The Economic Impact of Shale Gas Production in the U.S.

A thesis

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ABSTRACT

Energy is important to our daily lives. A price change of one energy type may influence our consumption choices, commodities prices and industry production. For the United States, shale gas is becoming a promising source of natural gas because of the rapid increase in its reserve and production capacity. Shale gas production is projected to be a large proportion of U.S. gas production, as predicted by Energy Information Administration (EIA). However, besides knowing the big picture, more details are needed before characterizing shale gas as a "game changer." It is interesting to address questions like to what extent the production of shale gas could affect other industries' production, stabilize commodities' prices, and what are the impacts on factor payments, capital returns, labor payments and household consumption. In this study, I use a CGE model to measure the impact on industry and the change in social welfare associated with shale gas production.

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Yang Yang

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The Economics Impact of Shale Gas Production in the U.S.

1. Introduction

Energy is closely related to our daily lives. Nowadays, energy is a substantial factor in economic growth, GDP, commodity prices, and interest rates. Almost every industry needs energy for production. The price change of one energy type may influence the supply, price, industrial production behavior and household consumption of other energy types.

The major types of primary energy include coal, oil, and natural gas. Coal usage was promoted by rapid industrialization of the economy, urbanization, and the growth of railroads in the 18th century. Coal has been dominant in history in the United States until it was surpassed in turn by both petroleum and natural gas in 1950s. The emergence of the automobile makes petroleum become the preeminent energy source for the US. At the same time, natural gas, as a cleaner-burning and more easily transportable, has replaced coal as the source of heating in home and industrial furnaces.

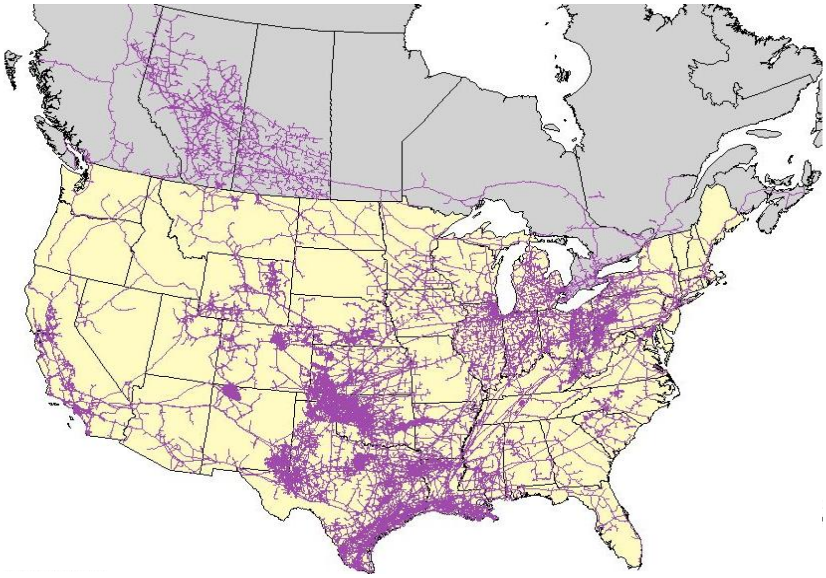


Figure 1 US/Canada Natural Gas Pipeline System (Source: MAPSearch)

Unlike petroleum, natural gas is a regional traded energy because of the limitation of transportation. a fully functional natural gas market requires multiple sources of supply, user and comprehensive infrastructure for transmission and distribution. Today both US and Europe have highly developed natural gas markets. European mainly imports oil and natural gas from Russia. In 2007, the European Union imported 100.7 million tons of oil equivalents of natural gas, which accounted 38.7 percent of total gas import. To ensure the EU's primary energy supplies, they lower imports concentrated among relatively few partners and choose a more diversified partner portfolio accordingly: from 2007 and 2010, Russia's share of EU-27 imports of natural gas declined from 38.7 percent to 31.8 percent, while Qatar's share rose from less than 1 percent to 8.6 percent.

Contrast to European Union strategy, US aims at reducing exposure to terrorism abroad and eliminating the reliance on energy purchased from outside the continent. Now more oil is imported from Canada than any other country. To reduce the North America's energy dependence on unstable regions such as the Middle East and South America, North American Energy Security policy is established. US mainly imports natural gas from Canada and Mexico. As in the figure above, Canada accounted for 60 percent of pipeline natural gas 80.7 million tons of oil equivalent of natural gas, and Mexico 40 percent. Between 1990 and 2008, import pipeline capacity from Canada increased by 181 percent.[1] These pipeline infrastructures have been proved to be costly. As a result, it requires mass importation of natural gas to reduce the average cost and thus make the importation plan profitable. For the United States, shale gas resources are large and located near demand a center, which triggers people's interest to utilization this new gas source. Shale gas production is projected to be a large proportion of U.S. gas production, as predicted by the

Energy Information Agency (EIA). By 2035 it will account for 50 percent of total US gas production. As a result, shale gas is considered as a promising source of natural gas because of the rapid increase in productive reserves and production capacity.

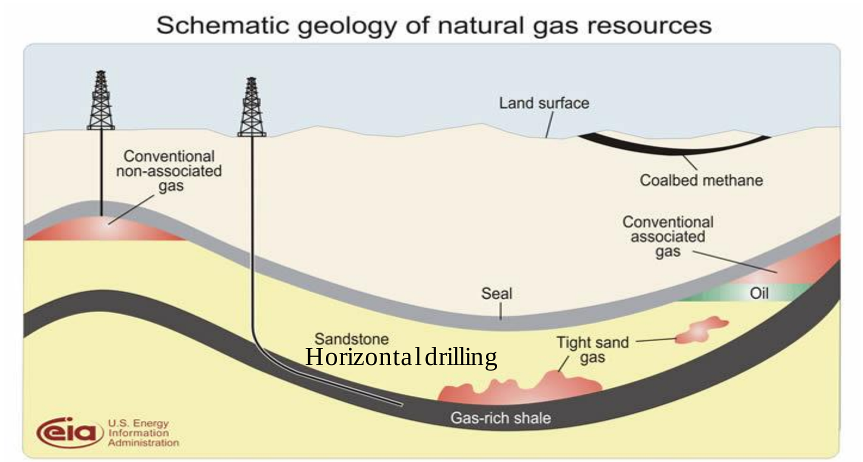


Figure 2 Illustration of shale gas compared to other types of gas deposits (Source: EIA)

The history of shale gas exploration can be traced back to 1821 when it was first extracted at a low-pressure fracture. Because shale has insufficient permeability to allow significant fluid flow to a well bore, shale gas was not commercial sources of natural gas. One hundred years later, from 1930s, horizontal drilling was first fracked in the U.S. however, on industrial-scale shale gas production had not been pay attention until conventional gas deposits decline in 1970s. After that, the United States federal government to invested in R&D to develop new extraction technologies, still it was not considered to be commercially viable by then. Only in recent years, has shale gas become a new source of commercial energy, as a consequence of the development of hydraulic fracturing technology and horizontal drilling. Unlike the conventional vertical, the horizontal drilling can drill lateral within the shale which creates maximum borehole surface area in contact with the shale. The modern hydraulic fracturing creates extensive artificial fractures around well bores and provides permeability to shale.

Despite all these efforts on shale gas production and its importance, most current analysis only addresses the change in production cost and how the productivity will drive down gas prices. However, besides knowing the big picture, more details are required before characterizing shale gas as a ‘game changer’ for energy markets.

The Computable general equilibrium model (CGE) provides a rich appropriate analytical approach to address issues such as (a) to what extent the exploration of shale gas could affect other industries’ production, stabilize commodities’ price and (b) what are the impacts on factor payments, capital return, labor payments and household consumption.

This study addresses two main aspects concerning the impact of shale gas production. First, the model measures other industry changes besides the gas industry. Second, the social welfare associated with shale gas production is assessed in the same frame, capturing the real production and consumption behaviors together with the substitution relationship between factor and commodity input.

Section 2 reviews related studies on the effects of an energy shock and introduces different ways to set up a CGE model. Section 3 discusses the static CGE model’s definition and analytical framework. Section 4 presents the data and the equilibrium model. Section 5 describes the scenario setting and analyzes the impact of shale gas production. Section 6 implements possible improvement of this model and discusses corresponding result. Section 7 summarizes the conclusion.

2. Literature review

2.1 Methodological review

Empirical studies of energy markets typically use two different techniques to quantitatively analyze of oil shocks: macro-econometric and equilibrium modeling. Prior researchers studying the economic reaction to energy shock usually use macro-econometric and equilibrium modeling methods.

For example, Bernanke (2004) and Hamilton(2003) have separately employed the vector auto-regression (VAR) to model the oil price shock impact from the aspect of impulse-response. In their study, one result found is that a 10 percent increase in the oil price would result in a 0.5 percent slower real GDP growth rate and a 0.4 percent higher GDP deflator.

The advantage of macro-econometrics modeling is that studies can take into account macroeconomic behavioral interactions for several periods by using lags. However, macro models do not capture sectoral effects and inter-sectoral effects. In contrast, equilibrium is based on firm micro production and household consumption behavior that optimize their own utility or profit with substitution of different intermediate commodities allowed. Since the energy supply cannot be expected to exert the same impact on the entire economy, applying macro-econometric modeling using a behavioral index as a representative agent would miss these microeconomics effects.

