Structural Change and Energy Use in China: A SAM-Based CGE Analysis[1]

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Abstract

An important feature of the rapid growth of the Chinese economy is its constant intensification of energy use per unit of labor. At the same time, China shows only slow improvement in energy intensity i.e. the use of energy per unit of output. This paper presents a structuralist computable general equilibrium (CGE) model for China based on a 3- productive activities based - agriculture, energy and industry - social accounting matrix. Four simulation exercises are conducted using this model--- industrial investment demand increase, industrial wage increase, exchange rate depreciation, and government spending increase in industry. Our results show that structural change associated with raising industrial labor productivity and employment share are likely to result in simultaneous intensification of per worker energy-use and slight reduction of energy productivity in China. Industrial wage increase creates cost-push inflation and output contraction caused by a decrease in exports, and devaluation is expansionary. Furthermore, when industrial output is insulated from foreign-domestic relative price effects, devaluation becomes contractionary and wage increase results in a slight contraction in real GDP due to the "forced saving" effect. The model illustrates some of the challenges China faces in its attempt to achieve "green growth" objective with high level of employment.

I. The Introduction

The rapid growth of the Chinese economy accompanied with trade expansion, industrialization, and labor productivity growth has been impressive. At the same time, the increase in energy-use associated with this high growth has generated a series of concerns and anxieties both domestically and globally. China is now the world's largest energy consumer as well as CO_2 emitter. Its patterns of energy consumption and production are constantly affecting energy and environment related issues such as resource depletion, geopolitical conflicts, and climate change around the world. China's enlightened position during COP 21 in Paris is indicative of the recognition of the

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[1] Preliminary draft, please do not quote or circulate without authors' consent.

problems related to China's growth.[2] Within China pollution is viewed as one of the most pressing domestic challenges in the 21st century. The cost of environmental degradation for China reached 9 percent of its GDP already in 2008 (World Bank, 2013), which ironically was equal to its real GDP growth rate.

In a country like China, economic growth to a large extent depends on industrialization, and the latter necessitates the increasing use of fossil fuel energy as an input for production. The intensification of energy use consequently leads to a series of negative externalities with the most obvious one being CO_2 emission. Energy inputs in China are both imported and domestically produced; in the final analysis the energy production and consumption are determined by China's production structure. Given its significance for China, it is important to set the energy sector at the center of the stage in a macroeconomic model for conducting relevant policy analyses.

This paper presents a 3-sector social accounting matrix (SAM) based macroeconomic model of China in the tradition of structuralist computable general equilibrium (CGE) analysis with the energy sector explicitly modeled. Using this model, we conduct simulation for four scenarios: industry investment demand increase, industry wage increase, exchange rate depreciation, and government spending increase in industry. These scenarios are either common policy instruments Chinese government tends to adopt or scenarios that are likely to arise in the future as China continues to develop (and some scenarios such as investment demand increase and wage increase can occur in both ways). These simulation exercises enable us to observe various effects of macroeconomic structural[3] and policy changes on the patterns of energy production and consumption in China in a *ceteris paribus* environment.

Section 2 discusses some stylized facts about the pattern of energy use in China's development process. Section 3 presents the 3-sector model and its properties. Section 4 illustrates and discusses the simulation results of the aforementioned four scenarios. Section 5 concludes the paper with some policy implications.

II. Growth and Energy Use in China: Some Stylized Facts

A reasonable place to start is a simple stylized fact about the overall relationship between industrial growth and energy-use over time in China.

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[2] "China has been the world's largest greenhouse gas (GHG) emitter since 2006. Under the 2009 Copenhagen Accord, China pledged to reduce its emissions intensity by 40-45 percent from 2005 levels by 2020. In a joint announcement with the United States in Beijing in November 2014, China announced two new goals: peaking greenhouse gas emissions by around 2030, and increasing non-fossil sources to 20 percent of total energy by 2030. China later included these two goals in its intended nationally determined contribution (INDC) to the new international climate agreement to be concluded in Paris in December 2015, along with a goal of reducing carbon intensity 60-65 percent below 2005 levels by 2030." Center for Climate and Energy Solutions October, 2015 http://www.c2es.org/international/key-country-policies/china

[3] For example, labor transfer from the agricultural to the industrial sector

Figure 1: China's Industrial Energy Intensity

Figure 1 above is a plot of China's industrial real energy intensity over time. Industrial energy intensity here is measured as the ratio between total energy consumption and total real value-added in Chinese industrial sectors, and the quantity of "energy" here is measured as million tons of standard coal equivalent. Essentially, this energy-output intensity (*EOI*) reveals how much energy is required for each unit of industrial outputs produced. At the first glance China's energy problem does not seem too dire. Economic growth in China seems to be accompanied by the steady reduction of intensification of energy-use. At the same time, the inverse of energy intensity is the output-energy ratio, which is called *energy productivity*, hence the counterpart of figure 1 must be the steady increase of Chinese energy productivity over time. Although China has gone through a period of increasing energy-output intensity (decreasing energy productivity) in the mid-2000s due to the rapid expansion of some energy-intensive sectors, the Chinese government acted swiftly and implemented a set of energy policies and eventually re-established the downward trend for industrial energy-output intensity (Ke et al., 2012).

However, the issue becomes more complicated and the outlook less optimistic when we consider dynamical structural change. It has been empirically established that labor productivity growth is the major contributing factor to economic growth, especially for developing countries [Taylor (1992)]. Moreover, Miroski (1989), Martinez-Alier and Schlupmann (1991) and later Taylor (2009) have pointed out that raising labor productivity is necessarily associated with the deepening of mechanization of production (more generally capital deepening), hence increasing the likelihood of increasing per worker energy use. Since labor productivity ξ_L is the output-labor ratio, it can be

decomposed as output-energy ratio ξ (which is essentially energy productivity) times energy-labor ratio ε. ε is also called energy-labor intensity or *ELI* (Khan, 1982, 1983, 1985, and 1997), measured as the ratio that gives the energy use per unit of labor. Thus, the growth rate of labor productivity must be the sum of energy productivity and energy-labor intensity growth rates:

$$\widehat{\xi_L} = \widehat{\xi_E} + \hat{\varepsilon} \quad (1)$$

The hat in equation (1) represents the growth rate. Essentially, this decomposition tells us that labor productivity growth can be driven by the growth of energy-labor intensity (ε) as mentioned earlier, and/or the growth of energy-productivity (ξ_E).

