# Estimating the Economic Impact of Large Hydropower Projects: A Dynamic Multi-regional Computable General Equilibrium Analysis

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# Estimating the Economic Impact of Large Hydropower Projects: A Dynamic Multi-regional Computable General Equilibrium Analysis

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**Abstract**：This paper uses SinoTERM, a dynamic multi-regional computable general equilibrium model (CGE) of the Chinese economy, to analyze the economic impact of large hydropower development projects. The model features regional labor market dynamics and an electricity subdivision module with substitutability between various types of electricity generation. The results suggest that hydropower development will boost economic growth in the project region. Most sectors in the project region will benefit from the hydropower development while some sectors will suffer a loss in output because of the substantial increase in real wages. Neighboring regions also benefit as a result of increased electricity supply in the operational phase of the proposed hydropower station. The impact of the hydropower development project on the national GDP as a whole is relatively small although positive. However, because of the long lag between the construction and operational phases, the hydropower development project will result in a national welfare loss measured by real household consumption and net foreign liability. Therefore, the project could only be justified if net environmental benefits outweigh this loss.

**JEL classification**：C68, O13, R58

**Keywords:** dynamic CGE model; hydropower development; multiple regions; economic impacts; electricity subdivision module, China

## Table of Content

## 1. Introduction

Many developing countries are investing in hydropower to increase the degree of electrification and improve national development (Siciliano *et al.*, 2015). China's burgeoning economic growth has been accompanied by soaring demand for electricity. In response to increasing greenhouse gas emissions in China, in September 2020, China announced to achieve carbon neutrality by 2060, with "more vigorous policies and measures" to curb greenhouse emissions before 2030(China news, 2020). Furthermore, in its 14th 'Five Year Plan', the Chinese government set an aim that by 2030, the share of non-fossil fuel energy in primary energy consumption will be increased to about 25 percent. As a clean energy, hydropower's low-cost, near-zero pollution emissions and ability to respond quickly to peak loads make it a valuable energy source (Cheng et al., 2012, Fujimoria et al., 2014).

Hydropower projects generate a vast array of economic impacts – both in the region where they are located, and at inter-regional, national and even global levels (Cestti and Mali, 2012). There are some researches in the area of the economic impact of hydropower development projects. Goldsmith and Hildyard (1984) provided an overview of the impacts of various large dam projects. Mallakh (1959) and Owen (1964) presented comprehensive economic analyzes of how the Egyptian economy was affected by the High Aswan project. The first dam built in Laos was the NamNgum Dam, which was evaluated by the World Bank (2004). The conclusion of the research is that the NamNgum dam's macroeconomic impact on Loas would be substantial. Elokhin and Goruleva (1969) found out that the Volga-Kama dam system had generated multiple economic benefits in the form of higher electric power output, higher capacity of river transport, and a further improvement in water supply for agriculture, industry and household use. Olsen (1996) and Ortolano et al. (2000) analyzed the multiplier effects of the Grand Coulee Dam, including irrigation, hydropower, flood control, recreation, ecological effects, and social-economic effects. The dam generates between 1.5 to 1.7 dollars of economic benefits for each dollar invented. Bhatia et al. (2008) noted that the benefits of dams include increased irrigation water, industrial water and water for flood protection, and reduced vulnerability to droughts. They found that the benefit from the dams in the Sub-Medio Sao Francisco may have accounted for 1.2% to 6% of GDP.

Some researchers also conduct researches on trade-off among economic, environmental impact, and cost of the dam. For example, Kotchen et al. (2006) conducted a cost-benefit analysis for the relicensing agreement for two hydroelectric dams in Michigan. The result suggests that the total revenue generated is more than twice the cost of production. Morimoto (2013) proposed a project assessment tool to quantitatively examine the economic and social impact of hydropower development by a holistic approach. The results of Xia et al (2020) indicated that the construction of large hydropower projects is beneficial for social welfare promotion, but the enhancement doesn't appear immediately at the startup but with a lag; negative externalities are prominent in the early phases while positive ones account for a major proportion in the late phases. The results show that there are obvious mutual constraints among the economic, environmental, and social objectives of hydropower development.

The above-mentioned studies used statistics or partial quantitative methods to estimate the impact of hydropower development on the economy. Since the impacts of dams will infiltrate many aspects of the economy through industrial connections, comprehensive evaluation with detailed information on the sectors is necessary. Computable general equilibrium (CGE) models with multiple sectors are ideal tools for investigating the economic influence of hydropower development. For example, Strzepek et al. (2008) used a single-region CGE model to estimate the economic impact of the High Aswan Dam. Wittwer (2009) used a multi-regional and dynamic CGE model when estimating the impact of the construction of the Traveston dam in South-East Queensland. He concluded that the magnitude of the project's net welfare benefits depends on basic assumptions about future rainfall patterns. Levent (2010) used a dynamic single-region CGE model of the Turkish economy to analyze the potential long-term impacts of hydropower. The simulation results showed that hydropower would increase real GDP by 0.14% per year, real consumption by 0.13%, and real investment by 0.07% in 2020. However, a single-region model cannot reflect the impact of a hydropower project on other regions. The impacts of a dam usually spread to other regions, indicating a need for multi-regional CGE models to comprehensively assess regional impacts. Tewodros et al. (2015) assessed the direct and indirect impact of the Grand Ethiopian Renaissance Dam (GERD) applying a multi-regional CGE model. By the time GERD be operational, its negative impact on the Egyptian economy had begun to be reversed; GERD had produced good economic benefits and improved the economic and welfare of all East Nile countries. Liu et al. (2015) applied a static multi-regional CGE model that provides a lot of information about the region to assess the economic and social impact of hydropower development in China. However, Liu's research used a static model. Large hydropower project often takes several years to construct, and the operational phases last for 50 years or more. Most of the costs and benefits associated with dam development have a long-time span. Furthermore, the construction and operational phases of a hydropower project should be represented year by year in the same simulation. Therefore dynamic linkages and year-by-year adjustments are necessary.

Wittwer (2009) used a multi-regional, dynamic CGE model to estimate the regional impacts of the construction of the Traveston dam. He concluded that the magnitude of the project's net welfare benefits depends on underlying assumptions concerning future rainfall patterns.

Following Wittwer (2009), we use a dynamic multi-regional model of China – SinoTERM (The Enormous Regional Model) – to assess the economic impacts of a large hydropower development project. In this paper, we extend the old version of SinoTERM by introducing regional labor market dynamics and an electricity subdivision module with substitutability between various types of electricity generation. The extended SinoTERM model includes detailed information of sectors and regions, especially disaggregated power generation sectors.

The rest of this article is organized as follows: Section 2, we describe the SinoTERM model and its extension; Section 3 discusses the development of the baseline scenario and policy scenario. Simulation results are discussed in Section 4. Discussions is displayed in Section 5 and Section 6 is conclusions.

## 2. Modeling framework

### *2.1. SinoTERM model*

SinoTERM is a dynamic multi-regional Chinese economic model developed by the Centre of Policy Studies in Australia. It is based on the Enormous Regional Model of the Australian economy –TERM model. The theory of the SinoTERM model is similar to the national dynamic CGE models such as MONASH (Dixon and Rimmer, 2002, Horridge et al., 2005) and CHINAGEM (Mai et al., 2010) except that it involves multiple regions. In fact, we treat each region in the model as a separate economy, and these economies are connected through trade (Wittwer and Horridge, 2008, 2010). When a shock is given to a specific region, with the economic connections among the regions, the SinoTERM model allows us to analyze the economic impacts of the shock on all the regions and the nation as a whole.

The equation system of SinoTERM described in Horridge et al. (2005) is similar to other models in the TERM series. The features of the SinoTERM model, which are summarized in Horridge and Wittwer (2008), include a complete input-output database, inter-regional trade matrix, and behavioral equations for each region. The master databases of SinoTERM contains input output data for 137 industries in 31 regions of China. It includes detailed profit margin information, including railways, highways, waterways and air transportation, pipelines, warehousing, trade (retail and wholesale), and insurance. In order to allow for the possibility of changes in specific items between regions and users (in raw data or as part of a simulation), the database contains detailed tax rate matrices. The equations in the model are linearized for simplicity, which combined with accuracy via multi-step solution methods, ensures model efficiency through the use of GEMPACK software (Horridge et al., 2013).