2.2 Partial equilibrium and general equilibrium

In equilibrium models, general equilibrium studies a number of economic variable, their inter relation and inter dependencies for understanding the economic system; the partial equilibrium studies equilibrium of only a part of the market, as studying one market in isolation keeping all the other market constant. For example, the supply and demand model is a partial equilibrium model where the prices of all substitutes and complements, as well as income levels of consumers are constant. Partial equilibrium analysis examines the effects of an action in creating equilibrium only in that particular sector or market which is directly affected, ignoring its effect in any other market or industry assuming that they being small will have little impact. In contrast, general equilibrium analysis extends to multiple markets simultaneously. While theoretically demanding, it helps us to recognize explicitly, for example, a policy intervention in one sector in fact can impact the entire system, perhaps having unintended consequences elsewhere. If the market is small partial equilibrium may be sufficient. However, since energy market is interrelated with many other markets and thus those other market may be affected by a natural gas change at the same time. Ignoring the impact of changes in natural gas market on other could be seriously misleading. I use the general equilibrium in this study.

2.3 CGE model in prior studies

The first general equilibrium models employed to study government policy started with two or three sectors. Currently, researchers usually divide the economy into more sectors. Other studies focusing on the changes in spending patterns typically include different consumption preferences specifying different income levels. In 1978, Hudson and Jorgenson used an integration of econometric modeling and input-output analysis to assess the impact of a tax program on the US economy. Their model consisted of production models for nine industrial sectors and began to consider the possibility of substituting other factors for energy as the relative commodity prices changed. Bergman (1991) used a static

CGE model with forty-five sectors and four types of inter-sectoral factors to simulate the impact of reductions of CO_2 on factor prices and emissions.

Due to the heavy computational work required, CGE models with multiple periods were not well developed until the 1980s. Goulder (1982) and Jorgenson and Wilcoxen (1990) started to use dynamic CGE models to study policy effects over time. Goulder (1982) developed a nine sectors model of the United States, five energy producing sectors and eighteen consumer goods. These sectors are connected to nine producer goods through a fixed-coefficient conversion matrix with differentiating current and future consumption. Hogan and Naughten (1990) used ORANI (Dixon et al., 1982), a large multi-sectoral dynamic model of 112 industrial sectors, to study the economy-wide effects of a 15 percent decline in production of crude oil in Australia. In this dynamic model, economic growth is mainly driven by the increase of production factors. Doroodian and Boyd (2003) studied the relation between oil price shocks in 1974 and inflation in the presence of technological advances in the US. Their model not only incorporates the effects of technology but also allows them to study the effects of technology dynamically.

Oil is an internationally traded good. Previous research on oil issues usually assumes the object economy as an open economy. Loisel (2009) used a dynamic CGE model to simulate the CO_2 market in Romania. In that paper, Loisel assumed an imperfect substitution of imported energy resources for domestic ones; he did so because there is a comparative advantage between the home country and world due to different carbon constraints. However, Loisel fixed the world price while Romania is modeled as a small open economy. Since the US is not a small country, this paper's model will imbed a demand function of the agent of the rest of the world to determine the world price of traded commodities.

Abdelbasset and Hajeeh (2010) studied the effects of oil volatility on the Kuwait oil-based economy. They found that the introduction of the value added tax on non-oil activities does not generate a significant increase in government revenues based on a static CGE model. Since Kuwait is a small country, the authors set exogenous import and export prices. In addition, they assumed that international supplies are infinitely elasticity at given world prices that can meet the derived demands for imported commodities. Facing a similar problem, the model in this paper also takes the rest of the world's supply as infinitely elastic.

Wang (2009) built a single country open economy CGE model TDGE_CHN for China with the international trade treatment following the work of Wing (2003). They both assume that export demands and import supplies are exogenous. They modeled the production sectors by exogenously determining how much to allocate to the domestic market and how much to export. Aydın and Acar (2011) also analyzed the potential long-term effects of an oil price shock for Turkey based on a recursive dynamic mechanism. Their model is based on ORANI, in which the dynamic structure is replicated T times by indexing all variables in the model with respect to time. They assumed Turkey is a small, open oil- and gas-importing country. From a macro perspective, their results show that the adverse economic impact of high oil prices on oil-importing developing countries is generally more severe than the impact on developed countries.

3. Model

In this paper, I choose to use a static model, which is sufficient to assess the effects of shale gas production. This model does not use the Armington assumptions or the assumption of constant elasticity of transformation (CET); instead, it assumes all imports, exports and domestic commodities are perfect substitutes. I solve the CGE model in the programming environment of GAMS. Using Mixed Complementarity Programming (MCP) as a path. Thus the local optimal result can be obtained.

3.1 Variable and parameter definitions

Variables of the model are defined in Table 1 and parameter definitions in Table 2.

Table 1 Variable definition

p_i	World and domestic price of commodity i, i={1,…,N}
w_f	Price of factor f, f={1, …,F}
$R_{NS,j}$	Price of combined factor NS for producing different commodities j
$R_{VA,j}$	Price of combined factor VA for producing different commodities j
R_a	Price of primary factor a, f={1, a} (here use capitalized R to avoid confusion between r with Gama)
$x_{i,j}$	Use of commodity i as intermediate input to output j. i={1,…,N}; j={1,…,N}
VA_j	Final combination factor into output j, j={1,…,N}
$v_{f,j}$	Use of factor input of f in industry j, f={1,……F}
$v_{NS,j}$	Use of natural resource and shale gas combination factor NS in industry j
$v_{a,NS}$	Use of primary factor a to produce NS, a={1,2}
$h_{a,NS,j}$	Input of primary factor a to produce $v_{NS,j}$, a={1,2}
$g_{i,C}$	Quantity of commodity i used by final demand activity c, g $_{i,c}$ indicates the level of expenditure on commodity i for consumption
V_f	Total input of primary factor f, $V_f = \sum_{j=1}^{N} v_{f,j}$, f={1,……F}

V_{NS}	Total input of combination factor f, $V_{NS} = \sum_{j=1}^{N} v_{NS,j}$
$H_{a,NS}$	Total input of primary factor a to produce NS, a={1,2}, representing natural resource and shale gas
y_j	Output by sector j, j={1,…,N}
B	Trade balance
u	Utility, also indicates the representative agent’s level of utility
μ	Agent’s deposable income, which is total factor income of factors less savings plus trade balance
θ	Unit expenditure index, which can be interpreted as the marginal utility of aggregate consumption
π_j	Profit for individual sector j, when producing output y_j, j={1,…,N}
$\hat{x}_{i,j}$	Unit input demand of producer j for intermediate commodity i, i={1,…,N}; j={1,…,N}
$\hat{v}_{f,j}$	Unit input demand of producer j for primary factor f, f={1,……F}; j={1,…,N}
$\hat{v}_{NS,j}$	Unit input demand of producer j for combination factor NS, j={1,…,N}
$\hat{h}_{a,NS,j}$	Unit input demand of producer j for primary factor a, a={1,2}; j={1,…,N}
$\hat{g}_{i,C}$	Unit consumption demand for commodity i, i={1,…,N}

Table 2 Parameter definition

η_j	Technical coefficients on factor combination VA to produce commodity j, j={j,…,N}
α_i	Technical coefficients of the utility function for consumption of good i, i={i,…,N}
$\beta_{i,j}$	Technical coefficients on intermediate commodity i in the production of commodity j, j={j,…,N}
$\gamma_{f,j}$	Technical coefficients on primary factor f in the production of commodity j, j={j,…,N}
$\gamma_{NS,j}$	Technical coefficients on combination factor NS in the production of commodity j, j={j,…,N}
$\phi_{a,NS,j}$	Technical coefficients on primary factor a to produce $v_{NS,j}$, j={j,…,N}
ω	Elasticity of substitution between different goods for representative agent
σ_j	Elasticity of substitution of the second tier factors to produce $\gamma_{f,j}$, j={ j,…,N}
$\sigma_{NS,j}$	Elasticity of substitution of the third tire factors to produce $\gamma_{NS,j}$, j={ j,…,N} $\sigma_{NS,j}$ is only set to a large value in natural gas production
σ_{NS}	Elasticity of substitution to produce NS, j={ j,…,N}
m_{i_im}	Coefficient of demand function from the rest of the world on commodity i, i={i,…,N}

m_{i_ex}	Coefficient of supply function to the rest of the world on commodity i, i={i,…,N}
ε_i	Demand price elasticity from the rest of the world on commodity i, i={i,…,N}
$-\varepsilon_i$	Supply price elasticity from the rest of the world on commodity i, i={i,…,N}

3.2 Household behavior

The demand for the consumption of each commodity i is found by maximizing a representative household's utility. Three assumptions are made to capture the household consumption behavior. First, the household acts as a single representative agent who supplies their factors F to firms and receives income μ . Second, there are no tax or subsidy distortions or quantitative restrictions on transactions. Third, savings are assumed to be equal to investment.