Figure 2: Growth rates for Energy Productivity, Energy-Labor Intensity, and Labor Productivity
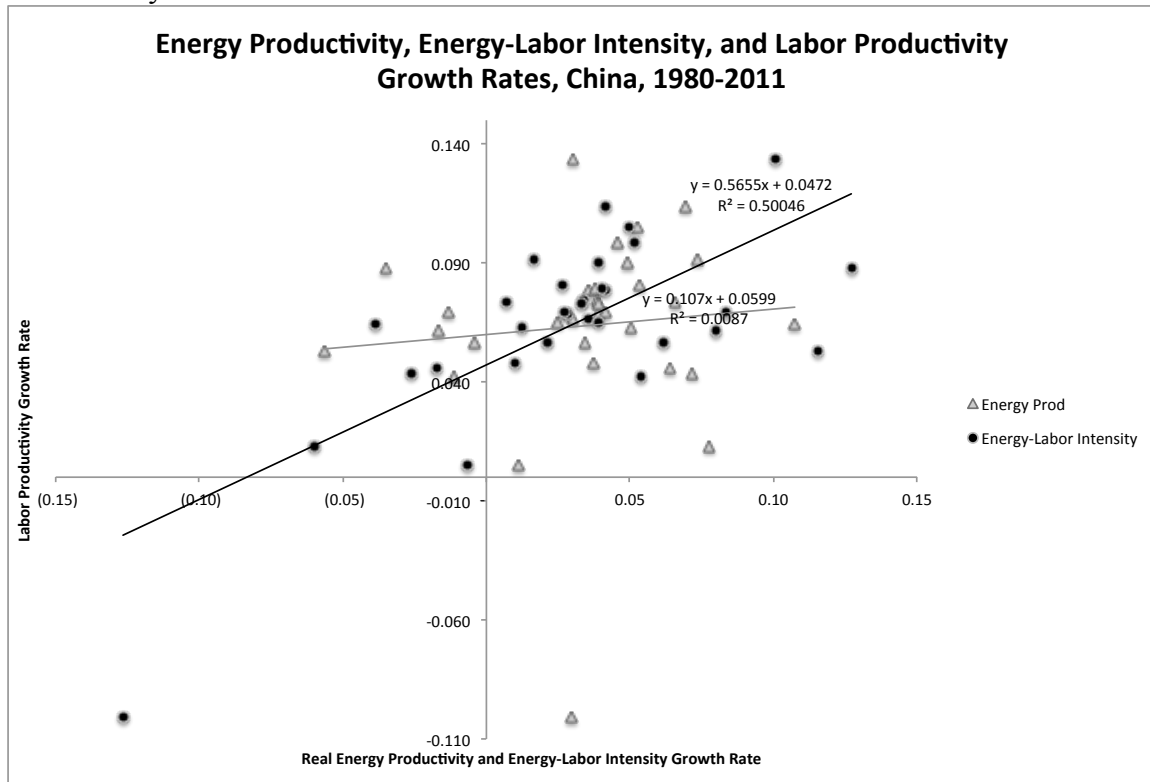

Figure 2 above is the scatter plot for China's energy productivity and energy-labor intensity growth rates on the horizontal axis against its labor productivity growth rates on the vertical axis. It is clear that, for the case of China, labor productivity growth tends to be driven by the growth of energy-labor intensity rather than energy productivity overtime with the linear fitted line for $\widehat{\xi_L}$ and $\hat{\varepsilon}$ exhibiting steeper slope and higher R^2 relative to $\widehat{\xi_E}$. Thus, despite the steady increase of energy productivity as implied in figure 1, the effect of increasing energy-labor intensity has been historically dominating China's developmental process.

The issue becomes even clearer as we look at the relationship between the growth rate of energy productivity and energy-labor intensity in figure 3 below.

Figure 3: China Energy productivity and energy-labor intensity growth rates
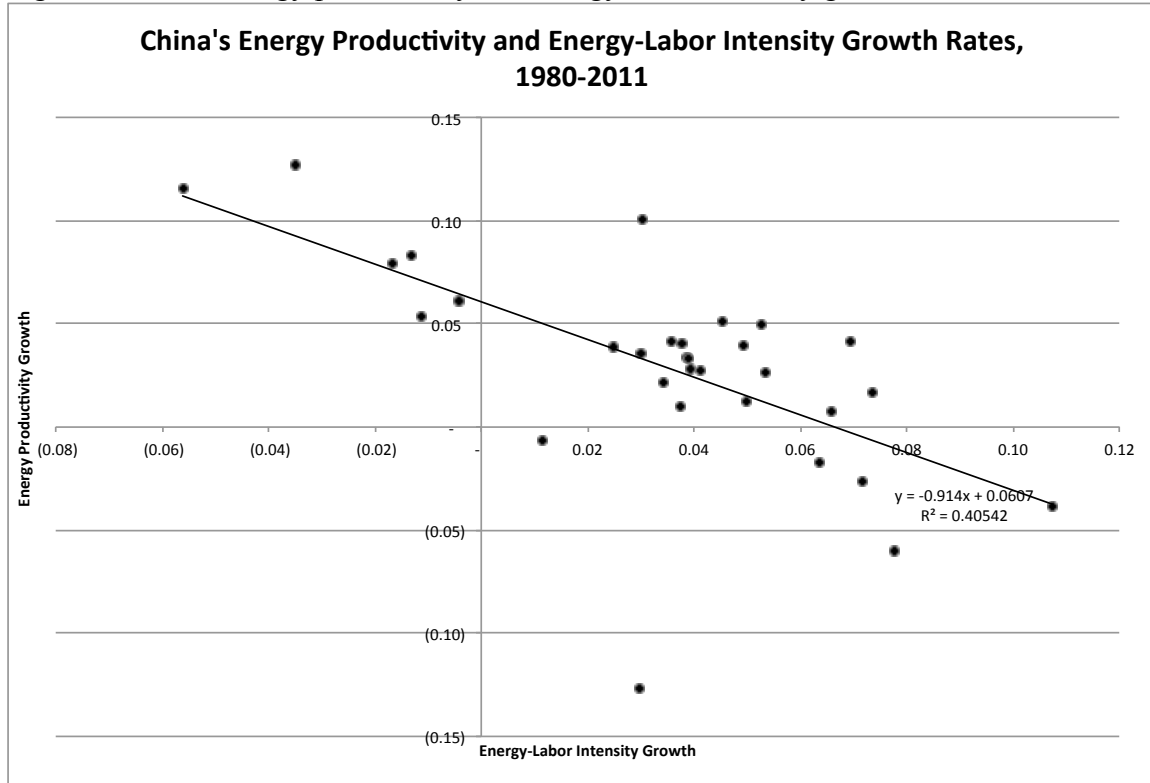
The scatter plot of China's energy-labor intensity growth rates against energy productivity growth rates in figure 3 establishes a negative linear relationship between those two variables with slope coefficient being -0.9. It implies that the increase of energy-labor intensity growth rate in China tends to be associated with the decline of energy productivity growth rate, which indicates the trade-off relationship between those two variables that determine labor productivity growth in equation (1). The implications of this plot are far from encouraging in the context of environmental concerns. Economic growth relies on the growth of labor productivity, and the latter depends on energy-labor intensity growth according to figure (2), but the growth of energy-labor intensity seems to be unfortunately associated with the decline of energy productivity according to figure (3). Thus, historically China has been facing the trade-off between the "greenness" and the "growth" of its economy.