Dynamics have been added to SinoTERM (Wittwer et al., 2008), following Dixon and Rimmer (2002). Linking capital and investment over time is the main dynamic mechanism. Under the dynamic approach, it is agreed that the construction and operation stages of a specific project in the simulation can be expressed year by year. Since the model is subject to policy impacts, the rate of return on capital will gradually be adjusted. This method allows us to model some adjustment costs. The dynamic mechanism of accumulation of net foreign assets is also added to the SinoTERM model so that considering the highly relevant characteristics of China's huge trade surplus, net foreign income is transformed into each family as part of the disposable income.

### *2.2. Model extensions*

#### *2.2.1. Electricity subdivision module*

An old version of the SinoTERM model analyzed issues such as the construction of the Chongqing–Lichuan rail link (Horridge and Pearson, 2011) and agricultural productivity (Wittwer and Horridge, 2008, 2010). The old version of SinoTERM did not include inter-fuel substitutability in electricity generation. For the present application, we split the composite electricity sector into generation and distribution as in MMRF-Green (Adams et al., 2003). Electricity-generating industries are distinguished based on the type of fuel used. The end-use supplier (electricity distribution) purchases generation and provides electricity to electricity users. In purchasing electricity, it can substitute different generation technologies in response to changes in generation costs.

In the SinoTERM model, electricity generation is disaggregated into four sectors: Coal-electricity, which uses coal to generate electricity; Hydroelectricity, nuclear electricity and renewable and gas electricity. All electricity generation industries sell only to the electricity distribution industry. The electricity distribution industry sources from these electricity-generation industries according to a CES (Constant Elasticity of Substitution) substitution. In configuration, we set the value of the substitution elasticity between the different electricity generation sectors at 2[1]. The structure of the production for an industry is showed in Fig.1.

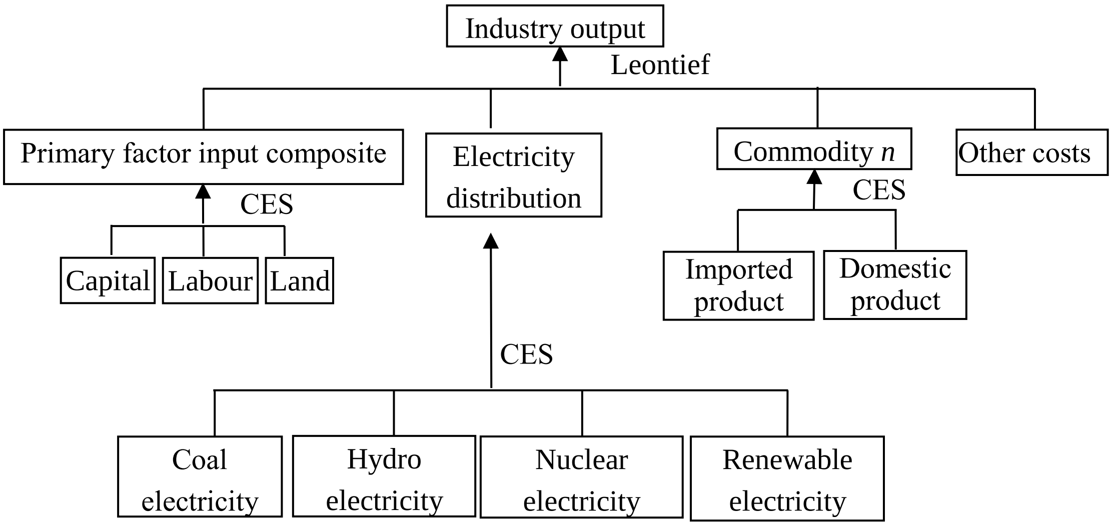

Fig.1. Structure of the production in the SinoTERM model

In terms of model design, the production sectors are assumed to maximize profits under nested production functions. The importance of splitting electricity into different types is that it enables us to provide different cost structures and investigate the substitute relationship for different types of electricity generation. For example, coal-generating electricity uses coal as the main input. Nuclear and hydroelectric generations are more capital intensive than other forms of generation.

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[1] 2 is commonly used for an energy substitution relationship in many models (Adams et al., 2013; Dai et al., 2016; Li et al., 2000; Antimiani et al., 2015). In SinoTERM, the substitution elasticity between other intermediate inputs for each industry is 0.15.

*2.2.2. Regional labor market dynamics*

Following Wittwer et al. (2009), regional labor market dynamics are also introduced into the SinoTERM model. As time goes by, in order to cope with the global shock, the regional labor force will be partially adjusted. The regional labor market adjustment mechanism in SinoTERM, in level form, is given by:

$$\left(\frac{W_t^r}{Wf_t^r}-1\right)=\left(\frac{W_{t-1}^r}{Wf_{t-1}^r}-1\right)+\alpha\left(\frac{EMP_t^r}{EMPf_t^r}-\frac{LS_t^r}{LSf_t^r}\right) \tag{3}$$

If in region *r*, relative to the predicted period *t,* the policy shock weakens the labor market, then in the policy scenario, the real wage $W_t^r$ is lower than the forecast wage $Wf_t^r$. In addition, relative to forecast levels $EMPf_t^r$ and $LSf_t^r$, in the labor market, the gap between labor market demand $EMP_t^r$ and supply $LS_t^r$ will expand. In the next few years, due to further declines in real wages, the gap between demand and supply will fall further to return to the predicted level. The speed of labor market adjustment is controlled by the positive parameter γ.

The regional labor supply equation is as follows:

$$\frac{LS_t^r}{LSf_t^r}=\frac{\left(W_t^r\right)^\gamma}{\sum_q\left(W_t^q\right)^\gamma S_t^q}\Bigg/\frac{\left(Wf_t^r\right)^\gamma}{\sum_q\left(Wf_t^q\right)^\gamma Sf_t^q} \tag{4}$$

The deviation of regional real wages relative to the predicted national real wages determines the deviation from the forecast caused by the policy shock of regional labor supply. In (4), $\sum_q\left(W_t^q\right)^\gamma S_t^q$ is a measure of the total work responsiveness of all regions to real wages, among which γ is a positive parameter and $S_t^q$ is the share of region *q* in national employment. This equation means that the labor supply in a given area will decline while other areas will increase. Combining (3) and (4), if you want to adjust the labor market in a particular area, you should first increase unemployment and lower real wages. Eventually, unemployment will return to the predicted level with lower real wages. As real wages decline relative to the basic situation, the labor supply in the region will also decline. Under this theory, the adjustment of the long-term labor market depends on the combination of labor migration between regions and changes in real wage differences.

*2.3. Regions and sectors*

The value matrix is divided into commodities, industries, sources, and regions, and these are included in the database of the SinoTERM model. The model contains quantity and price variables for each of these flows. In order to focus on the hydropower development issue, shorten the solution time, and present the simulation results in a targeted manner, we aggregate the sectors and regions to manageable dimensions while retaining details in sectors and regions of interest. We aggregate the master SinoTERM database of 137 sectors and 31 regions to 36 sectors and 6 regions, which include (1) the project region in Southwest China; (2) the rest of Southwest China; (3) South China (Guangdong, Guangxi, and Hainan); (4) Central China (Chongqing, Jiangxi, Henan, Hubei, and Hunan); (5) East China (Shanghai, Jiangsu, Zhejiang, and Anhui) and (6) the rest of China. The 36 sectors are listed in Appendix A.

This paper selected the construction of a dam and hydropower plant in the southwest of China as a case study[2]. With numerous rivers and intertwined lakes, the region has abundant potential hydropower resources. Other characteristics of the region are that it is rich in natural resources with a low degree of exploration and development, especially mineral resources, chromium, copper, and iron, etc. Transport and communications in the region are limited. Agriculture in the region uses traditional labor, with little agricultural machinery or modern agricultural technology. The per capita GDP of the region is less than 60% of the national average, and the per capita disposable income is only 75% of the national average. Generally speaking, the region is underdeveloped.

According to the Chinese government's plan, a total amount of 1000 billion RMB would be invested in the project region to build a hydropower station from 2015 to 2024. Its total installed capacity is 100 sets of water wheel turbines of 500,000 Kw. If the number of hours of the hydropower equipment operation increases to 6000 h, the station will generate 300 billion KWh of electricity annually in the operational phase from 2025.

## 3. Scenarios development

To analyze the economic effects of hydropower development, we must first make a prediction for the basic case, that is, the scenario of conducting daily business without the construction and operation of a specific hydroelectric power station. Then we conduct strategic simulations and make alternative predictions for the hydropower station. The effects of the hydropower construction and operation on the project region, other regions, and the nation as a whole are measured by deviations of variables in the alternative forecast from their baseline levels.