The household representative agent has a deposable income of μ , which is the income of all factors minus savings.

$$\mu = \sum_{f=1}^{F} w_f V_f + B \tag{1}$$

The representative agent has CES utility function:

$$u = [\sum_{i=1}^{N} \alpha_i g_{i,C}{}^{(\omega-1)/\omega}]^{\omega/(\omega-1)}$$

The household agent maximizes utility, subject to their budget constraint

$$\max_{g_{i,C}} \; u[g_{1,C}, \cdots\cdots \mathrm{g}_{N,C}] \tag{2}$$

$$s.t.\ \mu = \sum_{i=1}^{N} P_i g_{i,C}$$

Instead of solving (2) directly, the concept of duality is employed to find the compensated demands. The agent minimizes the expenditure that guarantees one unit of utility, by choosing the levels of commodity $\hat{g}_{i,C}$.

$$\theta = \min_{\hat{g}_{i,C}} \sum_{i=1}^{N} p_i \hat{g}_{i,C} \qquad (2')$$

$$s.t.\ 1 = [\sum_{i=1}^{N} \alpha_i \hat{g}_{i,C}{}^{(\omega-1)/\omega}]^{\omega/(\omega-1)}$$

Thus, the agent solves their demand for commodity i for consumption to satisfy their one unit demand conditional on utility $\hat{g}_{i,C} = \alpha^{\omega} \theta^{\omega} p_i^{-\omega}$. Substituting it into (2') results in

$$\theta = (\sum_{i=1}^{N} \alpha_i^{\omega} p_i^{1-\omega})^{\frac{1}{(1-\omega)}}$$

Thus, the final solution for final demand is solved in terms of the vector of μ units of consumption utility:

$$g_{i,C} = \hat{g}_{i,C} u = \alpha_i^{\omega} \theta^{\omega} p_i^{-\omega} u \qquad (3)$$

3.3 Producers behavior

Each industry is assumed to behave as a representative firm to maximize their profit using primary factors aggregate VA_j , with a second tier of natural resource and shale gas combination V_{NS} , and commodities as intermediate inputs.

$$\max_{x_{i,j},VA_j} \pi_j = p_j y_j - \sum_{i=1}^{N} p_i x_{i,j} - R_{VA} VA_j \qquad (4)$$

The three tiers of production function as shown in figure 1.

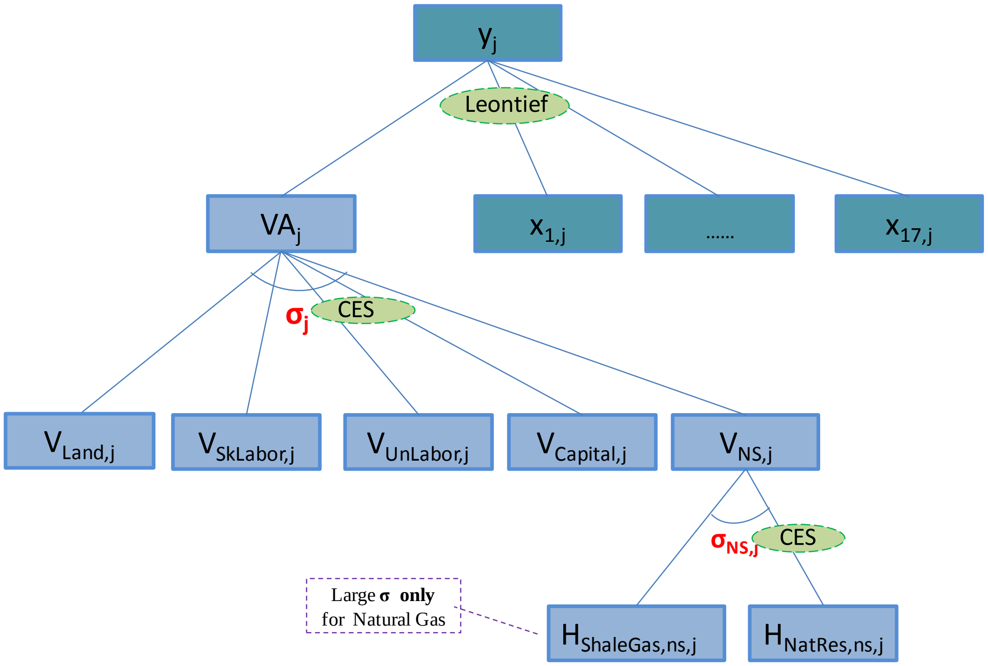


Figure 3 Traditional production structure

The *j*th producer's problem is to maximize profit (π_j) by choosing intermediate inputs ($x_{i,j}$) and aggregated factor VA_j to produce output (y_j).

VA_j consists of primary factors ($v_{f,j}$) and factor $v_{NS,j}$. The intermediate inputs' price follows the prevailing market prices of output (p_j), primary factors' price (w_f) and the price of R_{NS}. This paper assumes the production function takes a three tiers form.

The first tier is a Leontief production function:

$$y_j = \{\frac{x_{1j}}{\beta_{1j}}, \frac{x_{2j}}{\beta_{2j}}, \cdots\cdots \frac{x_{17j}}{\beta_{17j}}, \frac{VA_j}{\eta_j}\} \text{ where } VA_j = \eta_j y_j,\ \ x_{i,j} = \beta_{i,j} y_j$$

The second-tier is a Constant Elasticity of Substitution (CES) production function of factor combination:

$$VA_j = [\sum_{f=1}^{F} \gamma_{f,j} v_{f,j}{}^{(\sigma_j-1)/\sigma_j} + \gamma_{NS,j} v_{NS,j}{}^{(\sigma_j-1)/\sigma_j}]^{\sigma_j/(\sigma_j-1)}$$

The third-tier is a CES production function of the combination of natural resources and shale gas, where a large elasticity of substitution is set only for natural gas production.

$$v_{NS,j} = [\sum_{a=1}^{A} \phi_{a,NS,j} h_{a,NS,j}{}^{(\sigma_{NS,j}-1)/\sigma_{NS,j}}]^{\sigma_{NS,j}/(\sigma_{NS,j}-1)}$$

Based on the second-tier production function, the conditional factor demands are obtained.

$$v_{f,j} = \gamma_{f,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} VA_j = \eta_j \gamma_{f,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} y_j$$

Similarly, for the combined factor NS, the conditional demands equal:

$$v_{NS,j} = \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} VA_j = \eta_j \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} y_j$$

Then, consider the third-tier production function of the combination of natural resource and shale gas:

$$h_{a,NS,j} = \phi_{a,j}{}^{\sigma_{NS,j}} R_{NS}{}^{\sigma_{NS,j}} Ra^{-\sigma_{NS,j}} v_{NS,j} = \phi_{a,j}{}^{\sigma_{NS,j}} R_{NS}{}^{\sigma_{NS,j}} Ra^{-\sigma_{NS,j}} \cdot \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} VA_j$$

Thus unit demand can be expressed as below:

$$\hat{x}_{i,j} = \beta_{i,j} \tag{5}$$

$$\hat{VA}_j = \eta_j \tag{6}$$

$$\hat{v}_{f,j} = \eta_j \gamma_{f,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} \tag{7}$$

$$\hat{h}_{a,NS,j} = \eta_j \phi_{a,j}{}^{\sigma_{NS}} R_{NS}{}^{\sigma_{NS}} Ra^{-\sigma_{NS}} \cdot \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} \tag{8}$$

Following the duality property, firm *j* seeks to minimize its unit (y_i) cost by choosing the level of the unit input demands for commodities ($\hat{x}_{i,j}$) and the aggregated factor ($\hat{V}A_j$), subject to the constraint of its production technology. In sum, the unit input of intermediate commodities and factors as:

$$p_j = \min_{\hat{x}_{i,j}\hat{V}A_j} \sum_{i=1}^{N} p_i \hat{x}_{i,j} + R_{VA,j}\hat{V}A_j \qquad (4')$$

$$s.t.\ 1 = \{\frac{\hat{x}_{1j}}{\beta_{1j}}, \frac{\hat{x}_{2j}}{\beta_{2j}}, \cdots\cdots \frac{\hat{x}_{17j}}{\beta_{17j}}, \frac{\hat{V}A_j}{\eta_j}\}$$

Substituting $\hat{x}_{i,j}$, $\hat{v}_{f,j}$, $\hat{v}_{NS,j}$ into (8'), the price of commodity j under equilibrium can be obtained.

$$p_j = \sum_{i=1}^{N} p_i \hat{x}_{i,j} + R_{VA,j}\hat{v}_{VA,j}$$

$$p_j = \sum_{i=1}^{N} p_i \beta_{i,j} + R_{VA,j}\eta_j \qquad (13.a)$$

Moreover, the relationship between aggregated factor prices and primary factor prices can be obtained by solving

$$R_{NS,j} = \min_{\hat{h}_{a,NS,j}} \sum_{a=1}^{A} R_a \hat{h}_{a,NS,j}$$

$$s.t.\ \ 1 = [\sum_{a=1}^{A} \phi_{a,j} \hat{h}_{a,j}^{\ (\sigma_{NS,j}-1)/\sigma_{NS,j}}]^{\sigma_{NS,j}/(\sigma_{NS,j}-1)}$$

$$\hat{h}_{a,NS,j} = \phi_{a,NS,j}^{\ \ \sigma_{NS,j}} R_{NS,j}^{\ \ \sigma_{NS,j}} Ra^{-\sigma_{NS,j}}$$

$$R_{NS,j} = \sum_{a=1}^{A} R_a \cdot \phi_{a,NS,j}^{\ \ \sigma_{NS,j}} R_{NS,j}^{\ \ \sigma_{NS,j}} Ra^{-\sigma_{NS,j}}$$

Therefore, the price of combined factor can be expressed as:

$$R_{NS,j} = (\sum_{a=1}^{A} \phi_{a,NS,j}{}^{\sigma_{NS,j}} Ra^{1-\sigma_{NS,j}})^{\frac{1}{(1-\sigma_{NS,j})}} \tag{13.c}$$