One way to formally model this is to use an augmented Kaldor-Verdoorn equation, which lets a country's labor productivity growth depend on its industrial sector as well as the industrial sector's energy-use per worker. (Von Arnim and Rada, 2011) The equation is written as:

$$\xi_L = \alpha Y^\beta \varepsilon^\gamma \quad (2)$$

In equation (2), Y is the industrial sector's value-added, ε is the industrial sector's energy-use per worker, i.e. the industrial sector's ELI, β is the well-known Kaldor-Verdoorn elasticity, and γ is the labor productivity-energy-labor intensity elasticity. The specification of equation (2) is particularly relevant for the case of China given the aforementioned stylized facts. Although, in principle, the change of energy productivity can also affect labor productivity according to equation (1), this effect is dominated by the effect of increasing energy intensity; hence equation (2) does not include energy productivity ξ_E as an argument. Equation (2) plays an important role in the macroeconomic model to be introduced in the next section.

III. The Social Accounting Matrix Based Structuralist CGE Model

1. The Social Account Matrix (SAM)

The model features a 3-sector economy of China with sectors 1-3 being agriculture, energy and industry, respectively. Agricultural sector is assumed to be supply-constrained by its productive capacity but energy and industrial sectors are constrained by aggregate demand. The model is based on a 3-sector 2-household groups classification in the social accounting matrix (SAM) of China illustrated in table 1. The SAM is a snapshot[4] of China's macro-economy at a point in time with rows summarizing incomes and columns summarizing expenditures. Row and column sums are always equal, consistent with a single-entry bookkeeping rule.

-Table 1 about here-

-Table 2 about here-

Under columns 1, 2, and 3: rows 1-3 are the inter-sectoral intermediate flows amongst those three sectors; rows 5-6 are wage and profit incomes generated by the three sectors; row 6 and 7 are production tax and imported intermediate goods paid from each sector to government and rest of the world, respectively; and finally row 9 is flow of funds account, which is empty on the production side. Let's now turn to the expenditure side of each sector. To the right-hand-side of the first three rows, the first three columns are indeed the inter-sectoral intermediate flows, columns 4-6 are the consumptions of each sector's output by agriculture households, capitalist households[5], and wage-earner households. Rows 7-9 are rest of the aggregate demand for each sector's output, namely, government spending, net exports and investment demand (capital formation). Finally, the first three elements in the last column and row are each sector's total output.

The SAM above contains an input-output table, and this input-output table is the sub-matrix given by all the columns associated with rows 1-3 and all the rows associated

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[4] For a complete description of how SAM functions as a snapshot and the interconnections among the various accounts, see Khan and Thorbecke (1988, 1989), James and Khan(1993,1997) and Khan(1989, 1997).

[5] Noticing here that the SAM is constructed in such a way that capitalist households do not consume anything, which conforms the classical theory of saving.

with columns 1-3. What remains to be explained is the sub-matrix that consists of columns 4-8 and rows 4-9 of the SAM. [6]All the entries in this sub-matrix are payment flows amongst various households (agriculture, capitalist, and wage-earner) and institutions (government, foreign, and flow of fund). For the purpose of clearer illustration, let us turn to table 2, which is the symbolic counterpart of the numerical SAM in figure 4. U_{bw}, U_{gw}, and U_{fw} are the transfers from capitalist household (business), government, and foreigners to wage income. T_b, T_w and U_{fg} are income and foreign taxes that flow from capitalist and wage earner households and foreigners to the government. S_A, S_B, S_w, F and D are households, government and foreign savings that go in and out (as investment demand) of the flow of funds account. Finally, Y_A, Y_B, Y_w, Y_g and Y_f are total income (= expenditure) for all households and institutions.

2. Formal Structural CGE Model Setup

Let us start with output determination.

$$X_i = \sum_{j=1}^{3} a_{i,j} X_j + C_i^A + C_i^W + I_i + G_i + E_i \quad (3)$$

In equation (3), $a_{i,j}$ is the input-output technical coefficient, C_i^A and C_i^W are agriculture and wage-earner household consumptions, respectively. Essentially, this equation simply states that output in each sector equals to the sum of intermediate inputs, consumption, investment and exports. Furthermore, in this model, we let the output of energy and industrial sectors to be determined by aggregate demand, but agricultural sector's output is fixed exogenously at $\overline{X_1}$. The limiting factor could be the productive capacity in agriculture sector such as the amount of fertile land or capital stock.

Assuming the input-output coefficients are fixed during a particular time period, the value-added for each sector is determined by the fixed value-added coefficient v, which is given by the next equation:

$$v_i = \frac{V_i}{X_i} = 1 - \sum_{j=1}^{3} a_{i,j} - t_i - m_i \epsilon \quad (4)$$

where t is the indirect tax rate, m is the propensity to import with given total output (that is M/X), and ϵ is the exchange ratio that converts import value into domestic currency.