### *3.1. Baseline scenario*

The baseline scenario is divided into two periods: the first "historical" period from 2007 to 2016 and the second "forecast" period from 2017 to 2040. For the "historical" period, since the database of the SinoTERM model in this paper was based on China's 2007

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[2] Since the location of the hydropower station of the project is confidential, we could not reveal the exact location of the hydropower station.

Input-Output Tables[3], we updated the SinoTERM model to 2016[4], and the annual growth rates of economic variables from 2007 to 2016 were assigned according to their actual numbers published in China Statistical Yearbooks by the National Bureau of Statistics (NBS, various years) and in the United Nations commodity trade database (United Nations, 2009)[5].

### *3.1.1. Calibration of GDP growth and its components*

For the forecast period, the annual growth rates of GDP (Table 1) are from the "13th five-year plan" and "2030 Outlook" (NDRC, 2016). For the growth of the components of GDP regarding expenditure, we assume that household consumption is growing faster than investment. The reason is that China's growth model is changing from investment-driven growth to consumption-driven growth. The other reason is that with continued economic growth and increased income the consumption of income elastic goods and services will grow more rapidly than the consumption of income inelastic goods and services. With faster growth of consumption, the share of household consumption in GDP will become higher over time while the shares of investment and net exports will be falling (Table 2).

**Table 1:** The grow rates of GDP of China from 2007 to 2040

| Years (historical period) | Growth rate | Years (forecast period) | Growth rate |
|---|---|---|---|
| 2007 | 14.2% | 2016 | 6.7% |
| 2008 | 9.6% | 2017 | 6.7% |
| 2009 | 9.2% | 2018 | 6.7% |
| 2010 | 10.6% | 2019 | 6.6% |
| 2011 | 9.5% | 2020 | 6.4% |
| 2012 | 7.8% | 2021–2025 | 6.4% |
| 2013 | 7.7% | 2026–2030 | 5.0% |
| 2014 | 7.3% | 2031–2035 | 4.3% |
| 2015 | 6.9% | 2036–2040 | 4.3% |

Source: data for historical period are from China Statistical yearbooks and for forecast period are from 13th five-year plan and 2030 outlook (NDRC, 2016) and the World Bank[6].The 2007-2016 data are real data. The 2017-2040 data are forecast data.

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[3] China Input–Output Association (CIOA). Input–output table available online:
Available from: http://www.iochina.org.cn/Download/xgxz.html2007 [accessed 11/2015].

[4] The closures and data used to create a historical baseline from 2007 to 2016 are explained in detail in Dixon and Rimmer (2002).

[5] The data on household consumption, investment, government spending, international exports and imports of the detailed regions and sectors were all taken from China Statistical yearbooks. Even though the yearbooks include some commodity data on international trade, we chose to use more disaggregated data from the United Nation's commodity trade database. These are particularly useful in updating sectors with the most rapid trade growth: for exports, including manufacture sectors, and for imports including metal ores, coal, oil and gas (Dixon and Rimmer, 2002).

[6] The World Bank, World Development Indicators. GDP deflator [Data file].2012-2017. Retrieved from <http://data.worldbank.org/indicator/NY.GDP.DEFL.ZS>.

**Table 2:** The shares of GDP components

| | 2013 | 2015 | 2020 | 2030 | 2040 |
|---|---|---|---|---|---|
| Household consumption | 33% | 34% | 38% | 47% | 54% |
| Investment | 27% | 27% | 25% | 21% | 16% |
| Government consumption | 11% | 11% | 11% | 12% | 12% |
| Net export | 29% | 28% | 26% | 20% | 18% |
| GDP | 100% | 100% | 100% | 100% | 100% |

Source: simulation result of baseline scenario

### *3.1.2. Calibration of the electricity sectors*

Concerning the demand for electricity, we assume in the baseline that electricity demand may, at least in the longer run, grow at a slower rate than industrial output or income growth in China. This is based on two features of income growth: (1) the movement towards consumption of services; and (2) the impact of technological change. Technological change that reduces electricity inputs per unit of output can be accelerated by appropriate electricity pricing, which increases the incentive for industries to improve energy efficiency. For example, new widescreen television sets are more energy-efficient than those of several years ago due to LED technology. Lighting has also experienced substantial efficiency gains with the growing use of LED technology. New washing machines and refrigerators are more energy-efficient than those of a decade ago. Sectors are also becoming more energy-efficient so that as industrial output grows, industrial demand for electricity will grow at a slower rate than output.

There are many opportunities to increase the utilization of base-load electricity. Many electricity authorities around the world have introduced electricity pricing, which varies according to the time of day. This encourages consumers to delay the use of appliances such as dishwashing machines until a lower night tariff applies. One of the attractions of electric cars, for example, is that they could be charged overnight when factories are not operating, thereby increasing the utilization of off-peak electricity and reducing the marginal impact of cars on energy consumption.

An important component of supplying electricity to users is electricity transmission. This is particularly the case in China, in which there are substantial coalfields in the northeast and north and substantial water resources in the southwest, but most industrial activity and households are located in the east. Electricity grids increase the effective supply of generated electricity. A well-dispersed grid enables generators from one region to contribute to the needs of another region. For example, hydropower generation output has seasonal variations as water volumes peak after snow melts. At other times, users within a grid will rely more heavily on electricity sourced from elsewhere.

According to the national accounts, the value-add of the utility sectors totaled almost

1130 billion RMB in 2012[7]. We updated the SinoTERM model so that the value-add of the electricity sectors in 2012 was around 1200 billion RMB. We aim in this study to impose the same valuation on electricity as appears in the national accounts. In the SinoTERM database, this corresponds to 4977 billion kWh of generating capacity in 2012 (IEA, 2016).

In summary, gains in energy efficiency in industrial processes and households, the increased uptake of solar energy, time-of-use pricing, and improved electricity grids will all contribute to a lessening of future electricity-generating requirements relative to otherwise. We assume that in the forecast period, electricity consumption will keep increasing but at a lower rate. This assumption is consistent with the forecast conducted by Liu (2012), "China's Energy Development in the New Era"(The State Council Information Office, PRC, 2020) and the "Research on Medium and Long-term Development Strategy of China's Energy (2030, 2050)" conducted by the CAE (the Chinese Academy of Engineering, 2011). In the baseline simulation there will be 9,000 billion kWh of electricity demand by 2025 and 10,200 billion kWh by 2040 (Table 3)

**Table 3:** China's electricity demand (billion kWh) in the baseline scenario

| | 2020 | 2025 | 2040 |
|---|---|---|---|
| Household | 1220 | 1300 | 1400 |
| Production | 4780 | 7700 | 8800 |
| Total | 6000 | 9000 | 10200 |

Source: total electricity demand Liu (2012) and "Research on Medium and Long-term Development Strategy of China's Energy (2030, 2050)".

In 2009, China announced a goal to reduce the carbon intensity of GDP and increase the share of non-fossil fuels. This goal is very ambitious (NDRC, 2012). Recently China announced that the proportion of non-fossil energy in its primary energy consumption will increase to about 25% by 2030 (NEA, 2021). By the end of 2040, China plans to bring the total installed nuclear power capacity to 201GW, accounting for 6.8% of the total power generation. The total installed hydropower capacity will be increased to 568GW, accounting for 15.6% of the total power generation (Table 4).

**Table 4:** Installed capacity of non-fossil power (GW)

| | Hydro |
|---|---|
| 2010 | 260 |
| 2015 | 306 |
| 2020 | 360 |
| 2030 | 497 |
| 2040 | 568 |

Source: from Dai et al. (2016).

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[7] Data sources: China Statistical Yearbook

### *3.2. Policy scenario design*

In this study, the planned construction of the hydropower station is from 2015 to 2024. The operation of the hydropower station commences in 2025. There is a 10-year lag between investment and the additional capacity becoming operational. A lag of this length will reduce the net returns from this project.

A key assumption of this simulation is that labor for building the hydropower station is supplied by the project region and others due to a shortage of labor in the project region. That is, at the beginning of the construction phase, there is a planned movement of labor from the rest of China to the project region.

The hydropower project involves large up-front investment costs, most of which are related to financing the dam and plant construction, electricity grid, and other infrastructure constructions such as roads to the dam (Table 5). Apart from the investment costs, the other main cost is maintenance, including repairs and insurance during the operation period. The annual investment scheme is shown in Table 5. The average electricity generated annually will be about 300 billion kWh when the hydropower station is fully operational from 2030 (Table 6).