Similarly, the price of factor VA, $R_{VA,j}$ can be derived from the minimization program

$$R_{VA,j} = \min_{\hat{v}_{NS,VA,j}, \hat{v}_{f,VA,j}} \sum_{f=1}^{F} w_f \hat{v}_{f,VA,j} + R_{NS} \hat{v}_{NS,VA,j}$$

$$s.t.\ \ 1 = [\sum_{f=1}^{F} \gamma_{f,j} \hat{v}_{f,j}{}^{(\sigma_j-1)/\sigma_j} + \gamma_{NS,j} \hat{v}_{NS,j}{}^{(\sigma_j-1)/\sigma_j}]^{\sigma_j/(\sigma_j-1)}$$

yielding factor demand aggregates

$$\hat{v}_{f,VA} = \gamma_{f,VA}{}^{\sigma_{VA,j}} R_{VA,j}{}^{\sigma_{VA,j}} w_f{}^{-\sigma_{VA,j}}$$
$$\hat{v}_{NS,VA} = \gamma_{NS,VA}{}^{\sigma_{VA,j}} R_{VA,j}{}^{\sigma_{VA,j}} R_{NS}{}^{-\sigma_{VA,j}}$$

$$R_{VA,j} = \sum_{f=1}^{F} w_f \gamma_{f,VA,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} + R_{NS,j} \gamma_{NS,VA,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS,j}{}^{-\sigma_j}$$

The price of combined factor can be expressed as:

$$R_{VA,j} = (\sum_{f=1}^{F} \gamma_{f,j}{}^{\sigma_j} w_f{}^{1-\sigma_j} + \gamma_{NS,j}{}^{\sigma_j} R_{NS}{}^{1-\sigma_j})^{\frac{1}{1-\sigma_j}} \tag{13.d}$$

3.4 Equation definition

First, commodity market clearing implies that the gross output of industry i, which is also the domestic aggregate supply of the ith commodity (y_i) plus the net import of the same intermediate commodity from the rest of the world, must equal to the sum of the j intermediate demand ($x_{i,j}$) plus the final demands ($g_{i,C}$) which absorb that commodity. That is

$$y_i + S_i^{ROW} = D_i^{ROW} + \sum_{j=1}^{N} x_{i,j} + g_{i,C} \tag{9}$$

In the international trade market, supply and demand are in form of world market price p_i to the power of its elasticity:

$$S_i^{ROW} = m_{i\_im} \cdot p_i^{\varepsilon_i}$$

$$D_i^{ROW} = m_{i\_ex} \cdot p_i^{-\varepsilon_i}$$

Similarly, factor market clearing implies that the sum of a firm's individual demand on primary factor ($v_{f,j}$) fully untilizes the representative agent's endowment (V_f).

$$V_f = \sum_{j=1}^{N} v_{f,j} \tag{10}$$

This indicates the primary factors' market clearing requires that

$$V_f = \sum_{j=1}^{N} \gamma_{f,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} \eta_j y_j \tag{13.e}$$

and factor NS's market clearing implies that

$$V_{NS} = \sum_{j=1}^{N} v_{NS,j} \tag{10'}$$

$$V_{NS} = \sum_{j=1}^{N} \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS,j}{}^{-\sigma_j} \eta_j y_j$$

For primary factor natural resource and shale gas market clearing:

$$H_{a,NS} = \sum_{j=1}^{N} h_{a,NS,j} = \sum_{j=1}^{N} \hat{h}_{a,NS,j} y_j$$

$$H_{a,NS} = \sum_{j=1}^{N} \phi_{a,j}{}^{\sigma_{NS}} R_{NS,j}{}^{\sigma_{NS}} Ra^{-\sigma_{NS}} \cdot \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS,j}{}^{-\sigma_j} \cdot \eta_j y_j \tag{13.f}$$

The zero profit condition implies that the value of the unit output *j* sector (p_j) must equal the sum of the weighted value of unit inputs i variety of intermediate good $\hat{x}_{ij}$ and unit value primary factors:

$$p_j = \sum_{i=1}^{N} p_i \hat{x}_{i,j} + R_{VA} \hat{v}_{VA,j} \qquad (11)$$

The representative agent's deposable income μ is made up of the receipts from the rental of primary factors, all of which are assumed to be fully employed, plus the trade balance. The agent's gross expenditure on commodity demands must equal factor income plus the value of the trade balance. Together, these conditions imply that income is equivalent to the sum of the value of the elements of V plus the trade balance B, which in turn must equal the sum of the value of all elements in spending.

$$\mu - \left(\sum_{f=1}^{F} w_f V_f + \sum_{a=1}^{A} R_a H_{a,NS} + B\right) = 0 \qquad (12)$$

4. Data

4.1 Social Accounting Matrix

This study uses the Global Trade Analysis Project (GTAP) as the database to build the social accounting matrix (SAM). SAM is an array of input-output accounts. The value in all the cells is denominated in the units of value of the period for which the flows in the economy are recorded, typically in the currency for the benchmark year. The element in each cell records the value transferred from row i to column j. Thus the value of receipts from the sale of a commodity i appears in row i of the component i and the expenditure of an input i to a produce j appears down its column j.

Figure 3 demonstrates the data structure in a Social Accounting Matrix (SAM). The sum of any row in the upper quadrants $\overline{\mathrm{X}}$ and $\overline{\mathrm{G}}$ is equivalent to the expression for goods market clearing in the form of equation (9), and the sum across any row in V is equivalent to the expressions for factor market clearing from equation (10). Likewise, the sum down any column of the $\overline{\mathrm{X}}$ and $\overline{\mathrm{V}}$ is equivalent to the expression for zero-profits in industries from equation (11). Once this condition holds, the sums of the elements of $\overline{\mathrm{G}}$ and $\overline{\mathrm{V}}$ respectively should equal one another, which is equivalent to the income balance relationship from equation (12).

$\overline{X}$: $\mathrm{N}\times\mathrm{N}$ input-output matrix of industries' uses of domestic commodities as intermediate inputs

$\overline{V}$: $\mathrm{F}\times\mathrm{N}$ matrix of primary factor inputs to industries

$\overline{IM}$: $\mathrm{N}\times\mathrm{N}$ input-output matrix of industries' uses of domestic commodities as intermediate inputs

$\overline{G}$: $\mathrm{N}\times 1$ matrix of domestic commodity uses by final consumption demand activities

$\overline{G'}$: $\mathrm{N}\times 1$ matrix of imported commodity uses by final consumption demand activities

$\overline{EX}$: $\mathrm{N}\times 1$ matrix of domestic produced commodity exported to the rest of the world

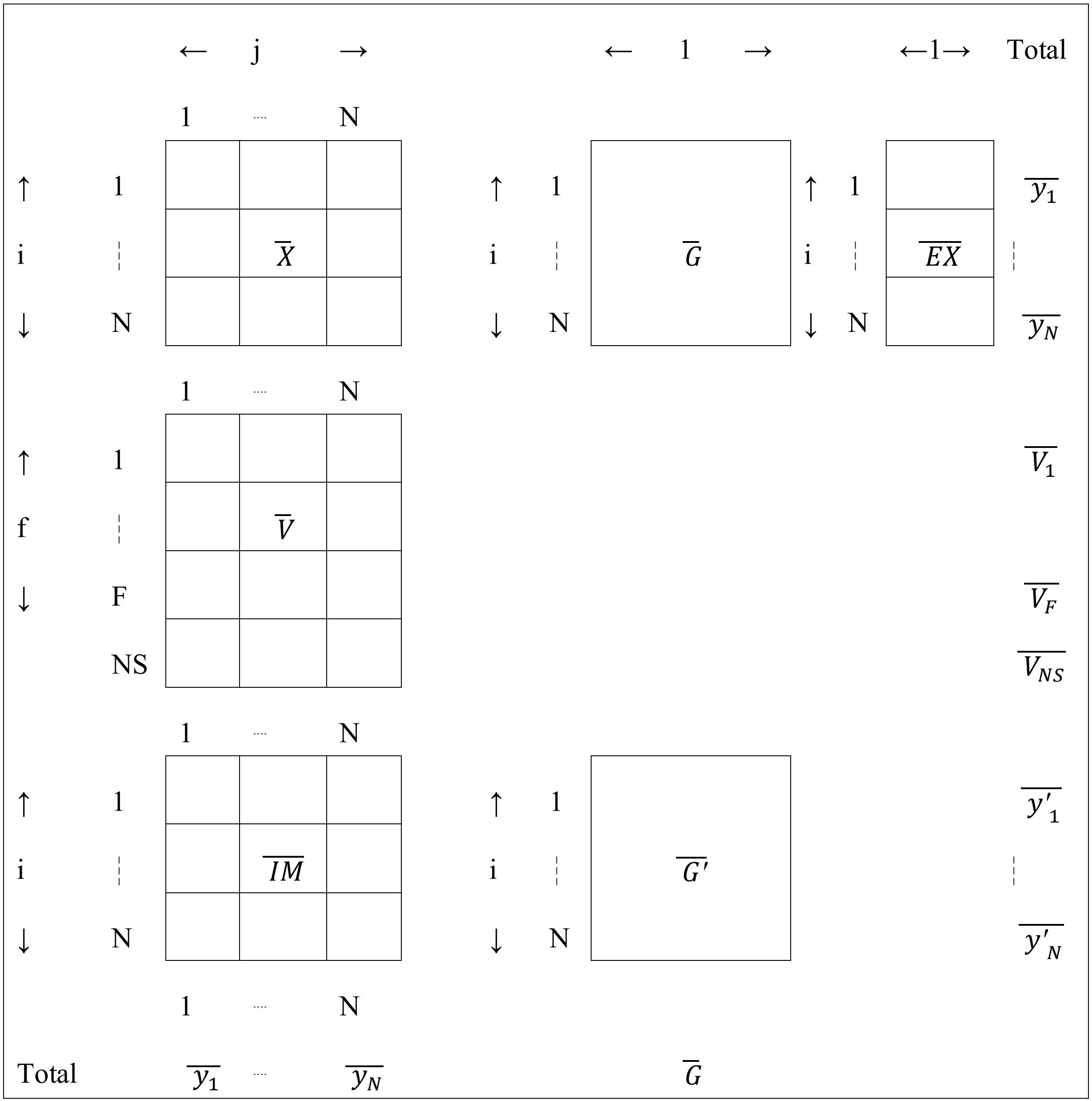


Figure 4 A social accounting matrix

4.2 General equilibrium

Keeping consistent with the circular flow in the SAM , substitute the answer of (3), (5), (6), (7) and (8) into (9)-(12), and then equations (9)-(12) may be expanded to resolve prices and quantities and yield the conditions for market clearing for goods and factors: zero profit for industries, and income balance for the representative agent. Similarly, inducing utility as a good within the equilibrium framework enables the specification of a market clearing condition for utility.