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[6] Khan(1989) gives an explanation of how to build a SAM step-by-step starting with an input-output table in the context of an input-output table and SAM for South Africa. Khan(1997a, 1983, 1982a,b) describes how to disaggregate and link energy sectors to the rest of the economy. To link distribution and production in nonlinear SAM-based models, see Khan(2002a,b,c) and Khan(2004).

Government spending and investment are assumed to be fixed exogenously during a particular period following the Keynesian tradition. Exports and imports are modeled after the standard textbook version of trade functions:

$$M_i = \phi_i^0 \rho_i^{-\phi_i} X_i = \phi_i^0 \left(\frac{\epsilon P_i^*}{P_i}\right)^{-\phi_i} X_i \quad (5)$$

$$E_i = \chi_i^0 \rho_i^{\chi_i} X_i^f = \chi_i^0 \left(\frac{\epsilon P_i^*}{P_i}\right)^{\chi_i} X_i^f \quad (6)$$

In equations (5) and (6), ϕ_i and χ_i are price-elasticity of imports and exports, respectively. ρ is the relative price ratio between foreign to domestic price, P is the foreign price, and X_i^f is the world import demand for all countries' sector i's outputs for China's product. Thus, the product of the first two items on the right hand side of equation (6) should give us the share of world demand for sector i's outputs that goes to China.

In this model, consumption of each household is characterized by the linear expenditure system below:

$$C_1 = (c_2 + c_3)C_F + \frac{(1 - c_2 - c_3)Y_d}{P} \quad (7)$$

$$C_2 = c_2 \frac{Y_d - P_1 C_F}{P_2} \quad (8)$$

$$C_3 = c_3 \frac{Y_d - P_1 C_F}{P_3} \quad (9)$$

Where the c_2 and c_3 are the consumption shares for the respective sectors, C_F is the floor level of consumption, which we assume are from the consumption of agriculture goods such as food. Y_d is the household disposable income, which is determined by following the accounting identity from the SAM.

$$Y_d = \left(\sum_{j=1}^{3} L_j w_j + U\right)(1 - s - t) \quad (10)$$

Equation (10) states: each household's disposable income equals to their wage income (which equals to employment (L) times wage (w)) plus all the income transfers (U) from government, firms, and foreigners, and minus saving and income tax. Thus s and t are saving and tax rates from household income inflows.

Let L be the total labor force of the economy, employment in agricultural sector simply equals the residual of the labor force that is not absorbed by the energy and industrial sectors, thus: $L_1 = \quad - L_2 - L_3$. However, energy and industrial sectors' employment equals the ratio of total value-added to labor productivity in each sector, that is:

$$L_i = \frac{V_i}{\xi_i}, \qquad i = 2,3 \quad (11)$$

In these sectors, labor productivity (ξ) increase will displace workers via labor-saving technical change, but aggregate demand increase will increase value-added (V) which generates employment. Thus, in this model, when additional employment is generated in energy or industrial sector, there is "labor transfer" from agriculture to those two sectors following the Kaldor-Verdoorn law of growth.[7] However, when there is employment contraction, labor gets transferred back to the agricultural sector (Khan, 2006). Some of these transferred workers might be unemployed; others would be underemployed, or find informal employment.

Labor productivity is exogenously fixed for the energy sector. However, for the industrial sector, labor productivity is endogenously determined by the augmented Kaldor-Verdoorn equation motivated by equation (2) in the beginning of this paper. In the context of the current model, we can rewrite the equation in following way:

$$\xi_{L,3} = \alpha V_3^\beta \left(\frac{a_{2,3} X_3}{L_3}\right)^\gamma \quad (12)$$

In this new expression, $a_{2,3}$ is the input-output coefficient for the flow of energy sector's outputs to industrial sector as intermediate inputs. $(a_{2,3} X_3)/L_3$ is therefore industrial sector's energy-labor intensity measured as the ratio between energy use per unit of labor. Labor productivity in agricultural sector simply equals the ratio of value-added to employment.

$$\xi_{L,1} = \frac{V_1}{L_1} \quad (13)$$

The determination of agricultural labor productivity essentially follows Kaldor's third law of growth (Thirwall, 1983). Since agricultural output is exogenously fixed by its productive capacity in the model, agricultural employment expansion will decrease its labor productivity, and vice versa with the labor transference from agricultural to other sectors, therefore decreasing returns to labor is a built-in feature for agricultural sector. In the industrial sector however, there will be increasing returns to scale[8] because labor

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[7] Notice the subtle difference between this model and models of dualism. In the latter, there is surplus labor in the traditional-agriculture to begin with and even in Harris-Todaro model the movement is in response to perceived job opportunities that may not necessarily correspond to an actual increase in labor demand in the non-agricultural sectors. For a historically motivated analysis of various dualistic models see Khan(1997, ch. 2) and for a model with more sectors and households that modifies the Harris-Todaro model, see Khan(2006).

[8] It can be demonstrated in structural models of economies modeled either in Banach or Vector Lattice that increasing returns can produce multiple equilibriums. (Khan,1998, 2002a,b,c) Given the base year social accounting matrix, we identify one equilibrium among many.

productivity is positively determined by industrial value-added according to equation (12).

Let us now turn to prices and the distribution of income. Agricultural price fluctuates to clear the excess aggregate demand or supply in the market. In other words, it is an endogenous variable in the macroeconomic system as a whole. Energy and agricultural prices are cost-determined by the weighted average of the cost of each component in its unit output, namely, intermediate inputs, value-added, and imports.

$$P_2 = \sum_{j=1, j \neq 2}^{3} \frac{a_{j,2}}{1 - t_2 - a_{2,2}} P_j + \frac{v_2}{1 - t_2 - a_{2,2}} P_{v,2} + \frac{m_2}{1 - t_2 - a_{2,2}} \epsilon P_2^* \quad (14)$$

$$P_3 = \sum_{j=1, j \neq 2}^{3} \frac{a_{j,3}}{1 - t_3 - a_{3,3}} P_j + \frac{v_3}{1 - t_3 - a_{3,3}} P_{v,3} + \frac{m_3}{1 - t_3 - a_{3,3}} \epsilon P_3^* \quad (15)$$

P_v is the price of value-added, which we will discuss later. It is clear from the equations above that the "weights" that are applied to the cost of each component in the unit output are the relative contribution of each component to a unit of final output.

