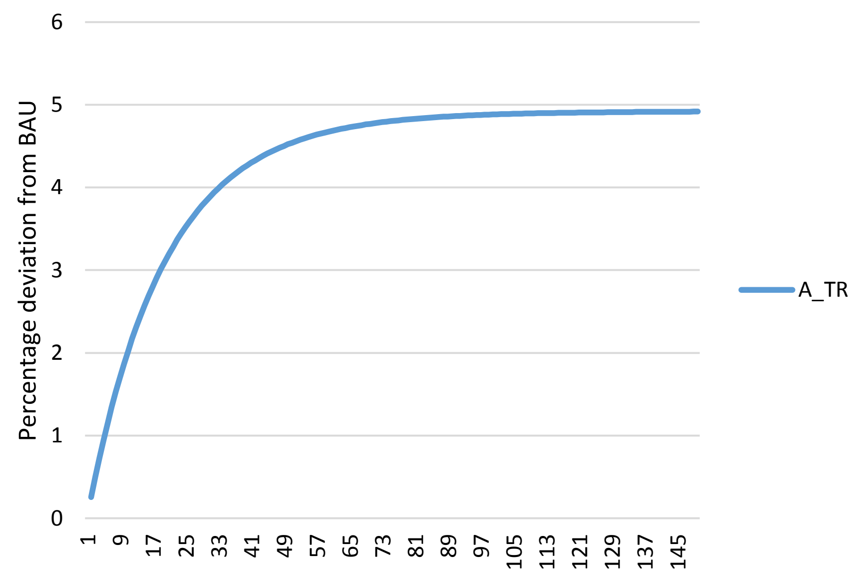
**Figure 2: Long-run Results for Simulation 2.**