$$y_i + S_i^{ROW} = D_i^{ROW} + \sum_{j=1}^{N} \beta_{i,j} y_j + \alpha_i^{\omega} \theta^{\omega} p_i^{-\omega} u \qquad (13.g)$$

$$V_f = \sum_{j=1}^{N} v_{f,j} \qquad (10')$$

$$H_a = \sum_{j=1}^{N} h_{a,NS,j} \qquad (10'')$$

$$p_j = \sum_{i=1}^{N} p_i \beta_{i,j} + R_{VA,j} \hat{V}A_j \qquad (11')$$

$$u - \mu / \theta = 0 \qquad (13.h)$$

$$\mu - (\sum_{f=1}^{F} w_f V_f + \sum_{a=1}^{A} R_a H_a + B) = 0 \qquad (13.i)$$

Besides market clearing for non-traded goods, traded goods are handled by a foreign agent in the form of international trade. Unlike Armington (1969), foreign-products and domestic goods are assumed as perfectly substitutes.

4.3 The CGE model in a complementarity format

After substituting (5)-(8), the algebraic system function 13 can be obtain. This system follows the mathematical statement of Walras' Law, which defines the pseudo-excess demand correspondence of the economy:

$$\Xi_{(z)} \geq 0, z \geq 0, z' \Xi_{(z)} = 0$$

Where Ξ= {$\mathbf{P}$, θ, $\mathbf{y}$, $\mathbf{V}$, u, μ, B, R, R_{VA}, R_{NS}}' is the stacked vector of 2N+F+A+6 equations and $\mathbf{z}$= {$\mathbf{y}$, u, $\mathbf{p}$, $\mathbf{w}$, q, μ, B, R, R_{VA}, R_{NS}} is the 2N+F+A+6 vectors of unknowns:

1. N+1 zero profit inequalities {$\mathbf{p}$, θ} in as many unknowns {$\mathbf{y}$, u},

2. N+F+A+1 market clearance inequalities {$\mathbf{y}$, $\boldsymbol{V}$, R, u} as many unknowns {$\mathbf{p}$, $\mathbf{w}$, R_a, θ}

3. A single income balance equation (μ) in a single unknown (μ)

4. A single trade balance equation with a single unknown trade balance B (spend on imported)

4. Two price equation for combined factor with two set of unknown price {$\mathbf{R}_{VA}$, $\mathbf{R}_{NS}$}

According to Walras' Law, its value may be close to zero in model replication.

Henceforth the shorthand notation '$\perp$' is used to denote the complementary slackness relationship exhibited by the model's equations and its associated variables, writing (13) compactly as: $\Xi_{(z)} \geq 0 \perp z$

Since all of the variables are assume greater than zero, the final equations of the model are reported in Table 3.

Table 3 Equations of the Theoretical CGE Model

Equations of the Theoretical CGE Model	#Unknown Variable	#Equation	
Zero Profit			
$p_j = \sum_{i=1}^{N} p_i \beta_{i,j} + R_{VA,j} \eta_j$	y(i)	N=17	13.a
$\theta = (\sum_{i=1}^{N} \alpha_i{}^{\omega} p_i{}^{1-\omega})^{\frac{1}{(1-\omega)}}$	θ	1	13.b
Zero Profit for Intermediate factor			
$R_{NS,j} = (\sum_{a=1}^{A} \phi_{a,NS,j}{}^{\sigma_{NS,j}} Ra^{1-\sigma_{NS,j}})^{\frac{1}{(1-\sigma_{NS,j})}}$	$R_{NS,j}$	N=17	13.c
$R_{VA,j} = (\sum_{f=1}^{F} \gamma_{f,VA,j}{}^{\sigma_j} w_f{}^{1-\sigma_j} + \gamma_{NS,VA,j}{}^{\sigma_j} R_{NS}{}^{1-\sigma_j})^{\frac{1}{1-\sigma_j}}$	$R_{VA,j}$	N=17	13.d
Market Clearance			
$V_f = \sum_{j=1}^{N} \gamma_{f,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} w_f{}^{-\sigma_j} \eta_j y_j$	$w_{(f)}$	F=4	13.e
$H_a = \sum_{j=1}^{N} \eta_j \phi_{a,j}{}^{\sigma_{NS}} R_{NS}{}^{\sigma_{NS}} R_a{}^{-\sigma_{NS}} \cdot R_{VA}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} \gamma_{NS,j}{}^{\sigma_j} \cdot y_j$	$R_{(a)}$	A=2	13.f
$y_i + S_i^{ROW} = D_i^{ROW} + \sum_{j=1}^{N} \beta_{i,j} y_j + \alpha_i^{\omega} \theta^{\omega} p_i{}^{-\omega} u$	$p_{(i)}$	N=17	13.g
$u - \mu / \theta = 0$	U	1	13.h
Income Balance			
$\mu = (\sum_{f=1}^{F} w_f V_f + \sum_{a=1}^{A} R_a H_{a,NS} + B)$	μ	1	13.i

4.4 Data source and calibration

The SAM is constructed from the database of the GTAP. The GTAP8 database represents the world economy in the base year of 2007. Despite the limitation of the underlying heterogeneous input-output table, its modified database enables one to simulate an economic model with a consistent set of economic facts. This SAM is an aggregation of the original GTAP8 with 57 commodities and 129 regions. The regions are finally aggregated to represent the US economy and the rest of the world (ROW). All the data in the SAM are in terms of value. As below, the resulting benchmark flow table is aggregated into 17 sectors to represent the US economy.

Table 4 Database aggregation

Energy	**Energy related industry**	**Non-energy industry**	**Primary factors**	**Final demands**
1.Refinery	5.Energy intensive industry	11. Other industry	Land	Consumption
2.Gas	6.Chemical		Unskilled Labor	Export
3.Coal	7.Vehicles		Skilled Labor	Intermediate input
4.Electric	8.Oil extraction		Capital	
	9.Gas extraction		Natural Resource	
			Shale Gas	
	Energy related service	**Non-energy service**		
	10.Energy related service	12. Other service		
		13. Transport		
		14. Financial		
		15. Trade		
		16. Food		
		17. Housing		

Since this paper does not focus on tax and subsidy effects, I calibrated the SAM according to No Tax Balance, and generally adjusted the final input without indirect taxes equal to the value of output.

In order to use (13.a)-(13.i) to capture the relationships in the IO table, I 'fit' equation 13 to the benchmark equilibrium in the SAM as set forth by Kehoe (1998 p.343) and Wing. Therefore, the price variables are treated as benchmark values of unity: $p_i = w_f = \theta = 1$. The technical coefficients of the consumer's spending functions and the firms' production functions, $\beta_{i,j}$, η_j, $\gamma_{f,j}$, $\gamma_{NS,j}$, $\phi_{a,NS,j}$, $\phi_{a,NS}$, $\gamma_{f,VA}$, $\gamma_{NS,VA}$, are computed according to the elasticity of substitution based on each production procedure, which is obtained from

GTAP8. Therefore, ratios can be obtained through the relevant cells of the SAM to the corresponding total consumer spending and total production output.

$$\beta_{i,j} = x_{i,j} / y_j$$

$$\eta_j = \frac{VA_j}{y_j} = (\frac{all\ \ factor's\ input\ to\ j}{y_j})$$

$$h_{a,NS,j} = \phi_{a,j}{}^{\sigma_{NS,j}} R_{NS}{}^{\sigma_{NS,j}} Ra^{-\sigma_{NS,j}} v_{NS,j} = \phi_{a,j}{}^{\sigma_{NS,j}} R_{NS}{}^{\sigma_{NS,j}} Ra^{-\sigma_{NS,j}} \cdot \gamma_{NS,j}{}^{\sigma_j} R_{VA,j}{}^{\sigma_j} R_{NS}{}^{-\sigma_j} VA_j$$