For the value-added prices, conventionally, they are determined by the neoclassical marginal productivity principle. However, this paper follows the structuralist tradition and computes value-added prices for energy and industrial sectors by the markup-pricing rule. Let us first look at agriculture sector, since its price functions to clear the market, its value-added price ($P_{v,1}$) simply clears its cost decomposition in following equation:

$$P_{v,1} = \frac{1 - t_1 - a_{1,1}}{v_1} P_1 - \sum_{j=2}^{3} \left(\frac{a_{j,1}}{v_1} P_j \right) \quad (16)$$

For the energy and industrial sectors, their value-added prices follow the markup pricing equation below:

$$P_{v,i} = \frac{L_i w_i}{V_i \omega_i} \quad (17)$$

Where ω is the wage share of value-added, and $1 - \omega$ is therefore the profit share. The price of value-added (P_v) is considered as the result of wage bill (Lw) plus the markup at a rate of τ, which happens to be $1/\omega$.

Finally, energy and industry sectors' wages are exogenously given; however, agriculture wage is determined by the ratio between wage bill (income) and employment, that is:

$$w_1 = \frac{P_{v,1}\omega_1 V_1}{L_1} = \omega_1 P_{v,1}\xi_1 \quad (18)$$

Essentially the second half of equation (18) tells us that agriculture wage is proportional to the agriculture labor productivity ξ_1.

Overall, the model features 38 equations with 38 endogenous variables and 60 exogenous variables. With correct calibrations, the solution of the system should return to us a set of values for those endogenous variables that exactly matches the values in the SAM. Furthermore, simulation exercises can be conducted by solving the system after altering some of those exogenous variables. However, the variables of interest here are those directly related to possible policy measures.

3. Calibrations

Most of the parameters in this model are calibrated based on the SAM accounting relationships as exhibited in tables 1 and 2. Sectoral employment data is taken from China Labor Statistical Yearbook (CLSY). For the consumption functions, the floor consumption levels for urban and rural households are obtained by estimating the Engel's equation for each households. The household disposable income and consumption data for the regressions are taken from the CLSY (various years). The consumption shares (c_i) are obtained by solving for the linear expenditure system independently. The augmented Kaldor-Verdoorn equation is estimated using China Energy Databook (CED) V. 8.0 and China's Statistical Yearbook (CSY). Finally, due to the fixed exchange rate regime China had adopted, difficulties with consistently estimating Chinese export and import are well documented in the literature, and the few existing empirical findings also exhibit large variances. (Cheung et al., 2010; Imbs and Mejean, 2010; Aziz and Li, 2007) For simplicity, initially we follow Von Arnim and Rada (2011) and assume industrial import and export elasticities to be 0.75 in the baseline model. However, we are aware that simulation results can be quite sensitive to trade elasticities, thus when discussing our results, we also exhibit some alternative simulation results at various trade elasticity levels and carry out sensitivity analyses in the following section.

IV. Simulation Results

The correctly calibrated model is then used to conduct simulations for four relevant scenarios, namely, 10% increase in industry investment demand, 10% increase in industry wage, 10% exchange rate depreciation, and 10% increase government spending in the industrial sector. The simulation results are shown below in table 3.

Table 3. Baseline Simulation Results

|	10% △ I_ind.	10% △ w_ind.	10% △ ∈	10% △ G_Ind.
Inflation	2.574	5.349	1.182	0.628
Growth	3.785	−3.427	1.08	1.228
△ S−I (to GDP)	−3.236	−0.964	0.38	0.476
△ T−G (to GDP)	0.36	−0.339	0.258	−1.372
△ X−M (to GDP)	−2.275	−0.388	0.808	−0.705
△ Ind. L Share	1.178	−1.407	0.282	0.384
△ Ind. X Share	−0.921	0.726	−0.426	−0.255
△ Ind. ξL	2.206	−1.45	1.068	0.696
△ Ind. ξE	−0.318	−1.698	−1.005	−0.066
△ Ind. E/L	2.531	0.253	2.094	0.763
△ Agr. ξL	3.038	−3.32	−0.218	0.97
△ Agr. ξE	−0.197	0.045	−0.835	−0.057
△ Agr. E/L	3.241	−3.363	0.622	1.027

With a 10% increase in industrial investment (which could either be stimulated by government or the result of further industrialization and structural change in China---a mixture of accelerator effects and other factors), the overall economy-wide effect is expansionary with both inflation (measured by Fisher's index[9]) and real GDP growth, and these effects are in part built in the Keynesian demand-driven feature of this model. The private balance $(S − I)$ falls, which might trigger other exogenous changes such as interest rate hike to bring saving and investment into balance in the longer run. Public balance $(T − G)$ improves due to the increased tax income as the result of economic growth. External balance $(X − M)$ declines because of the increase of domestic price relative to foreign price. The extent of the decline depends on export and import elasticities. Structural change triggers labor transfer from agricultural sector to industrial sector as suggested by Kaldor-Verdoorn, hence leading to an increase in the industry employment share. It might seem surprising that the industrial sector's output share (Ind. X share) out of total output declines instead of increasing. But a closer examination reveals that it is the result of relative price-effect. Since the industrial output share is measured as: $P_3X_3/(P_1X_1 + P_2X_2 + P_3X_3)$, while the increase in industrial investment indeed increases the real term X_3, such structural change also triggers high agriculture price (P_1) inflation due to the supply constraint in the agricultural sector; thus the industrial output share declines despite of the increase in industry's real output. Industrial labor productivity (Ind. ξ_L) increases following the Kaldor-Verdoorn effect. Industrial energy productivity (Ind. ξ_E) declines while energy-labor intensity ELI (E/L) increases, replicating the stylized fact presented in figure 3. Agricultural labor productivity (Agr. ξ_E) increases because labor outflow combined with fixed agricultural output results in higher value-added to labor ratio. Finally the energy use pattern in agricultural sector follows that in the industrial sector with increasing ELI and declining ξ_E.