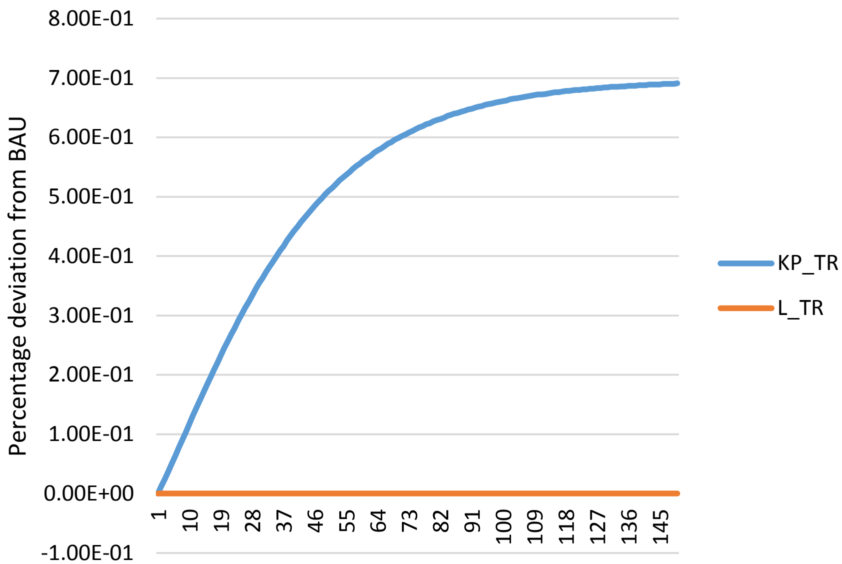


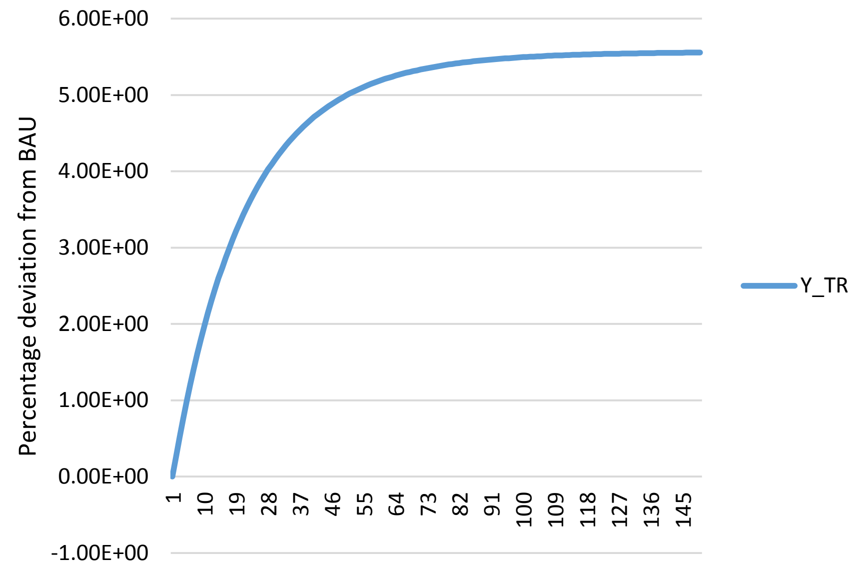

Percentage deviation from BAU
6.00E+00
5.00E+00
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
-1.00E+00
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
KP_1
L_1
D_TR

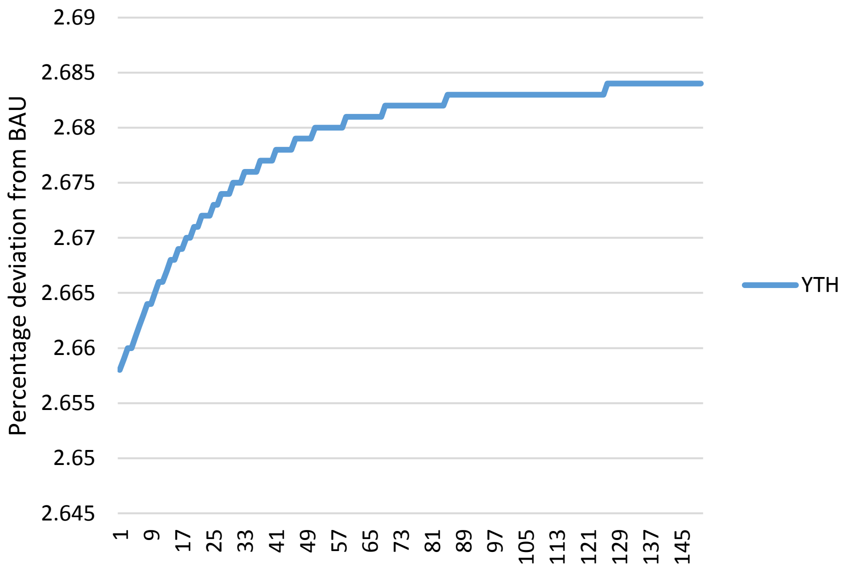

Percentage deviation from BAU
5.00E-01
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
Y_1

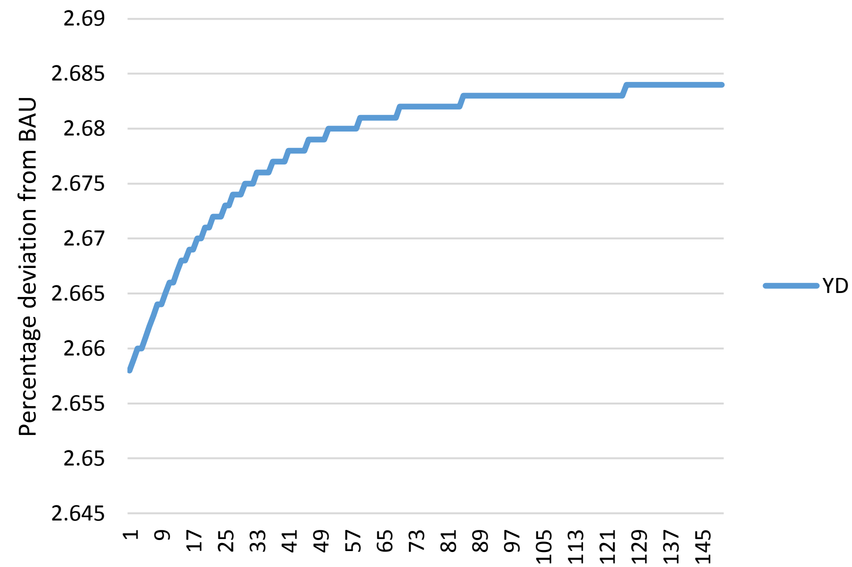

Percentage deviation from BAU
2
1
0
-1
-2
-3
-4
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
DS_1
EX_1