**Table 5**: The investment (million RMB) allocation of hydropower station in project region

| Years | Hydropower plant | Hydropower equipment | Electricity grid | Infrastructure | Total investment |
|---|---|---|---|---|---|
| 2015 | 76200 | 38400 | 2400 | 3000 | 120000 |
| 2016 | 76200 | 38400 | 2400 | 3000 | 120000 |
| 2017 | 63500 | 32000 | 4500 | 0 | 100000 |
| 2018 | 50800 | 25600 | 3600 | 0 | 80000 |
| 2019 | 50800 | 25600 | 3600 | 0 | 80000 |
| 2020 | 44450 | 22400 | 3150 | 0 | 70000 |
| 2021 | 44450 | 22400 | 3150 | 0 | 70000 |
| 2022 | 44450 | 22400 | 3150 | 0 | 70000 |
| 2023 | 44450 | 22400 | 3150 | 0 | 70000 |
| 2024 | 38100 | 19200 | 2700 | 0 | 60000 |
| 2025 | 38100 | 19200 | 2700 | 0 | 60000 |
| 2026 | 25400 | 12800 | 1800 | 0 | 40000 |
| 2027 | 12700 | 6400 | 900 | 0 | 20000 |
| 2028 | 9525 | 4800 | 675 | 0 | 15000 |
| 2029 | 9525 | 4800 | 675 | 0 | 15000 |
| 2030 | 6350 | 3200 | 450 | 0 | 10000 |
| 2031–40 | 64 | 32 | 5 | 0 | 100 |

Source: The Draft Plan of Hydropower Development in the project region

**Table 6**. The electricity generation of the hydropower station (billion kWh)

| Years | Electricity generation | Years | Electricity generation |
|---|---|---|---|
| 2025 | 60 | 2033 | 290 |
| 2026 | 110 | 2034 | 300 |
| 2027 | 140 | 2035 | 300 |
| 2028 | 140 | 2036 | 300 |
| 2029 | 230 | 2037 | 300 |
| 2030 | 280 | 2038 | 300 |
| 2031 | 280 | 2039 | 300 |
| 2032 | 280 | 2040 | 300 |

Source: The Draft Plan of Hydropower Development in the project region

We assume that the electricity generated from the proposed hydropower station from 2025 will be transmitted to South China, Central China, and East China. The shares of the electricity received by these three regions are 60%, 20%, and 20%, respectively.

Because of the increasing demand for labor in the project region, as a result of the huge amount of investment in hydropower development, the labor cost, at least in the initial several years of dam construction, will increase. As a result, some sectors will be affected negatively. In the policy scenario in the operation period, we assume that some of sales of electricity will be used to fund additional investment across a number of "target" sectors in the project region such as education, health, and other service sectors.

## 4. Results

### *4.1. Macroeconomic impacts on the nation*

### *4.1.1. Impact on the national labor market and real GDP*

The macroeconomic effect of the huge regional project in hydropower development is relatively small at the national level. The inflow of labor to the project region reduces the labor supply in other regions. But for the nation as a whole, the total labor supply will be fixed in the long run. The increased labor demands generated from the massive construction project in the project region will raise employment initially and strengthen the national labor market from 2015 until 2024 (Fig. 2). The sluggish adjustment in real wages implies that real wages persist above the baseline scenario,, even as expenditure on the construction phase will be reduced around 2020. This means that national employment will fall slightly below the baseline scenario in the later years of the construction phase as the labor market weakens. The operational phase will raise working capital and provide a technological gain as additional electricity generation commences. This will raise the marginal product of labor and therefore move real wages further above the baseline scenario. By the end of 2040, the real national wage will be around 0.16% higher than the baseline scenario (Fig.2). Employment will remain around 0.02% below the base, implying that a little further downward adjustment of wages will be required before it returns to base.

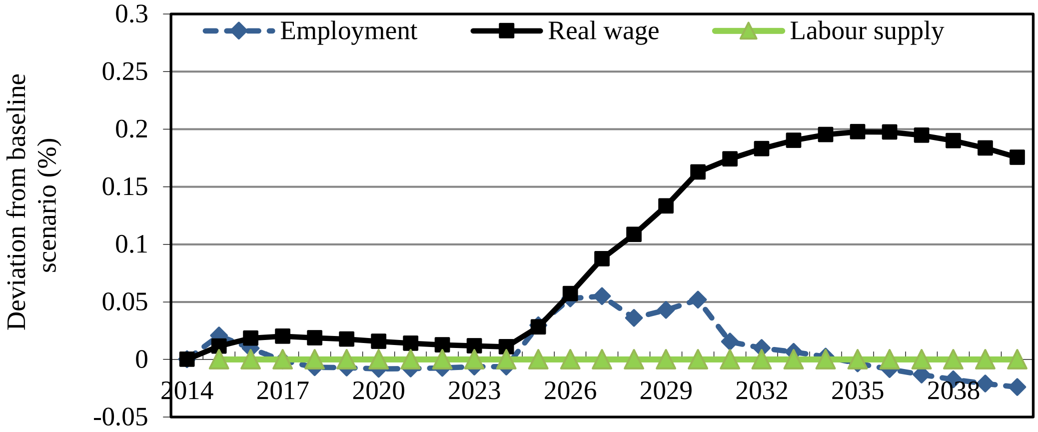


Fig.2. National labor market (Cumulative deviation from baseline scenario)

*Source:* Policy simulation results

Fig.3 shows the impact of the construction and operational phases of the project on national GDP. GDP (Y) is defined as a function of the underlying technology *A*, capital *K* and labor *L*, $Y = 1/A^*F\ (K, L)$. Although capital rises above the baseline scenario during the construction phase, the capital constructed by this project does not become operational until 2025. Therefore, real GDP falls slightly below the baseline scenario during the construction phase. Once the capital becomes operational, there is a jump in real GDP and a technological gain reflecting the commencement of electricity generation. The national real GDP will be 0.04% higher than that in the baseline scenario at the end of simulation period 2040. Capital will be 0.08% higher.

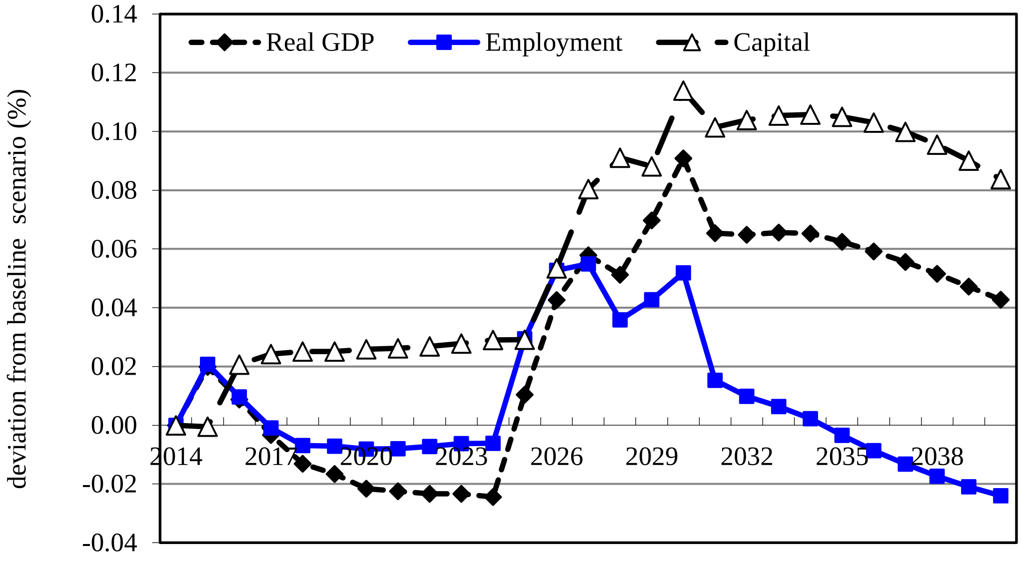


Fig.3. National GDP in the policy scenario (Cumulative deviation from baseline forecast)

*Source*: Simulation results

### *4.1.2. Impacts on national welfare*

At the national level, the diversion of labor from other regions reduces income in the rest of China during the construction phase. Other regions of China obtain benefit from the increase in electricity supplied by the project region during the operational phase.

We use real household consumption and net foreign liability to measure national welfare. The formal measure of welfare using the equation (see Appendix B) is close to *minus* 12.6 billion RMB. The main reason for the national welfare loss arises from the long lag between commencing construction and the operation of the hydropower station. Although the value of electricity in the model has been calibrated so as to align with the latest available data from China's national accounts, it is possible that electricity generated by the project could be more valuable to the economy than that modeled. In particular, fossil-fueled electricity generation in the future may be subjected to carbon tax, raising the competitiveness of hydropower as "clean" electricity. In this case, the national welfare gain will be greater after the operation of the hydropower station.