Wage increase is a scenario that has been happening in China especially for the past decade, and it is expected to continue in the future. Holding everything else constant, a 10% wage increase in China results in contractionary effects on the economy with

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[9] Fisher's index is the geometric mean of the Laspeyres and Passche price indices.

declining real GDP and cost-push inflation. These are expected results given the structure of the model. However, the extent of the contractionary effect of wage increase depends on the value of trade elasticities. At the current stage, export and import elasticities are assumed to be 0.75. Figure 4 below illustrates the effect of 10% wage increase on real GDP growth rate at various trade elasticities.

Table 4: Real GDP Growth and Trade Elasticities with 10% Wage Increase
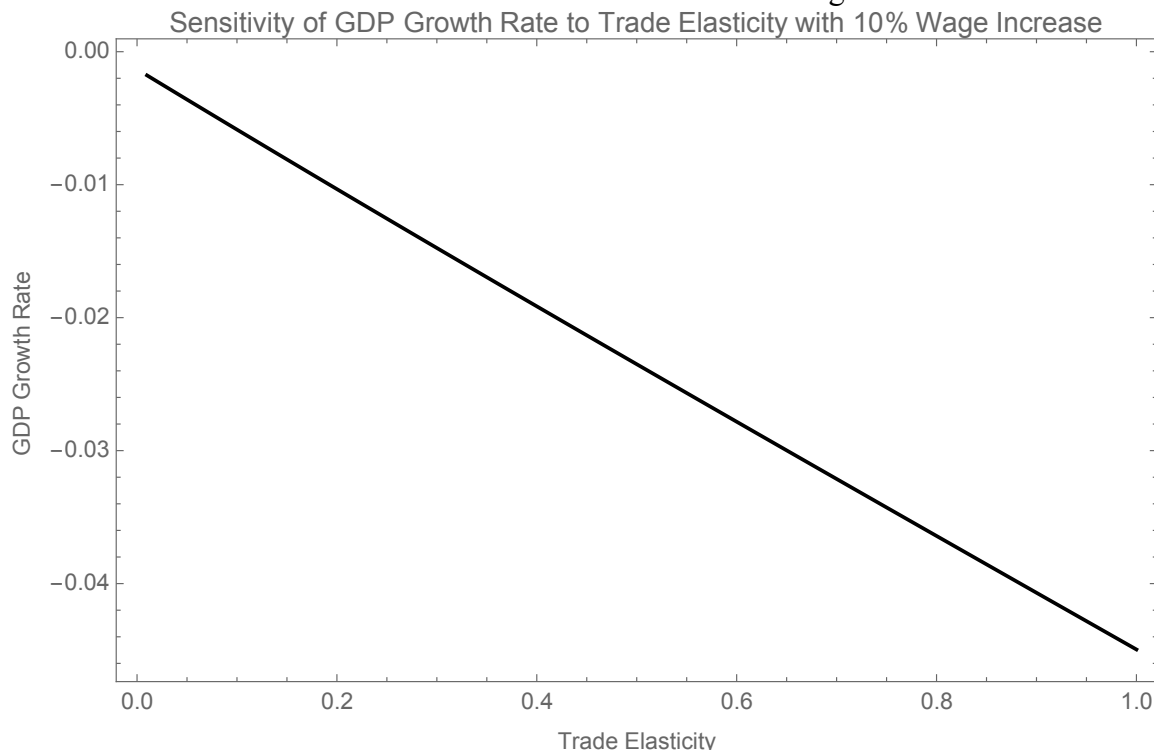
It is clear from Figure 4 that the contractionary effect of wage increase is stronger when trade is more sensitive (elastic) to price changes. With high trade elasticities, wage increase and cost-push inflation is likely to generate severe deterioration of trade balance; hence the economy severely contracts due to its demand constraint. Later in this section we will investigate the extreme scenario with zero trade elasticities.

Continue with trade elasticities being 0.75, private and public balances deteriorate due to the reduction of real income, and external balance falls because of higher domestic price. Industrial employment share declines indicating unemployment or underemployment in that sector, but as discussed before, the unemployed may find informal employment in the agriculture sector. [10] The fall in overall aggregate demand to some extent releases the agricultural constraint, and the result is the rapid fall of agriculture price (P_1). The relative price effect is then set in motion which increases the nominal industry output share while the real industry output actually declines. Labor productivity falls in industrial sector due to the contraction and it also falls in agriculture

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[10] This is similar to the dual-dual model mechanism verified for Africa by Stifel and Thorbecke and for South Asia by Khan.

sector because of the "reverse labor transfer". Agricultural energy use pattern reverses compare to the expansionary scenario considered earlier.

Perhaps the most curious case is the energy use pattern in the industrial sector with wage increase. Apparently, with 10% wage increase, we observe simultaneous *decline* of energy productivity, real GDP, and *increase* of energy-labor intensity - contradicting the stylized fact in figure 3. The result might seem to suggest that there exists a "green" growth path that is associated with increasing energy productivity, declining energy intensity, and real GDP growth, and to go on such path wage has to *fall*. To examine this possibility, we simulated the path of energy productivity and energy-labor intensity growth by the steady decline of nominal wage, and the result is illustrated in figure 5 below.