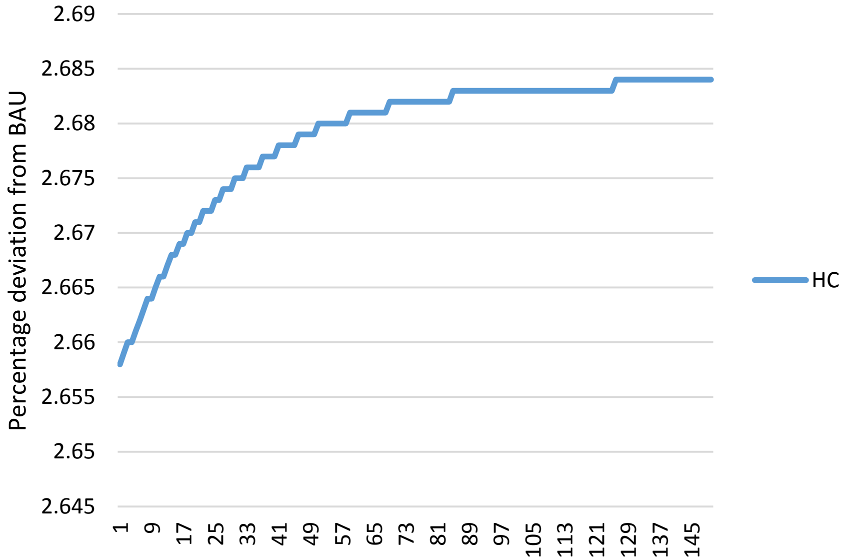

Percentage deviation from BAU
6
5
4
3
2
1
0
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
A_TR

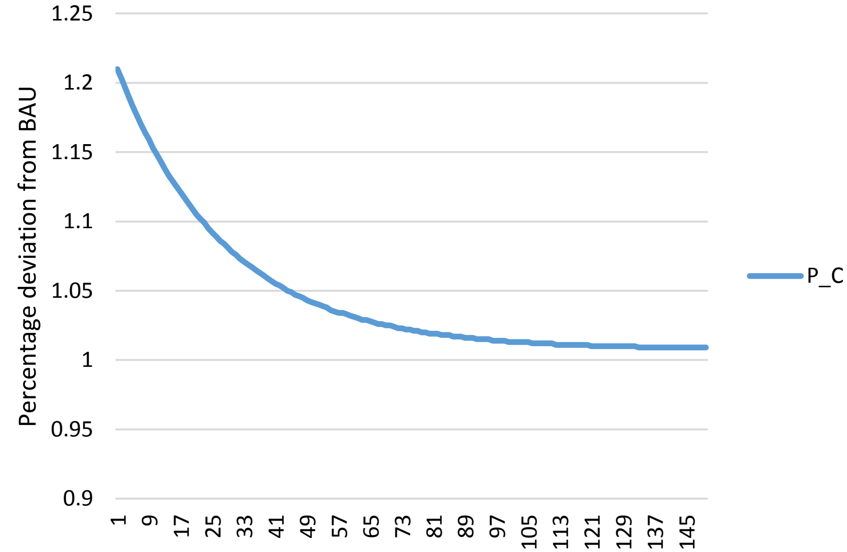

Percentage deviation from BAU
8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
KP_TR
L_TR