Moreover, while we would expect investments in remote regions to be relatively expensive, it is also possible that earnings on investment in more densely populated regions of China could fall in the future due to problems arising from pollution and congestion. If so, the welfare outcome of this project would improve.

### *4.1.3. Impacts on national electricity security*

Hydropower development in the project region will increase the nation's electricity supply. The electricity supply will be 0.28% higher in the first year of the operational phase, and by the end of 2040, the electricity supply will be 0.89% higher than that in the baseline scenario.

Our SinoTERM model incorporates an electricity subdivision module that considers a substitution relationship between various types of electricity generation as we explained in the subsection 2.2.1. The increase in hydroelectricity will substitute some amount of other types of electricity. Fig.4 shows that hydroelectricity replacing coal electricity makes a decrease in the output of coal electricity from a nationwide perspective. By the end of 2040, the output of coal electricity will be 0.51% lower than that in the baseline scenario, Gas and renewable electric and nuclear electricity will be 0.52% and 1.14% lower, respectively (Fig.4). The increase in the hydroelectricity will improve China's electricity structure. The share of coal electricity will fall while the share of electricity generated by clean energy will increase in the policy scenario when we compare with the baseline scenario.

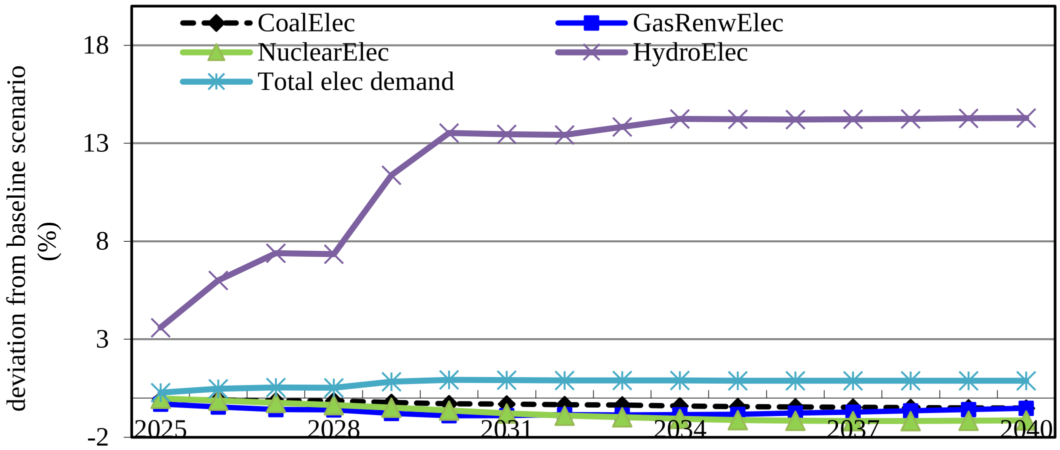


Fig.4. National electricity output in the policy scenario
(Cumulative deviation from baseline scenario)
*Source*: Policy simulation results

## *4.2. Impacts on project region*

### *4.2.1. Macroeconomic impact on the project region*

The huge investment in the construction of the proposed hydropower station has a significant effect on the project region. We look at the effects on the labor market first. A key assumption is that labor is supplied by other regions. Such a large investment relies on a substantial inflow of workers. That is, at the beginning of the dam construction phase, there is a planned movement of labor from the rest of China to the project region. As a consequence, labor supply plateaus at around 20% or 80,000 workers above the baseline scenario in the region from 2016. The exogenous inflow of labor subdues but does not eliminate real wage growth relative to the baseline scenario during the investment phase in the project region. The project region is an underdeveloped area, implying that base wages are much lower than elsewhere in China. Labor demand (employment) increases because of the construction of the dam. As long as this demand exceeds the labor supply, there is upward pressure on wages. After 2020, rising real wages will bring employment closer to labor supply, thereby subduing further real wages increases. In 2025, the first year of operation of the dam, income generated by the dam will provide additional employment in the project region. Once again, labor demand will jump above labor supply in 2025, imposing additional upward pressure on wages, and real wages will continue to rise. Rising real wages will restrain labor demand and bring employment gradually below the labor supply. Therefore real wages will show a downtrend from 2033 to 2040 (Fig.5). By the end of 2040, the employment of the project region will be about 22% higher than the baseline scenario, and the real wage about 40% higher.

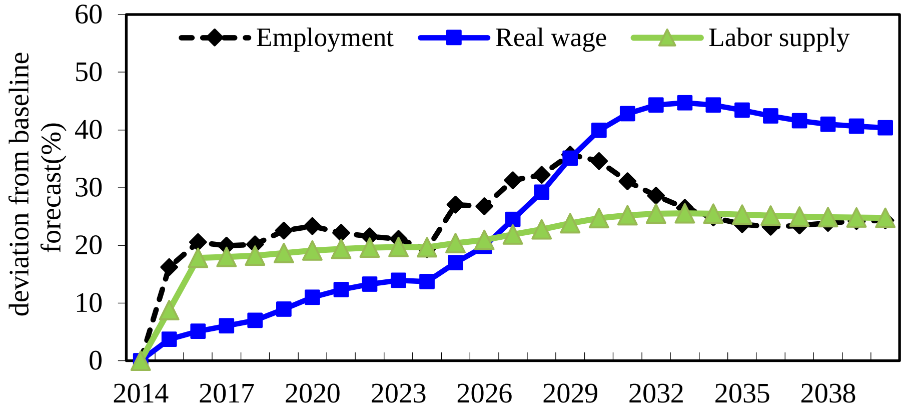


Fig.5. Labor market in the project region in the policy scenario
(Cumulative deviation from baseline scenario)
*Source:* Policy simulation results

The construction of the hydropower station results in a many-fold increase in the project region's aggregate investment from 2015 onwards. As the construction phase winds down (from 40 billion RMB in 2026 to 0.01 billion RMB in 2031), aggregate investment in the region will move back towards the baseline level (Fig.6). The investment will be dominated by the investment imposed directly on dam construction until 2025. From 2026, the second year of the operational phase, we assume that some sales of electricity will be used to fund additional investment across a number of industries in the project region and, to a lesser extent, the rest of the southwest region. This ensures that investment in the project region remains more than 200% above the baseline scenario during the operational phase of the project. Nevertheless, additional demands in the project region continued to be supplied to a considerable extent by increased inter-regional imports. This reliance on trade reduces the extent to which investment and output increase relative to the baseline scenario in the project region's industries other than hydropower generation and electricity distribution.

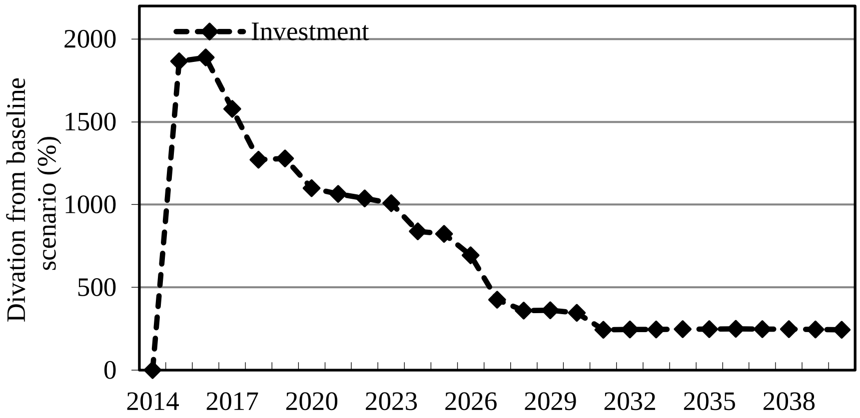


Fig.6. Investment in the project region in the policy scenario
(Cumulative deviation from baseline scenario)
*Source:* Policy simulation results

Household consumption (Figure 7) is consistent with the movement of the GDP in the project region which is shown in the Figure 8. From 2017 household consumption moves back in the direction of the baseline as construction expenditures taper off over time. In 2025, the first year of operation of additional hydropower capacity, household consumption will jump further above the baseline scenario. Household consumption will remain around 90% above the base in 2040, implying an increase in consumption per capita in the project region (Figure 7). This is because labor supply (which approximates population) will only be around 25% above the baseline scenario in the same year, implying an increase in per capita consumption in the region of 65% [=90% - 25%].