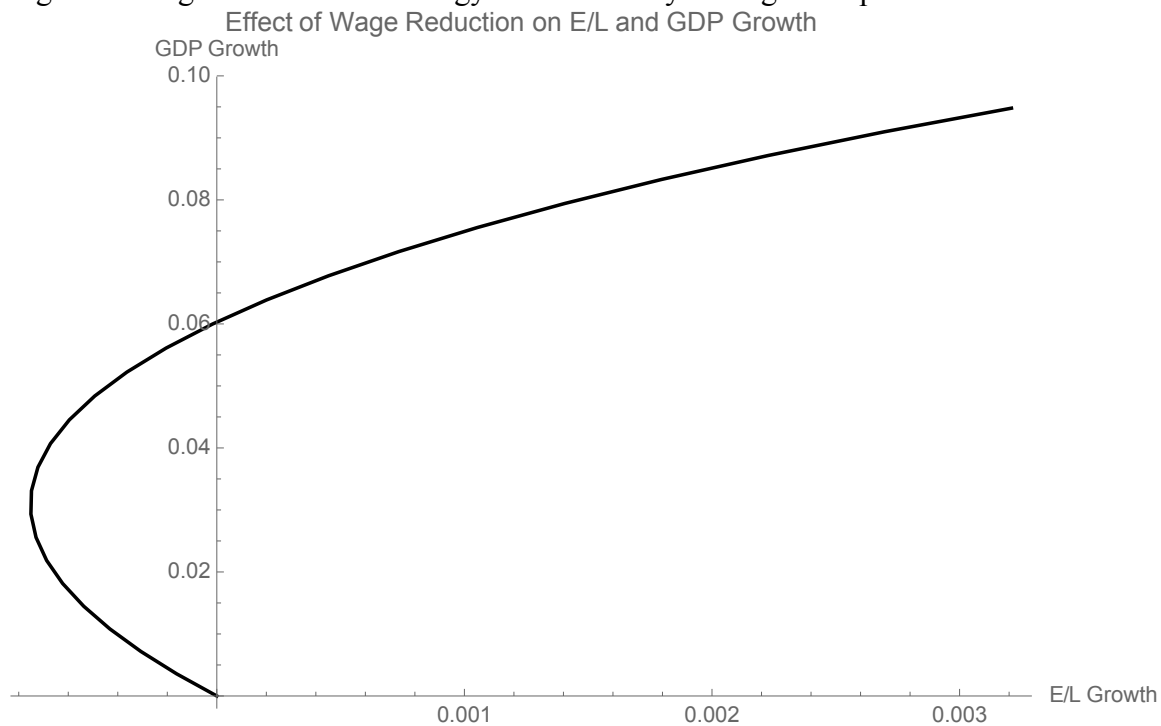Figure 5: Wage reduction and energy-labor intensity GDP growth path

Figure 5 shows the effects of steady wage decline in the real GDP growth and E/L growth plane with the origin being the starting position. It is evident that due to some nonlinear properties of this model, some initial wage reductions would result in a negative relationship between GDP and E/L growth rates, but soon enough, the direction of the plot turns and the positive relation between these two variables is restored as suggested by the stylized facts. Thus, industrial wage cut should not be viewed as a sustainable path towards the much-desired "green" growth. Simple linear models can give misleading results. Furthermore, it is important to point out that the growth path in figure 5 depends again on the value of trade elasticities.

Figure 6: Effects of wage reduction on E/L and GDP growth at various trade elasticities
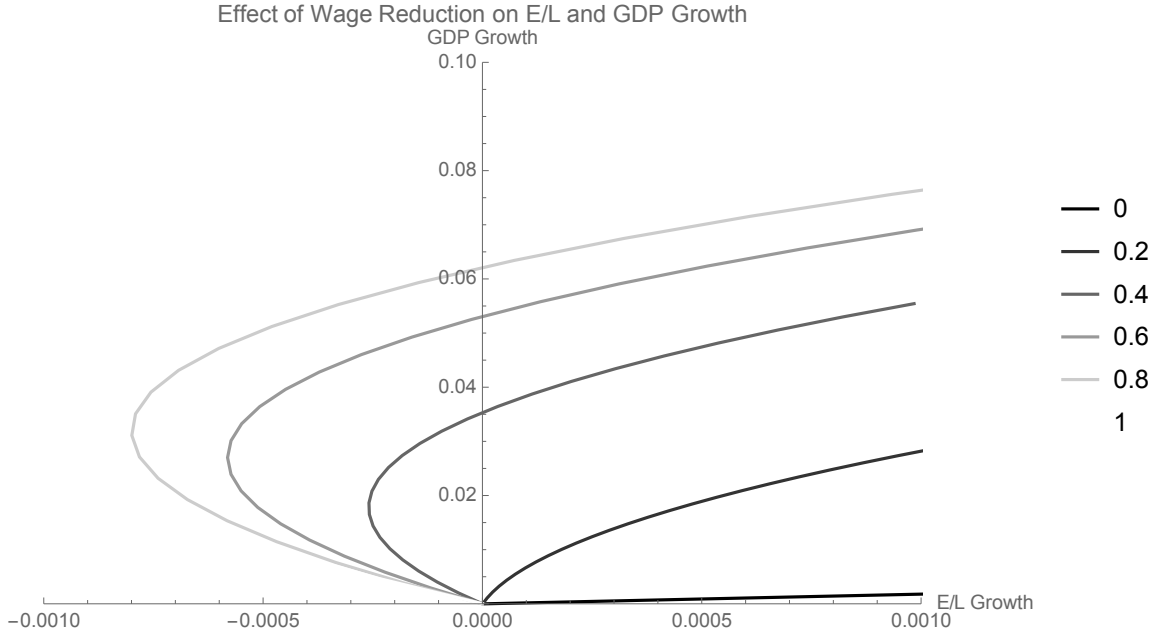

Figure 6 above exhibits six alternative paths for E/L and real GDP growth with steady wage reduction, each led by a different trade elasticity as indicated in the legend to the left of the figure. It is clear that the negative region between E/L and real GDP growth only emerges with sufficiently large trade elasticities. The main reason for this result can be found in equation (4). With high trade elasticities, an initial wage cut would generate downward pressure on domestic price level, which suppresses import demand via high import elasticity, and ultimately the result would be an increase of value-added share v_i. In the absence of other effects, an increase in value-added share would uniformly create real GDP growth without demanding more energy; and at same time, wage cut would generate more employment, hence the industrial E/L ratio will decline. However, as mentioned earlier, as wage cut continues, the nonlinear Kaldor-Verdoorn effects start dominating hence the turn of the growth path. Thus, both the methodological importance and policy-relevance of nonlinearities are revealed by our exercises.

With China's high dependence on international trade, a 10% devaluation results export-led expansion. This result to a large extent depends on the Marshall-Lerner condition; in other words, it again depends on trade elasticities. Since import and export price elasticities are assumed to be 0.75 in the model, Marshall-Lerner condition is met, hence devaluation improves the balance of trade, and ultimately stimulates GDP growth in a demand-constrained setting. Figure 7 below illustrates the effect of 10% devaluation on real GDP growth at various levels of trade elasticities.