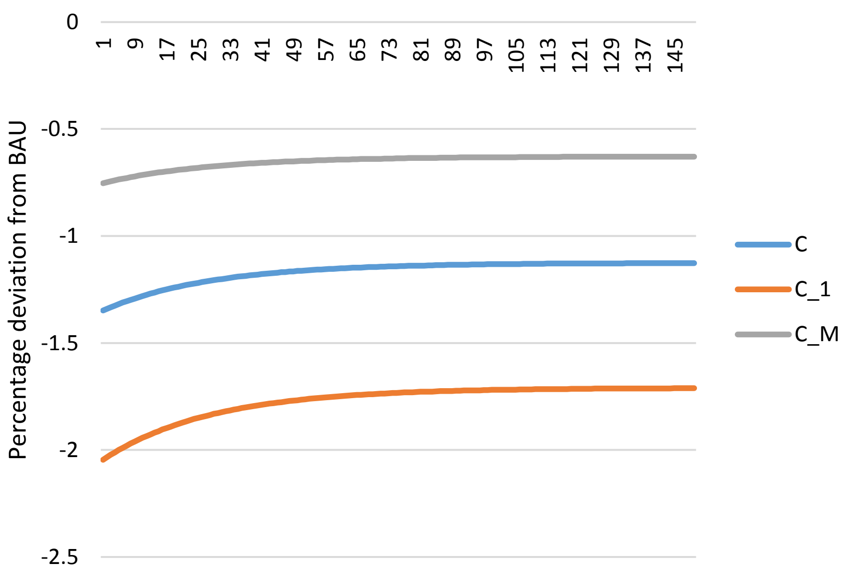

Percentage deviation from BAU
6.00E+00
5.00E+00
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
-1.00E+00
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145
Y_TR

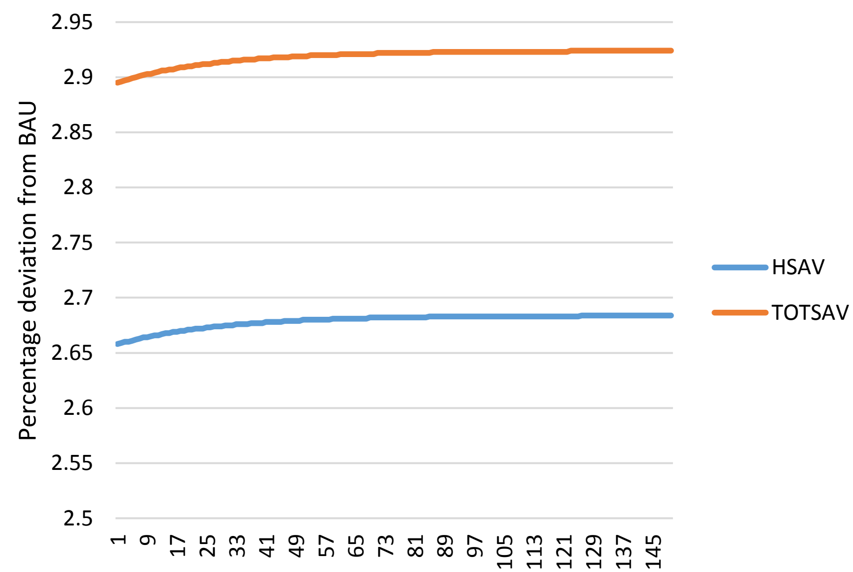

Percentage deviation from BAU
2.69
2.685
2.68
2.675
2.67
2.665
2.66
2.655
2.65
2.645
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
YTH

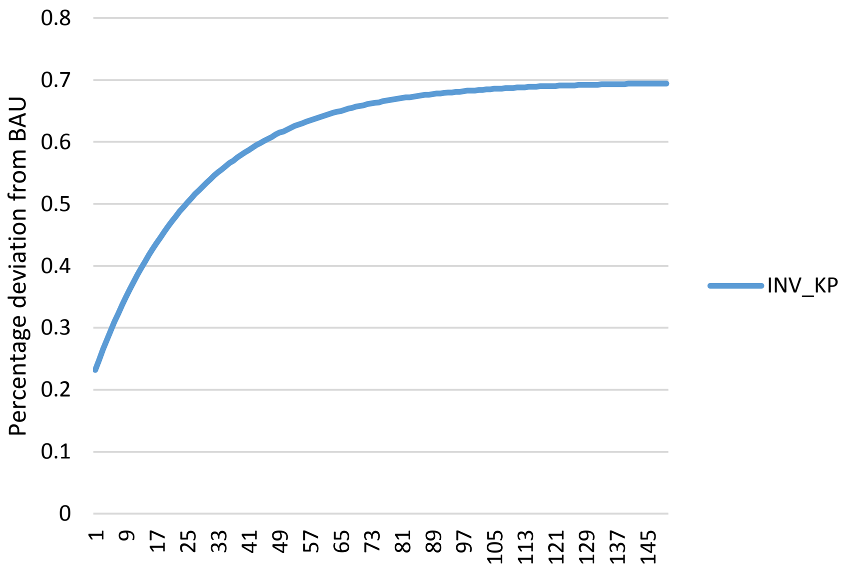

Percentage deviation from BAU
2.69
2.685
2.68
2.675
2.67
2.665
2.66
2.655
2.65
2.645
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
YD