$$\gamma_{f,j} = (\frac{v_{f,j}}{\eta_j y_j})^{\frac{1}{\sigma_j}}$$

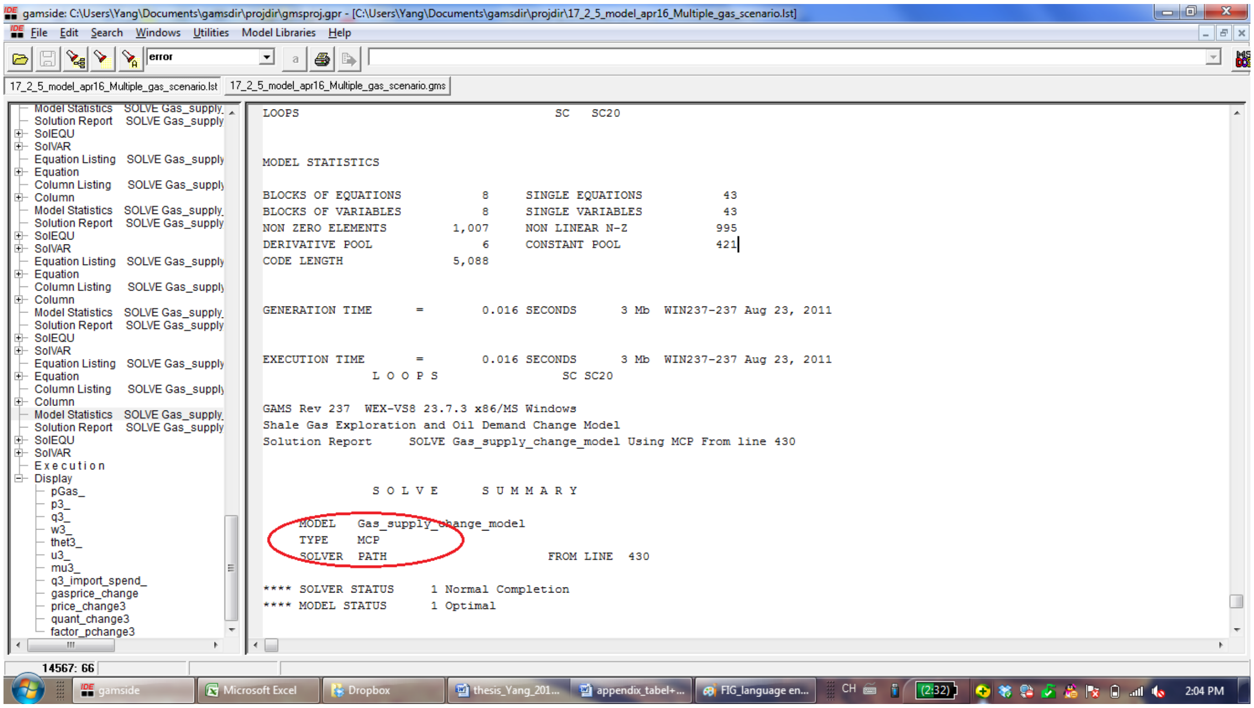
$$\gamma_{NS,j} = (\frac{v_{NS,j}}{\eta_j y_j})^{\frac{1}{\sigma_j}}$$

$$\phi_{a,NS,j} = (\frac{h_{a,NS,j}}{v_{NS,j}})^{\frac{1}{\sigma_{NS,j}}}$$

The elasticities of substitution among inputs to production, σ_j , are the same as given by GTAP. $\sigma_{NS,j}$ is introduced into the scenario case, where it is set to a large value only in natural gas production. ω is assumed to lie within the range observed in other modeling studies (Mckibbin and Wilcoxen, 1998). In this paper, the commodities for consumption are set to be as inelastic substitutes of 0.5. m_{i_im} and m_{i_ex} are determined by the value of the total imported and exported amount of commodity i from the SAM.

Estimates of the demand and supply elasticity with respect to price are obtained from the literature. Cooper (2003) used a multiple regression model to estimate both the short-run and long-run elasticities of crude oil, which is useful in this paper to establish the demand curve of the rest of the world. The other commodities' export and import elasticities from ROW, ε_i , are based on the estimated result in other previous research such as Drusilla (1984).

The model is specified and calibrated in GAMS. Therefore, these non-linear equations can be solved through the PATH solver of the Mixed Complementarity Programming (MCP), as in Figure 3. Finally, the data from SAM and values assumed or determined by the calibration formulas are put into the replication model to ensure that the model is validly built.



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LOOPS                                   SC    SC20


MODEL STATISTICS

BLOCKS OF EQUATIONS           8     SINGLE EQUATIONS           43
BLOCKS OF VARIABLES           8     SINGLE VARIABLES           43
NON ZERO ELEMENTS         1,007     NON LINEAR N-Z            995
DERIVATIVE POOL               6     CONSTANT POOL             421
CODE LENGTH               5,088


GENERATION TIME      =        0.016 SECONDS      3 Mb  WIN237-237 Aug 23, 2011


EXECUTION TIME       =        0.016 SECONDS      3 Mb  WIN237-237 Aug 23, 2011
               L O O P S                          SC SC20

GAMS Rev 237  WEX-VS8 23.7.3 x86/MS Windows
Shale Gas Exploration and Oil Demand Change Model
Solution Report     SOLVE Gas_supply_change_model Using MCP From line 430


               S O L V E      S U M M A R Y

     MODEL   Gas_supply_change_model
     TYPE    MCP
     SOLVER  PATH                           FROM LINE  430

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      1 Optimal
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Figure 5 Programming Language Environment

5. Scenario analysis

5.1 Scenario setting

In the Annual Energy Outlook for 2012, the US Energy Information Administration (EIA) projected that shale production would increase from 23 percent of total US natural gas production in 2010 to 49 percent by 2035. Therefore, I am interested in assessing the effects when the shale gas endowment takes an equivalent of 50 percent of total US natural gas production in the scenario analyzed. Also, in order to allow the production method to match with new available natural resources, the production technology of shale gas-related industries is adjusted accordingly. Thus, the technology coefficients $\eta_j, \gamma_{a,NS,j}, \phi_{a,NS,j}$ are adjusted to match the new factor endowment of shale gas.

5.2 Scenario result

5.2.1 Macro Effects

The representative agent's deposable income will increase by 0.2 percent. As can be seen in Figure 4, the increase of total output is identically equal to the increase of deposable income. The increase in income is reflected in an increase in the representative agent's level of utility by 0.04 percent. From the household perspective, the marginal utility of aggregate consumption will decrease by 0.17 percent.

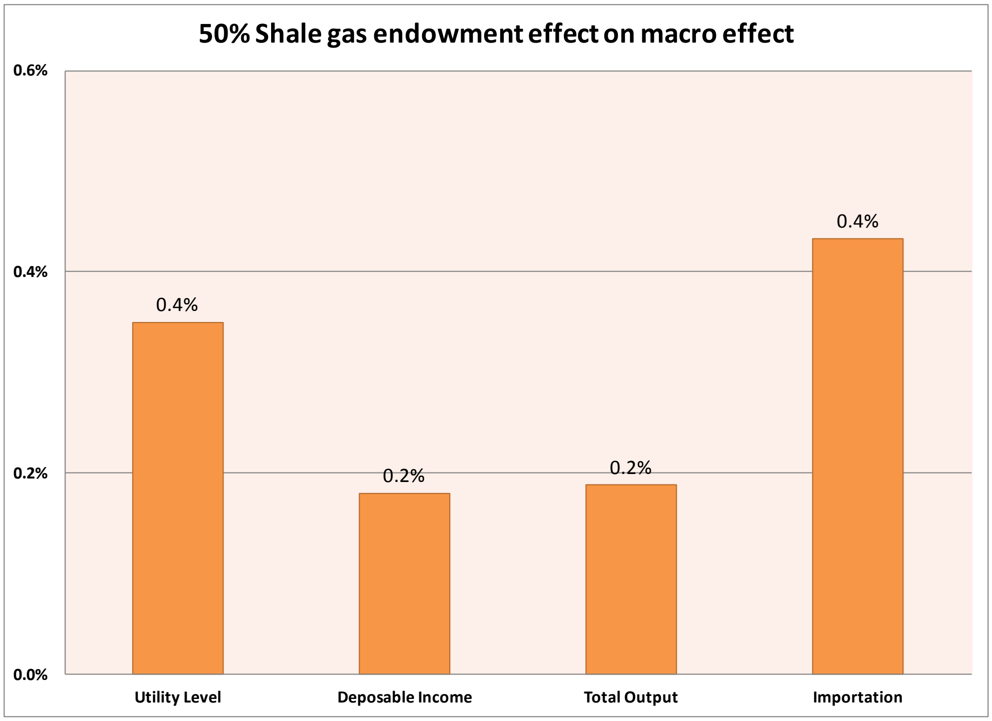

Figure 6 Changes on macro effect under shale gas production

5.2.2 Quantity and price impact on commodities

The shale gas exploration will have an obvious impact on gas and electricity prices. It also widely benefits other industries. Gas production will increase significantly by 9.85 percent. The refinery, electricity, coal and chemistry industries, the energy related industry and energy relative service will all increase their production between 0.5 percent and 1.3 percent. Only domestic oil extraction will decrease by 0.86 percent due to the substitution effect.

Gas prices decrease by about 39.42 percent and electric prices decrease by about 3.91 percent as its major input price goes down. Because of the fixed price index, energy-intensive industries, vehicles, and housing together with all other industries' prices decrease by a slight percentage.