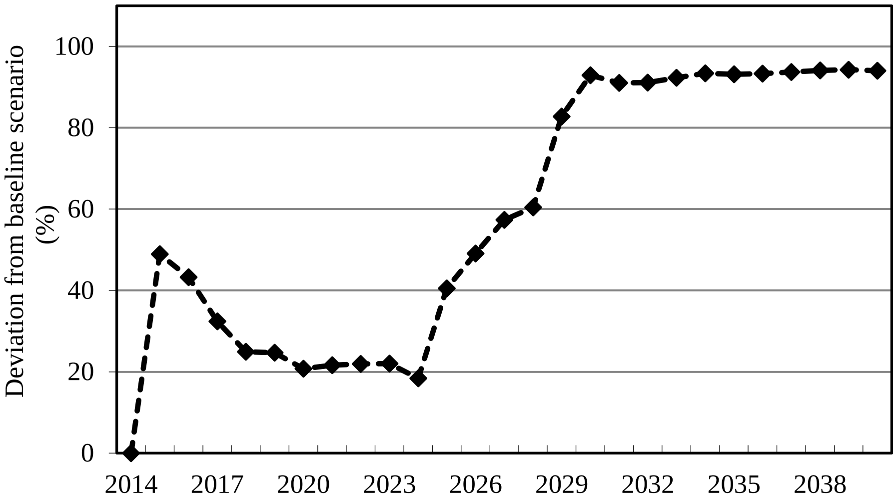


Fig.7. Household consumption in the project region in the policy scenario (Cumulative deviation from baseline scenario)

*Source:* Policy simulation results

Higher investment growth will bring higher capital stock growth. By the end of the simulation period, capital stock is 52% higher than the baseline scenario.

The huge investment in the project region, particularly the investment in the infrastructure such as road building, will increase the productivity of the region. The simulation shows that by the end of 2040, productivity (technology improvement) will be 63.4% higher than the baseline scenario. Fig. 8 also shows that while the dam and hydropower plants are under construction, real GDP in the region will fall below the share-weighted sum of the percentage changes in labor and capital. This is because the capital remains dormant until the project enters the operational phase: dormant capital is equivalent to a technological deterioration. Once the operational phase commences, an increase in capacity utilization (Table 5) implies an increase in productivity. The productivity growth arising from the hydropower plant will eventually make a dominant contribution to the region's real GDP growth while the percentage increases in labor and capital in the region will become much smaller than the region's real GDP during the operational phase. By the end of 2040, GDP will be 114% higher than the baseline scenario (Fig.8). The calculation of real GDP growth in the project region is presented in the Appendix C.

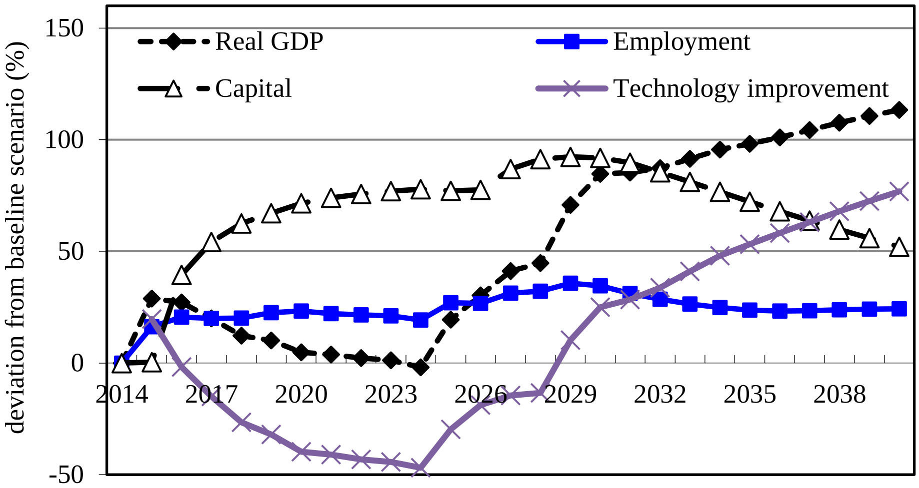


Fig.8 GDP in the project region in the policy scenario
(Cumulative deviation from baseline scenario)

*Source*: Policy simulation results

### *4.2.2. Impacts on sectors*

Industries that experience increases in output relative to the baseline scenario in the project region are those directly affected by the construction phase, notably construction and transport. During the operational phase, the outputs of hydropower generation and electricity distribution will increase relative to the baseline scenario, in line with the scenario shocks imposed on the model. Other industries with increases in output are those benefiting most directly from the rise in household consumption relative to the baseline scenario or from targeted investment such as other services, health and education. However, within the assumptions of the policy scenario, in which investment is directed at physical infrastructure, there are industries within the region that will suffer decreases in output relative to the baseline scenario. This is because the substantial increase in real wages relative to the baseline scenario will reduce the competitiveness of industries not directly benefiting from the project. For instance, livestock industries will suffer from higher wage costs and consequently lose output relative to the baseline scenario (Fig.9).

In summary, the impact on output of any industry in the project region is due to several factors: (1) Increased income in the project region as a result of large investment in the hydroelectricity sector will induce a spending effect, which mainly impacts sectors satisfying household consumption. (2) Increased labor costs induced by the region’s investment boom will reduce the competitiveness of lagging sectors and contribute negatively to their output growth. (3) Demands for goods and services associated with construction industry will rise during the investment phase, which will increase the price of those goods and services, therefore increasing the supply of these goods and services either by import from the region or produced by the project region.

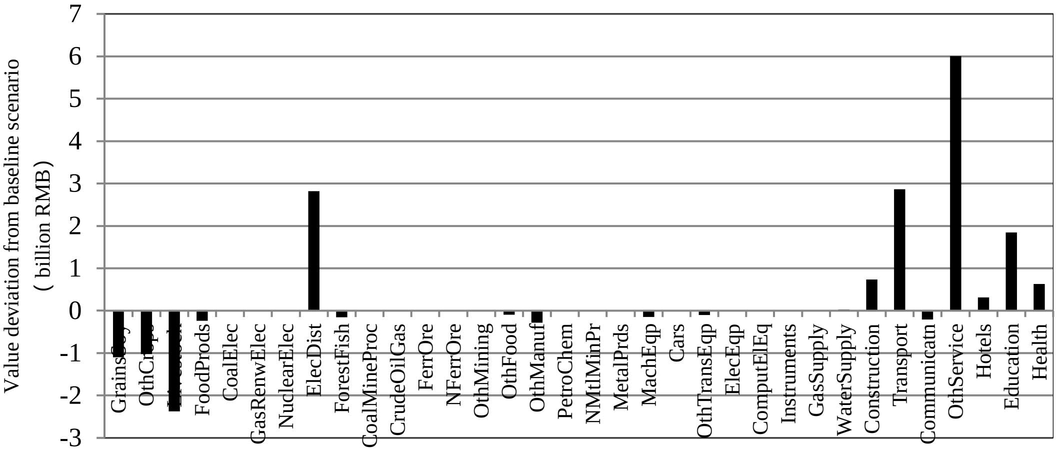


Fig.9. Sector outputs of the project region in 2040 in the policy scenario (billion RMB)-cumulative deviation from baseline scenario

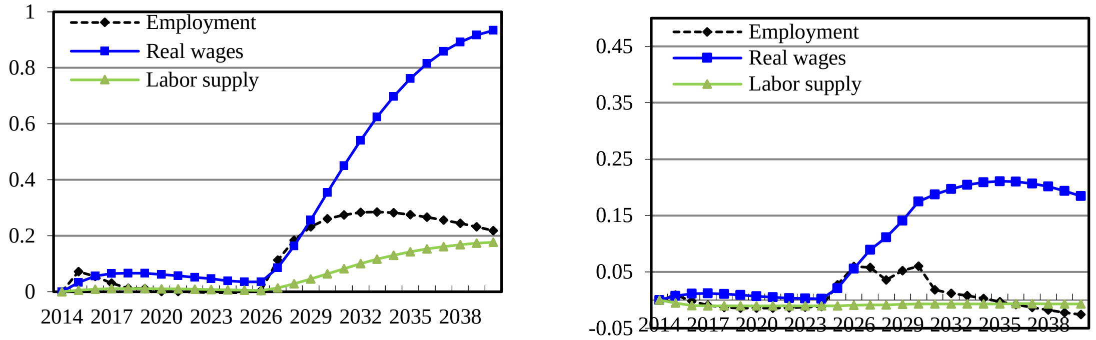
*Source*: Policy simulation results

Fig.9 shows the deviations in industry outputs in the project region from the baseline scenario in 2040. Some industries would grow more relative to the baseline scenario during the operational phase if they received larger targeted investment funds. However, no details of targeted investment funds were available for the project when we conducted this research. In this context, it is sufficient to show that targeted investment can spread to regional growth across a number of industries, and reduce the potential adverse consequences for industry output of rising real wages relative to the baseline scenario.