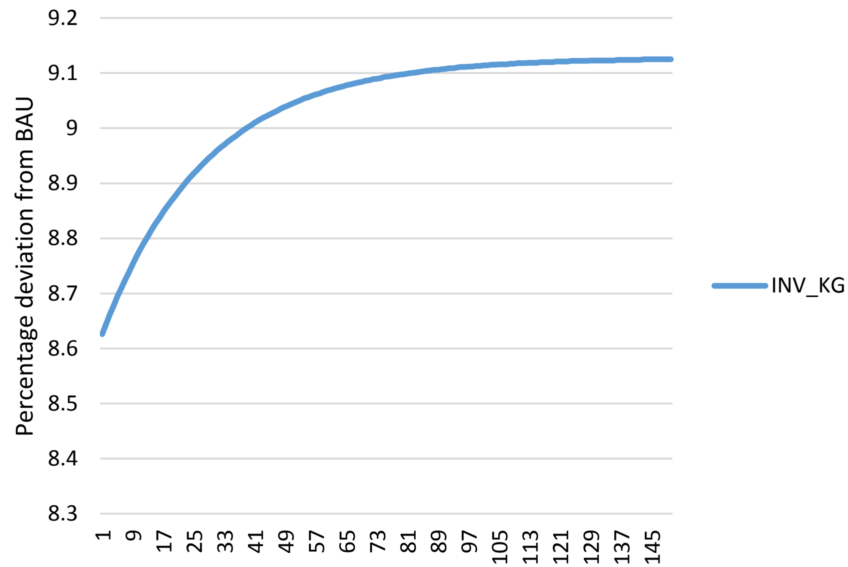

Percentage deviation from BAU
2.69
2.685
2.68
2.675
2.67
2.665
2.66
2.655
2.65
2.645
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
HC

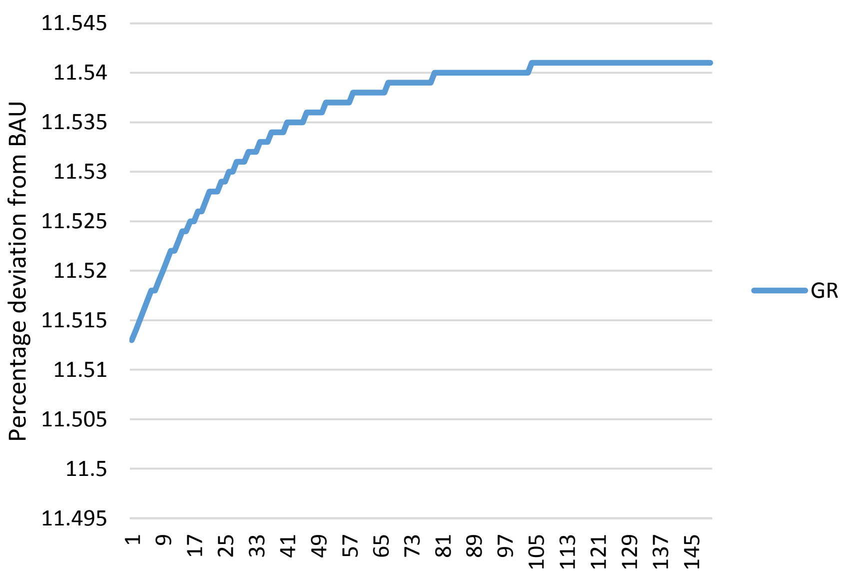

Percentage deviation from BAU
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
P_C


Percentage deviation from BAU
0
-0.5
-1
-1.5
-2
-2.5
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
C
C_1
C_M


Percentage deviation from BAU
2.95
2.9
2.85
2.8
2.75
2.7
2.65
2.6
2.55
2.5
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
HSAV
TOTSAV


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Percentage deviation from BAU
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
INV_KP


9.2
9.1
9
8.9
8.8
8.7
8.6
8.5
8.4
8.3
Percentage deviation from BAU
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
INV_KG