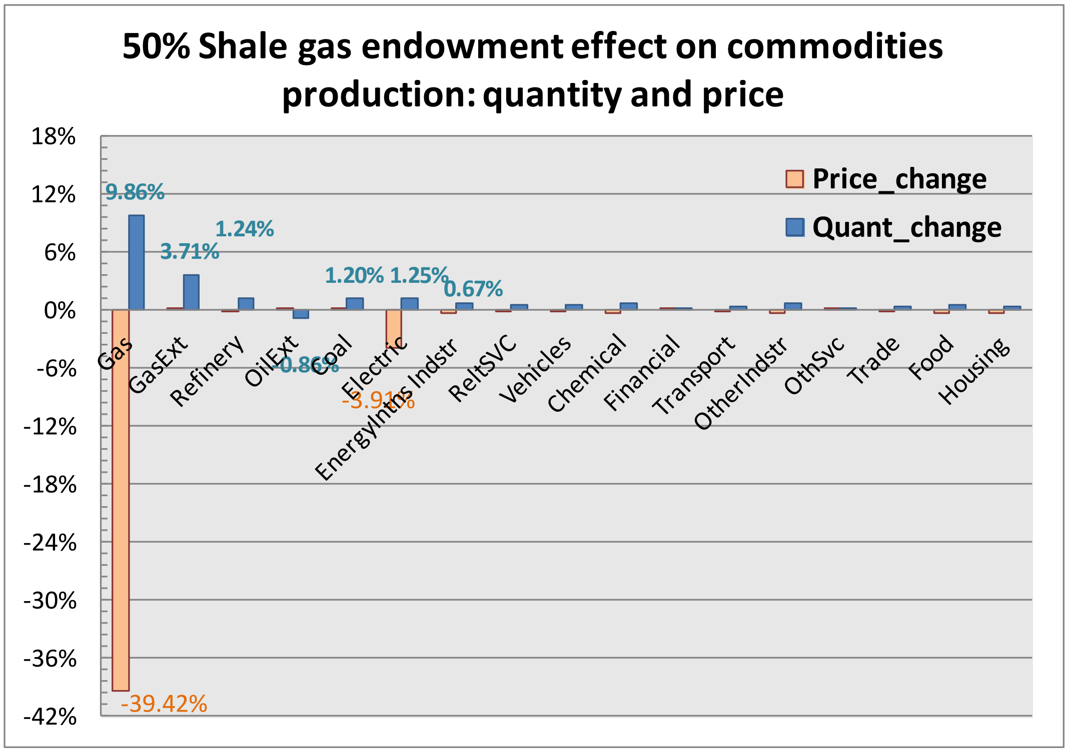

Figure 7 Quantity and price changes under shale gas production

5.2.3 Impact on social welfare

The impact on social welfare is generally positive but small. The change in the returns to land, labor and nature sources are positive; the return to capital is negative. Labor payments, unskilled and skilled, will increase by 0.4 percent and 0.5 percent, respectively. Payment of land will increase by 1.1 percent, together with a slightly increase in natural resource factor payments by 1.1 percent. Capital returns will decrease by 0.3 percent.

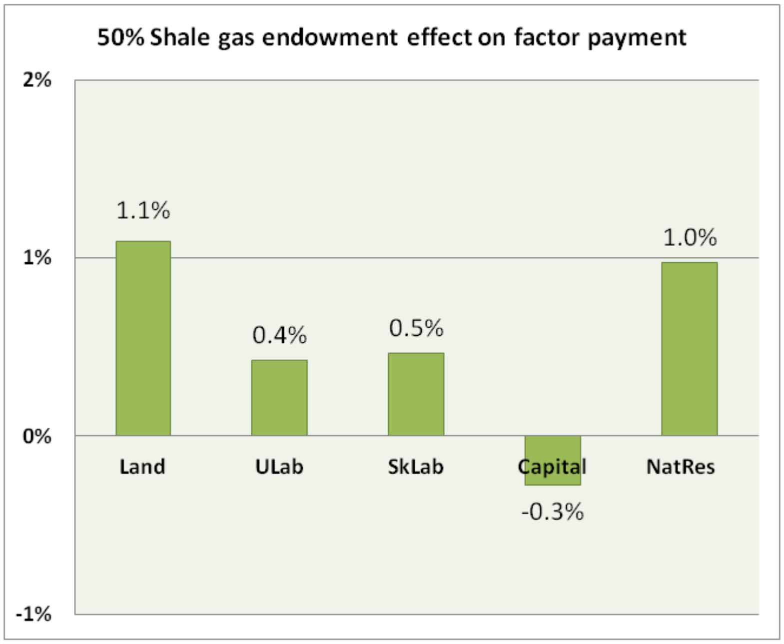

Figure 8 Factor payment changes under shale gas production

5.2.4 Sensitivity Analysis for Multiple scenario

The shale gas endowment is in y percent equivalent of natural gas, y percent=0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0.

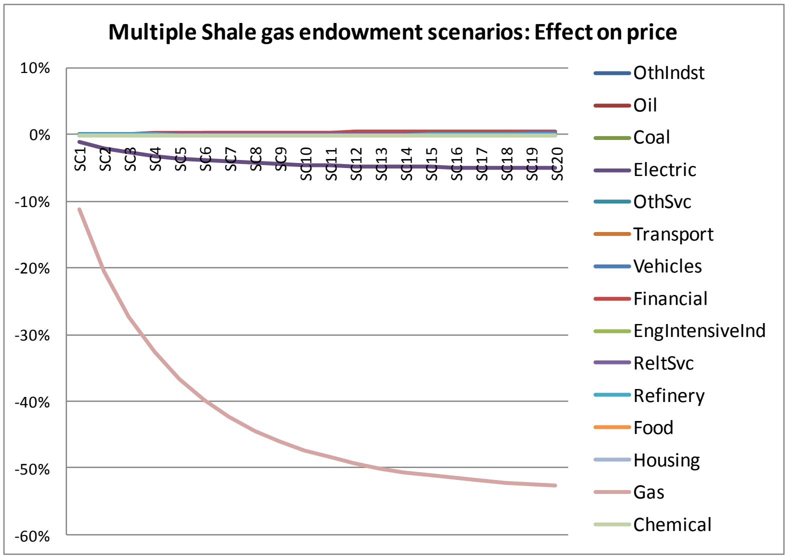

Figure 9 Effect of shale gas endowment on commodities prices

Following a non-linear trend, the gas price decreases by about 52 percent after running multiple scenarios, which implies the benefit of shale gas exploration will decay as more is produced. Similarly, the benefit on the electricity price is also following a decrease relative to the production scale trend.

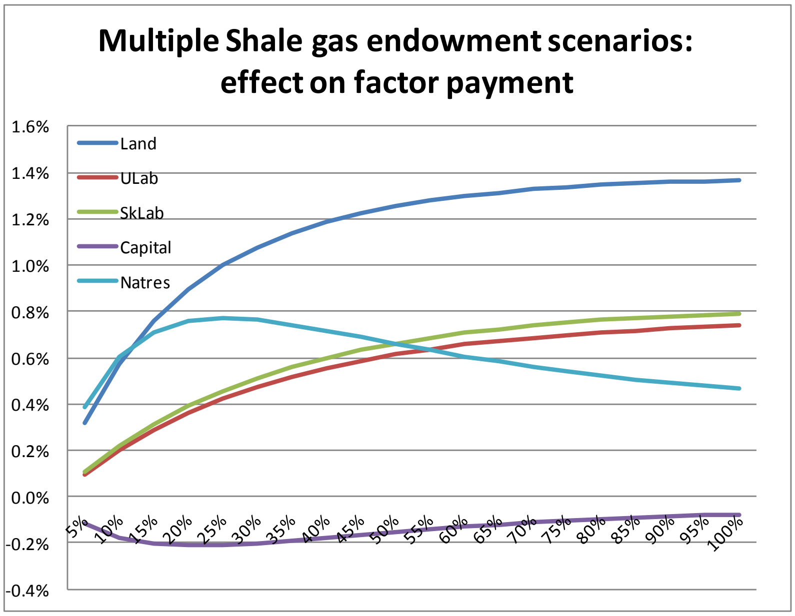

Figure 10 Multiple shale gas endowment scenarios: effect on factor payment

Even in the multiple scenario analysis, land return increases by at most 1.4 percent even with the shale gas endowment increase equivalent to 100 percent of the natural gas endowment. The payment to capital declined by 0.2 percent. The payment to labor and natural resources will increase by at most 0.8 percent, because the industries use gas uses land, labor and natural resource as complementary inputs. The hump trend of natural resource prices implies that the shale gas endowment causes an increase demand for other natural resources much more than its supply. As the endowment of shale gas passes by the critical value of 25 percent, the payment to natural resources gradually recedes to an increase of 0.4 percent of its original price.

6. Improvement and further discussion

6.1 Improvement in modeling

After finishing a review of the traditional model, I find there is a pitfall of failing to control the saved gas (natural resource) flowing into other industries' production as factor input in the three tiers production model. This contradicts the fixed feature of natural resources. So the result under the three tiers production model will have a relatively lower increase in gas production.

To meet the fixed feature of gas resources, I designed another production structure, which separates the input factor natural resources into two parts: one is its factor inputs into gas industry; the other is for other industries input. As illustrated below, the production structure turns to be two tiers and the shale gas endowment will directly go to the part of natural resources.

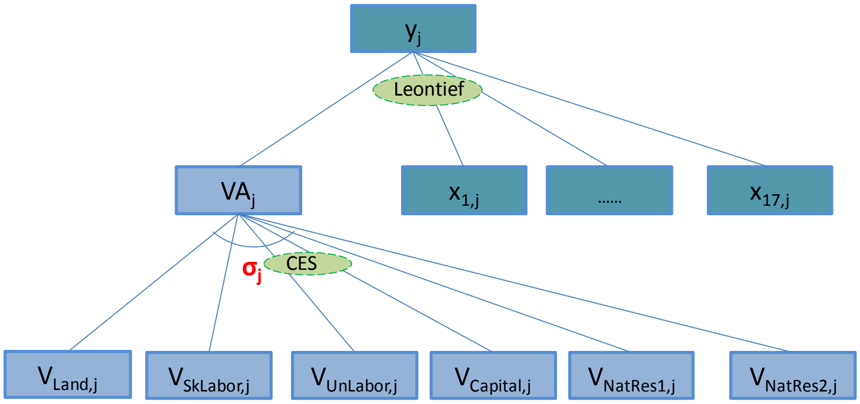

Figure 11 Traditional production structure

After adjusting the computation program according to the structure above, the new result shows that the gas production will increase by 59.25 percent much more than the 9.86 percent increase in the traditional production structure. However, the gas price will decrease by 28.72 percent instead of 39.4 percent, and thus the electricity price gains less under the scenario of the modified production structure. In addition, the refinery industry will have more supply in the market. Further, the overall benefit of shale gas production to the whole society production is very small.