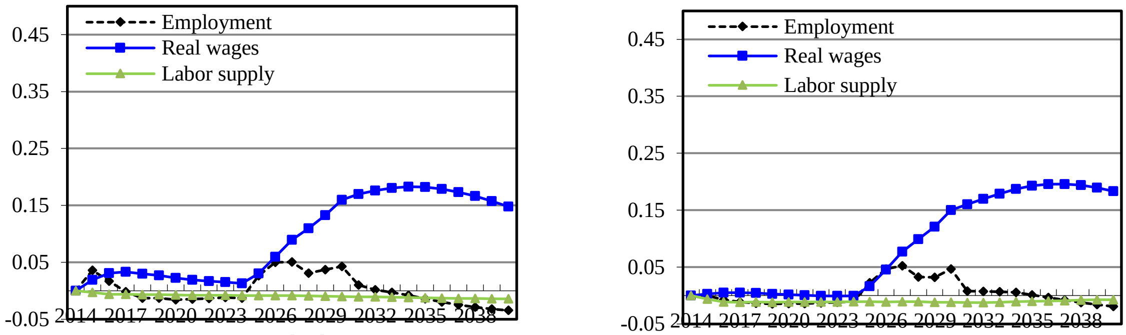
### *4.3. Macroeconomic impact on other regions*

The excess demands in the project region imply that the region will import heavily from the rest of Southwest China. The gravity assumption of trade within the model ensures that relatively proximal regions will trade more with the project region than more distant regions. Under this assumption we expect the rest of Southwest China will be affected more than the other regions, employment will rise relative to baseline scenario in the construction phase, and will rise further during the operational phase (Fig.10).

There are two reasons for the wage increase in the operational phase in this region. First, the increased electricity output in the project region will have the effect of strengthening the national labor market, as described above. Second, some of the electricity income will be used to fund investments in the rest of Southwest China. In summary, real wages in the rest of Southwest China will rise more than in the rest of China, albeit from a lower base. The project will also increase employment in the rest of Southwest China relative to the baseline scenario because of the increased investment and export to the project region.



Rest of Southwest China East China



Central China South China

Fig.10. Other regions' labor markets in the policy scenario
(Cumulative deviation from baseline scenario %)
*Source:* Policy simulation results

The labor market in the remaining regions will follow a relatively similar pattern, though with smaller percentage changes. Increased labor demands in the early years of the construction phase will raise employment above the baseline scenario until the real wages increase sufficiently to force employment back towards the baseline. The operational phase will strengthen the labor market by raising the marginal product of labor through a combination of increased operating capital and technological gains (i.e. smaller input requirements per unit of output). Employment in other regions will eventually move back towards and below the baseline because of rising real wages (Fig.10).

All regions except for the project region will experience small GDP losses relative to the baseline in the construction phase, arising from the resource squeeze imposed by the demands of the project region (Fig.11).

In the operational phase, the economies of electricity-importing regions will rise, driven by electricity-lowering costs of production. In Central China, which receives 40% of the project's generated electricity, GDP will be 0.052% higher than that in the baseline scenario in 2040. Fig.11 shows smaller percentage gains for East China and South China. For the rest of Southwest China, the investment funded from the electricity sale in the operational period plus the cheaper electricity will boost the GDP growth in this area. By the end of 2040, GDP in this region will be 0.72% higher than the baseline scenario.

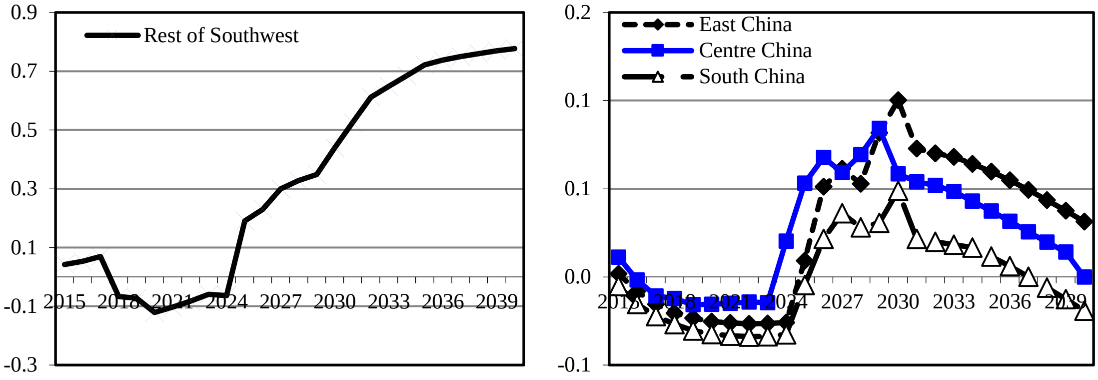


Fig. 11. GDP in electricity-importing regions in the policy scenario
(Cumulative deviation from baseline %)

*Source*: Policy simulation results

## 5. Discussions

### *5.1. Comparison with other studies*

Using a dynamic multi-regional CGE model of China, this paper explores the economic effect of a 1000 billion RMB hydropower station development investment on the project region, other regions, and the nation as a whole. Our study shows that hydropower development will bring economic benefit. The results of this research are consistent with previous studies (Cestti and Mali, 2012; Wichelns,2002, Bhatia et al., 2008, Strzepek et al., 2008, Levent, 2010, Tewodros et al., 2015, Liu et al., 2015, Ma et al., 2015, Wittwer, 2009, Lao, 2016).

Our study shows that the hydropower development project will boost the economic growth of the project region. GDP will be 114% higher than the baseline scenario in the project region. This means that every one RMB of hydropower investment can boost 0.8843 RMB of the GDP for the project region. This value is lower than the 0.9676 RMB of Lao's (2016) research. One reason for this is that the great mass of electricity generation is transmitted to other regions in China.

Our study shows that national GDP will fall slightly below the baseline scenario during the construction phase, and it will be between 0.04% and 0.06% higher than the baseline scenario during the operational phase. In the research of Liu et al. (2015) and Ma et al. (2015), this trend was also observed. These two studies showed that national GDP was 0.01% higher than the baseline scenario in the construction phase and was 0.10% higher than the baseline scenario in the operational phase. These two studies used a static model and did not consider the capital stock accumulation and the dormant capital during the construction period. Our study used a dynamic model. As discussed in the previous sections, dormant capital is equivalent to the deterioration of technology. The lag between the construction of the hydropower station and the start of the operation of the station is ten years. That is the reason that, in our study, the national GDP in the construction period is lower than that that in the baseline scenario.

Our study reveals that national welfare by the end of the simulation period is close to minus 12.6 billion RMB. The main reason for this loss is due to the long lag between the construction and operation of the hydropower station, even though national welfare will be positive in the operational phase. In the research conducted by Tewodros et al. (2015), the welfare loss due to large-scale hydropower development projects has also been observed. They found that Egypt experienced a welfare loss of about USD 82 million from the GERD (Grand Ethiopian Renaissance Dam).

### *5.2. Limitations*

The current study does not take account of the full economic consequences of a hydropower project. The following sections outline a few of the potential costs and benefits of dam construction not including in the current study, which may lead to overstating – or in some cases, understate – the net benefits of a project.

#### *5.2.1 Environmental impacts*

Nevertheless, major hydropower dams have also been controversial in terms of environmental sustainability. People in the project-affected area have experienced the flooding of vegetable gardens, reduced fish catches, loss of freshwater drinking sources, and transportation difficulties since the project began operation (Bakken et al., 2014; Brown et al., 2009; Burke et al., 2009; McCallum, 2008, Kotchen et al., 2006).

##### (1) Fisheries decline

From a biophysical viewpoint, the main impacts of major hydropower dams relate not only to the fragmentation of river systems, but also fragmentation of the vegetation and negative effects on soil and water quality. A decline in fisheries was one of the hydropower project's most significant impacts.

##### (2) Sedimentation

The impact of dam construction on siltation will vary between specific projects. Silt flowing freely downstream will provide farmers with soil nutrients. Silt accumulated behind a dam wall therefore has two potentially negative effects. It may reduce land productivity downstream and it may affect water quality behind the dam wall. Water quality behind the dam wall may also be reduced by algae and chemical runoff that would not have accumulated without the dam (Hu et al., 2009).