11.545
11.54
11.535
11.53
11.525
11.52
11.515
11.51
11.505
11.5
11.495
Percentage deviation from BAU
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
GR

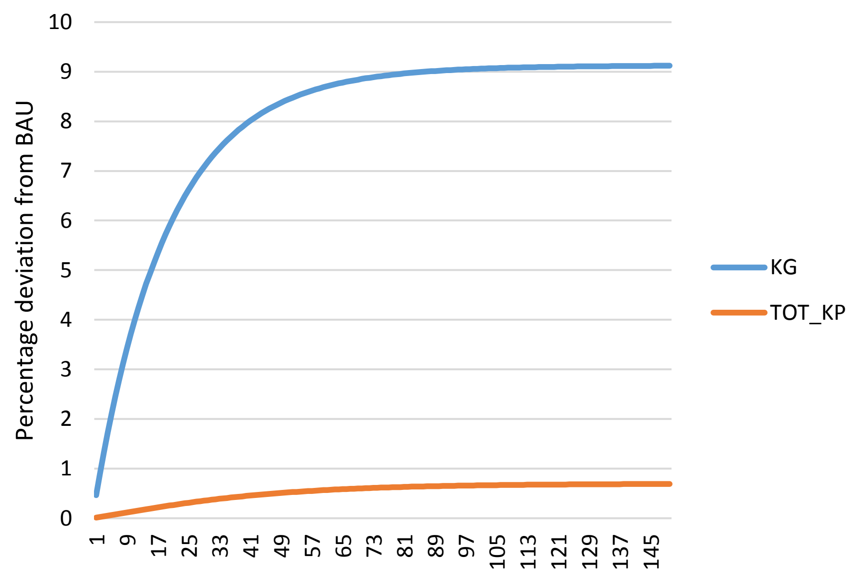

10
9
8
7
6
5
4
3
2
1
0
Percentage deviation from BAU
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145
KG
TOT_KP

**Table 5.3: Selected Variables from Sensitivity Analysis for Simulation 1 (percentage deviations)**

| | **$\epsilon_{EX}$ 1.5 times** | | **$\epsilon_{EX}$ halved** | | **ζ 1.5 times** | | **ζ halved** | | **σ 1.5 times** | | **σ halved** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | first period | long-run | first period | long-run | first period | long-run | first period | long-run | first period | long-run | first period | long-run |
| **P1** | -0.61 | -0.74 | 3.26 | 3.59 | -9.76 | -15.03 | 10.85 | 16.99 | -3.41 | -3.33 | 4.75 | 4.60 |
| **PTR** | -0.61 | -0.64 | 3.26 | 3.12 | -89.65 | -89.83 | 768.64 | 941.29 | -3.41 | -2.88 | 4.75 | 3.99 |
| **W** | -0.61 | -0.77 | 3.26 | 3.74 | 0.63 | 1.02 | -0.58 | -0.85 | -3.41 | -3.47 | 4.75 | 4.79 |
| **R** | -0.61 | -0.68 | 3.26 | 3.31 | 0.63 | -15.30 | -0.58 | 17.30 | -3.41 | -3.06 | 4.75 | 4.24 |
| **Y_1** | 0.00 | -0.03 | 0.00 | 0.15 | 11.32 | 18.43 | -10.17 | -14.96 | 0.00 | -0.15 | 0.00 | 0.20 |
| **DS_1** | -0.07 | -0.12 | 0.38 | 0.57 | 10.63 | 17.26 | -9.61 | -14.16 | -1.58 | -1.74 | 2.01 | 2.20 |
| **EX_1** | 0.20 | 0.21 | -1.02 | -0.99 | 13.22 | 21.59 | -11.70 | -17.14 | 4.28 | 4.14 | -5.46 | -5.25 |
| **Y_TR** | 0.00 | -0.11 | 0.00 | 0.52 | 762.22 | 1116.41 | -88.40 | -93.62 | 0.00 | -0.51 | 0.00 | 0.66 |
| **C** | -0.32 | -0.42 | 1.71 | 2.02 | 5.29 | 8.44 | -5.12 | -7.69 | -1.51 | -1.59 | 1.96 | 2.06 |
| **C_M** | -0.46 | -0.59 | 2.45 | 2.85 | 2.94 | 4.67 | -2.88 | -4.34 | 0.98 | 0.96 | -1.31 | -1.26 |
| **GR** | 10.94 | 10.77 | 15.19 | 15.72 | 12.30 | 12.73 | 10.97 | 10.67 | 7.87 | 7.80 | 16.83 | 16.87 |
| **INV_KP** | -0.05 | -0.10 | 0.28 | 0.46 | 11.21 | 18.24 | -10.06 | -14.79 | -0.31 | -0.46 | 0.39 | 0.59 |
| **INV_KG** | 0.00 | -0.04 | 0.00 | 0.17 | 12.44 | 20.25 | -11.18 | -16.44 | 0.00 | -0.17 | 0.00 | 0.22 |
| **TOTSAV** | -12.26 | -12.43 | -8.11 | -7.60 | -10.93 | -10.51 | -12.23 | -12.52 | -15.26 | -15.33 | -6.51 | -6.47 |