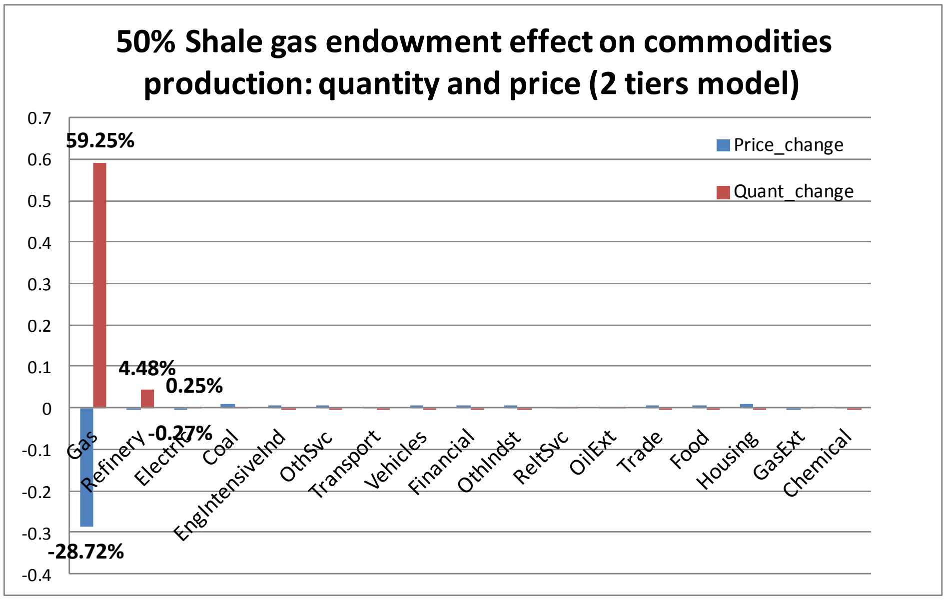

Figure 12 Quantity and price changes under shale gas production

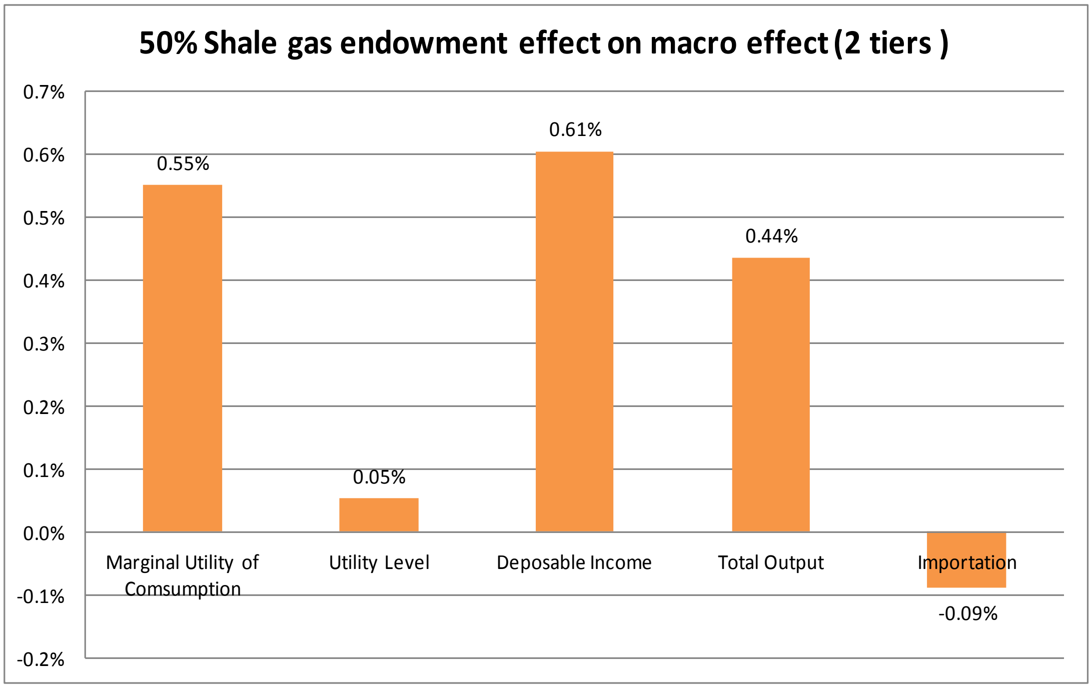

Figure 13 Factor payment changes under shale gas production

Changing the production structure barely affects social welfare. The return increasing most is natural resources, followed by capital returns and labor payments. Payment to land will decrease by 0.3 percent.

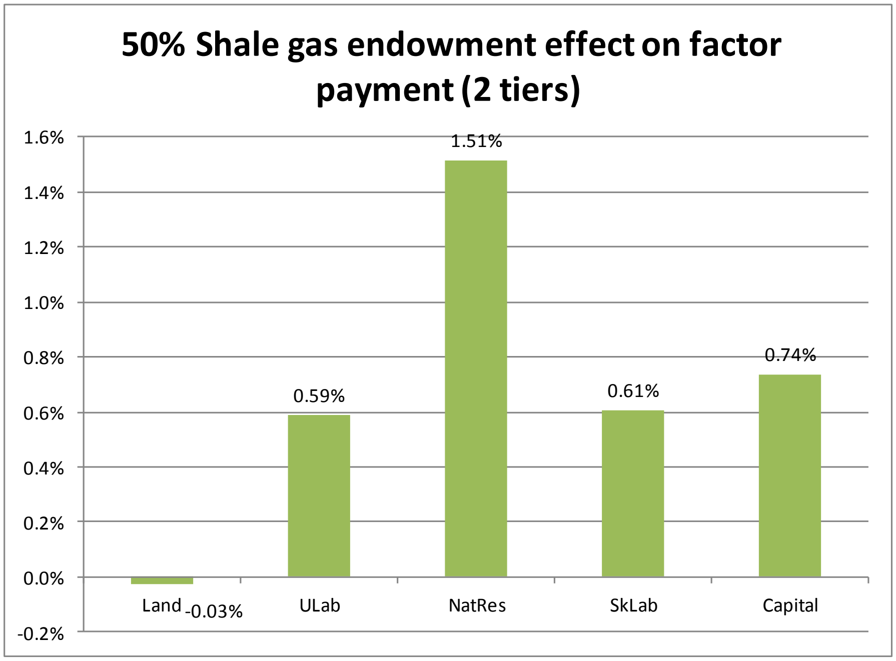

Figure 14 Factor payment changes under shale gas production

6.2 Further discussion in impact scale

As in the result of the improved model, the impact of shale gas production is not that significant as people expected. If using the partial equilibrium model, the shale gas scenario could result in an even lower overall price level of the entire production market. However, there will be no change in disposable income and total output. The unit expenditure index will decrease. Therefore the household utility in partial equilibrium condition will increase as in the general equilibrium. There will be no change in factor payment either. However, such a result from partial equilibrium cannot be applied in this study due to the limitation of partial equilibrium itself.

Asserting that the shale gas discovery as a 'game changer' is not feasible, based on the results found in this study. The definition of 'game changer' implies that an idea should transform the accepted processes, strategies and leads a movement of related businesses in the same direction. Obviously, the impact of shale gas development is far from that significant extent. Even in the situation of adjusting some technology parameters significantly still cannot make shale gas impact be that influential. In Wang's TDGE_CHN model for China, he discussed the change of technology based on increasing input of more intellectual property and found in the situation of allowing a substitution relationship of knowledge input and all other input as 2.5 other than a more conventional substitution of 0.5, the GDP growth rate of China will be 6% higher. For this point, if shale gas exploration could have such an impact to the US, this could count as a 'game changer'. The implication to my study is that by allowing a relative large substitution relationship of knowledge input and other input for every industries, such as the possibility of using less input and more intellectual property, can help to achieve a 'game changer' result. However, this is more like a technology innovation other than a discussion of developing a substitution technology between petroleum and natural gas in transportation sector. These are completely two different concepts. Substitution cannot bring the same order of magnitude of impact as technology innovation. Therefore, valid analysis of shale gas production impact may add in another production tier and equate intellectual property as a substance.

7. Conclusion

In sum, the production of shale gas will enhance the overall US industrial production, lowering the domestic gas and electricity prices. However, the gas price will not follow a linear trend. As more shale gas is developed, the gas price will decrease more slowly. Moreover, its economic impact is apparently quite small, in terms of social welfare. It is apparently too small to assert that the shale gas discovery as a 'game changer', due to the fact that the natural gas sector itself is too small as a fraction of total GDP.

Therefore, the best way to let households enjoy the increased social welfare and the production sectors to collect the benefit of decreasing gas price is to let the market determine which level the shale gas reserve should be developed, with respect to the current debate of subsidy and regulation on shale gas.

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