##### (3) Seismic activity

There are many moderate to very high seismic hazard zones in western China. Earthquakes may damage dams and other structures. Moreover, the weight of water stored in dams may induce additional seismic activity (Yao et al., 2013). Clearly, analysis of seismic activity is outside the domain of economists.

##### (4) Flood control

One of the benefits of dam development may be flood mitigation. However, it does not always follow that a dam will make a positive contribution to flood mitigation. The contribution of a dam to flood mitigation may depend on a number of local specific features (Plessisa and Viljoen 1999).

(5) Water quality

Altered water flows following dam construction may reduce the quality of water available to users (Hvistendahl, 2008).

### *5.2.2 Displaced communities*

Massive dam projects may entail the relocation of hundreds of thousands of people. Displacement, resettlement and migration, changes in livelihood strategies, poor compensation, effects on culture and social relations, impacts on community health and loss of land and water access, all cause social problems (Brown et al., 2009; Lerer & Scudder, 1999; McDonaldWilmsen et al., 2010; Jackson & Sleigh, 2000; Tilt et al., 2009; Tullos et al., 2013; Urban et al., 2013; WCD, 2000; Cooke et al., 2017).

However, the project presented here will be located in a relatively isolated area. It will affect relatively few people directly.

### *5.2.3 Climate change*

Climate change and receding glaciers may affect the hydropower station's electricity generation due to changes in the magnitude and seasonality of river runoff and increases in reservoir evaporation. These physical impacts will in turn have economic consequences through both the changes of producer revenues and consumer expenditures. Climate change may have a positive projected effect on electricity generation (Boehlert *et al.*,2016), and a negative effect on firm power generation, for example Henderson et al. (2013) and Lettenmaier et al.(1999) find that GHG mitigation reduces hydropower generation. In this paper, we do not consider the long-term climate variability. We assume that 300 billion kWh are an average electricity generation for the proposed hydropower station.

### *5.3. Further research*

The model developed in this study provides some useful insights into the possible impacts of a Large Hydropower Development Project. Further work will concentrate on sedimentation and other missing benefits/costs of hydro projects and environmental impacts. Further work will also be done on the econometric estimation of some of the behavioral parameters used in the model. Finally, it would be useful to incorporate carbon emissions in future work, given concerns over climate change and the need to consider how China could benefit from carbon credits.

## 6. Conclusion

We extend the old version of SinoTERM by introducing regional labor market dynamics and an electricity subdivision module with substitutability between various types of electricity generation. The extended SinoTERM model includes detailed information of sectors and regions. We use this extended model to assess the long run economic impacts of a large hydropower development project. Our simulation shows that：

（1）For the nation as a whole, real GDP will be between 0.04% and 0.06% higher than that in the baseline scenario during the operational phase. By the end of the simulation period 2040, the national real wage will be around 0.16% higher than that in the baseline scenario. Employment will be around 0.02% lower. However, because of the long lag between the construction and operational phases, the hydropower development project will result in a national welfare loss of around 12.6 billion RMB measured by real household consumption and net foreign liability.

（2）For the project region, the dam will boost the economic growth significantly. Real GDP will be 114% higher than that in the baseline scenario in 2040. Employment and capital will be 24.3% and 52.1% higher, respectively. The massive investment in the dam, transportation and grid will stimulate the project region’s technology improvement. Most sectors in the project region will benefit from the hydropower development while some sectors will suffer a loss in output because of the substantial increase in real wages.

（3）For neighboring regions, the neighboring regions will also benefit as a result of increased electricity supply in the operational phase of the proposed hydropower station. The rest of Southwest China will benefit most. By the end of 2040, GDP in this region will be 0.72% higher than that in the baseline scenario. In Central China, which will receive 40% of the project’s generated electricity, its GDP will be 0.052% higher than that in the baseline scenario in 2040. East China and South China will get smaller percentage gains from the proposed hydropower station.

（4）Because of the long lag between the construction and the operational phases, the hydropower development project will bring about a national welfare loss. However, the tendency to use clean energy to replace fossil fuel energy in China will certainly make hydroelectricity more valuable in the future. In this case, the welfare outcome resulting from this project may be improved.

## *Acknowledgments*

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### *Appendix A: List of sectors in the SinoTERM model in this study*

There are 42 sectors in this study. These are GrainsSoy, OthCrops (other crops), Livestock, FoodProds (food production and processing), Coal-electric, GasRenw-electric (electricity generated from gas and renewable resources), Nuclear-electric, Hydro-electric, Electric-Dis (electric power distribution and transmission), ForestFish, CoalMineProc (coal mining and quarrying), CrudeOilGas, FerrOre (ferrous metals mining), NFerrOre (other metals mining except ferrous metals), OthMining (other mining except above-mentioned), OthFood (meat product), OthManuf (other manufacturing except above-mentioned), PetroChem (petroleum and chemicals), NMtlMinPr (nonmetal mineral products), MetalPrds (basic metals and fabricated metal products), MachEqp (machinery and equipment manufacturing), Cars, OthTransEqp (other transport equipment except cars), ElecEqp (electrical equipment manufacturing), ComputElEq (communication equipment and computers manufacturing), Instruments, GasSupply, WaterSupply, Construction, Transport, Communication, OthService (other service industry), Trade, Hotels, Education, Health.

### *Appendix B: Calculation of the national welfare*

We can calculate the change in welfare at the national level by accounting for the impact of the project on aggregate consumption and net foreign liabilities, as follows:

$$\text{dWELF} = \sum_{d}\sum_{t}\frac{\text{dCON}(d,t)}{(1-r)^{t}} - \frac{\text{dNFL}(z)}{(1-r)^{z}} \qquad \text{(B.1)}$$

Where $\text{dWELF}$ is the change in welfare; $\text{dCON}(d,t)$ is the deviation in real household consumption in region *d* at year *t*; $\text{dNFL}(z)$ is the deviation in real net foreign liabilities in the final year (*z*) of the simulation; and *r* is the discount rate (0.04%).

### *Appendix C: Back of the envelope (BOTE) analysis of the project region's real GDP growth*

The macroeconomic production function is as follows.

$$GDP = \frac{1}{A} * F(K, L,) \qquad \text{(C.1)}$$

$K$ is capital stocks, $L$ is labor and $1/A$ is the technological level. Assuming that land is either a small share of GDP or embedded in capital.

In percentage change terms, Equation (C.1) becomes:

$$gdp = \mathrm{k} * Sk + \mathrm{l} * Sl - a \qquad \text{(C.2)}$$

Where $gdp$, l, k is the percentage change of real GDP, labor and capital, respectively, $Sl$ is the share of labor. $Sk$ is the share of capital. $a$ is the percentage change of technology.

In the final year of simulation, the share of labor in the project region is 0.561, and the share of capital is 0.439. By the end of simulation period 2040, the change of labor (the cumulative deviation of aggregate employment from the baseline scenario) is 24.3%, and the change of capital (the cumulative deviation of aggregate capital from the baseline scenario) is 52.1%. The improvement of technology is 63.4%. So the change of real GDP is: $gdp$ = 0.561*24.3%+0.439*52.1%+63.4 %= 99.9%. While the real GDP change in the project region from simulation is 114%. What is missing? We find that there is a big change in "tax" in the project region. Here "tax" means the production tax and indirect tax etc. The change of "tax" (the cumulative deviation of tax from the baseline scenario) is 16.4%. This change comes from the construction of the hydropower station and related development of transportation in the constructional period, selling the hydroelectricity in the operational period and the related change of output in other sectors with target investment during the operational period. So we get $gdp$ = 99.9+16.4 = 116.3, which is very close to the simulation result of 114.

Using the above BOTE analysis, we can further decompose the project region's real GDP increase relative to the baseline scenario.

- The increase in the aggregate employment as a result of the construction of the hydropower station and also the related expansion in other sectors has contributed 11.7% to the region's GDP increase.
- There is increased capital stock due to massive investments in the hydroelectricity sector and in the transportation and other sectors. By the end of the simulation period, the contribution of capital to the region's GDP increase is 19.7%.
- We assume that massive investments result in technological improvement (technology refers the input requirements per unit of output). This is particularly the case in the hydropower sector. Technological improvements contribute 54.5% to the region's overall long-term GDP increase.
- Increased economic activity results in increased indirect and production tax revenues. These taxes contribute 14.1% to the project region's long-term GDP increase.