**Table 5.4: Selected Variables from Sensitivity Analysis for Simulation 2 (percentage deviations)**

| | $\epsilon_{EX}$ 1.5 times | | $\epsilon_{EX}$ halved | | ζ 1.5 times | | ζ halved | | σ 1.5 times | | σ halved | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | first period | long-run | first period | long-run | first period | long-run | first period | long-run | first period | long-run | first period | long-run |
| **P1** | -1.09 | -0.88 | 5.91 | 4.32 | -9.87 | -15.08 | 10.98 | 17.05 | -3.56 | -3.38 | 4.99 | 4.67 |
| **PTR** | -1.09 | -0.76 | 5.91 | 3.71 | -90.68 | -88.95 | 777.48 | 931.18 | -3.56 | -2.90 | 4.99 | 4.01 |
| **W** | -1.09 | -0.92 | 5.91 | 4.53 | 0.63 | 1.03 | -0.58 | -0.86 | -3.56 | -3.54 | 4.99 | 4.90 |
| **R** | -1.09 | -0.80 | 5.91 | 3.92 | 0.63 | -15.07 | -0.58 | 17.04 | -3.56 | -3.06 | 4.99 | 4.24 |
| **Y_1** | 0.00 | -0.04 | 0.00 | 0.18 | 11.32 | 18.57 | -10.17 | -15.08 | 0.00 | -0.15 | 0.00 | 0.19 |
| **DS_1** | -0.13 | -0.14 | 0.66 | 0.68 | 10.69 | 17.50 | -9.67 | -14.35 | -1.61 | -1.74 | 2.05 | 2.21 |
| **EX_1** | 0.34 | 0.25 | -1.78 | -1.18 | 13.04 | 21.49 | -11.54 | -17.06 | 4.37 | 4.17 | -5.57 | -5.29 |
| **Y_TR** | 0.00 | -0.13 | 0.00 | 0.61 | 762.22 | 1139.56 | -88.40 | -95.66 | 0.00 | -0.52 | 0.00 | 0.66 |
| **C** | -0.57 | -0.50 | 3.01 | 2.41 | 5.27 | 8.43 | -5.10 | -7.68 | -1.54 | -1.60 | 2.00 | 2.07 |
| **C_M** | -0.81 | -0.70 | 4.36 | 3.40 | 2.93 | 4.67 | -2.87 | -4.34 | 1.02 | 0.97 | -1.35 | -1.27 |
| **GR** | -1.18 | -1.00 | 6.42 | 4.92 | 0.69 | 1.12 | -0.63 | -0.94 | -3.87 | -3.85 | 5.42 | 5.32 |
| **INV_KP** | -0.09 | -0.12 | 0.47 | 0.55 | 11.41 | 18.72 | -10.24 | -15.18 | -0.31 | -0.46 | 0.40 | 0.59 |
| **INV_KG** | 0.00 | -0.04 | 0.00 | 0.20 | 12.30 | 20.18 | -11.05 | -16.38 | 0.00 | -0.16 | 0.00 | 0.21 |
| **TOTSAV** | -1.18 | -1.01 | 6.44 | 4.94 | 0.69 | 1.12 | -0.63 | -0.94 | -3.88 | -3.86 | 5.44 | 5.34 |