Figure 7: Real GDP Growth and Trade Elasticities with 10% Devaluation

Sensitivity of GDP Growth Rate to Trade Elasticity with 10% Devaluation
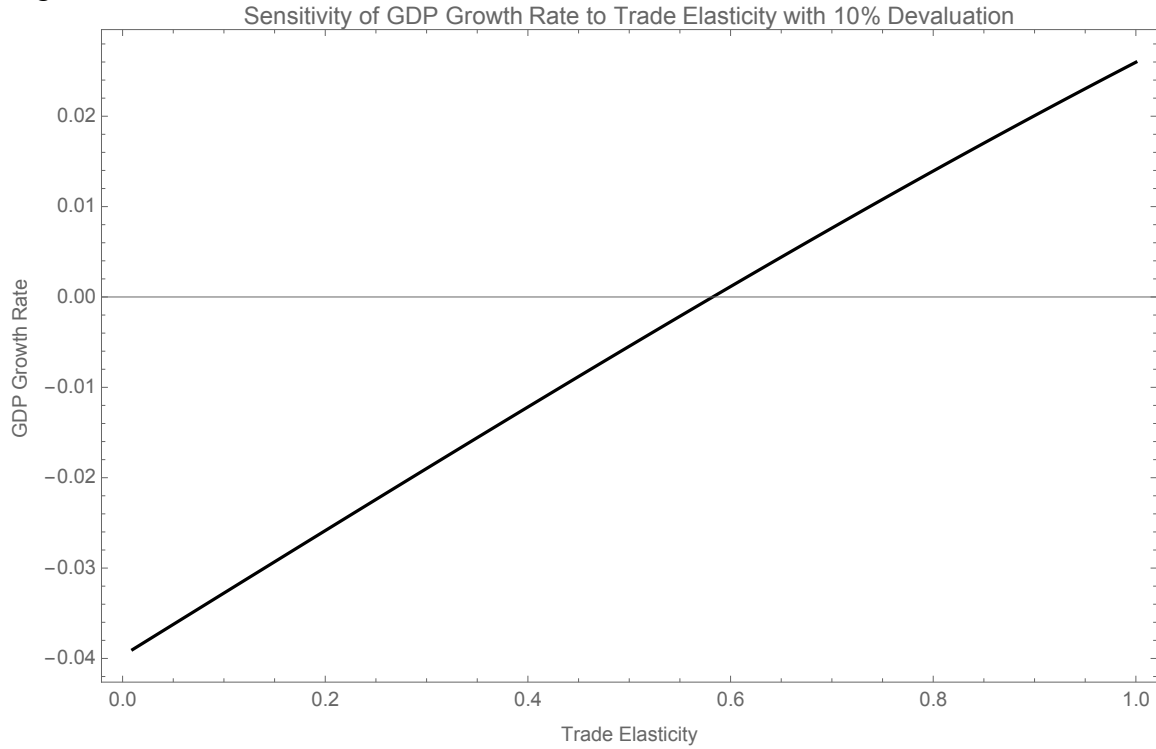
It is evident from Figure 7 that there exists a threshold for trade elasticity near the value of 0.55, above which the devaluation will result in export-led real GDP expansion, and vice versa for a trade elasticity below this value. Since the plot for the effect on balance of trade at various trade elasticity levels is very similar to figure 7, it is not shown here. Recall that the Marshall- Lerner condition requires the sum of the import and export elasticities to be above one in order for devaluation to improve balance of trade (and real GDP in a demand-constrained framework), but here the threshold is found to be around 0.55 hence 1.1 as the sum of export and import elasticities. Such deviation can be attributed to the complex linkages in the nonlinear macroeconomic system as a whole.

If we continue our analysis under the assumption of trade elasticities being 0.75, the results are similar to the 10% industrial investment shock discussed earlier with a few exceptions. Private and external balances improve in this case, the reason for the latter is obvious, and for the private balance the additional saving comes from raising income as the result of balance-of-payments improvement. Agricultural labor productivity declines slightly because the exchange rate depreciation makes imported intermediate inputs more expensive, hence the reduction of agricultural value-added share. Since labor productivity in agriculture is determined by V_1/L_1, the decline of V_1 must be more drastic than the decline of L_1 due to labor transfer, hence the fall of overall agricultural labor productivity. And finally, with 10% government spending increase in industry, the effects are analogous to the 10% industry investment spending increase; however, in this case, the private balance improves due to the windfall income gains from government spending-led expansion, and public balance declines as the direct result of autonomous government spending increase.

An important part of the mechanisms discussed in the first set of simulations comes from the external trade sector. In order to contrast the domestic dynamics of the Chinese economy with the previous simulations, we set the industrial export and import price elasticities to zero, and run the simulation again for those four scenarios. In other words, these are results isolated from international price effects in open-economy macro (at least for the industrial sector). The results are shown in table 4 below.

Table 4: Simulation results with zero trade elasticities

	10% $\triangle$ I$_{ind.}$	10% $\triangle$ w$_{ind.}$	10% $\triangle$ ϵ	10% $\triangle$ G$_{Ind.}$
Inflation	2.96	6.128	−0.296	0.671
Growth	4.457	−0.131	−3.97	1.361
$\triangle$ S−I (to GDP)	−2.953	0.399	−1.769	0.529
$\triangle$ T−G (to GDP)	0.377	−0.142	−0.001	−1.363
$\triangle$ X−M (to GDP)	−1.869	1.638	−2.431	−0.623
$\triangle$ Ind. L Share	1.462	−0.042	−1.829	0.44
$\triangle$ Ind. X Share	−1.055	0.331	0.283	−0.274
$\triangle$ Ind. ξL	2.504	−0.072	−1.095	0.754
$\triangle$ Ind. ξE	0.	0.	−3.568	0.
$\triangle$ Ind. E/L	2.504	−0.072	2.564	0.754
$\triangle$ Agr. ξL	3.768	−0.147	−5.042	1.106
$\triangle$ Agr. ξE	−0.223	−0.042	−0.672	−0.061
$\triangle$ Agr. E/L	4.	−0.105	−4.4	1.168

Let's discuss the effects of 10% industry investment demand and government spending increase first. Similar to the first set of results in table 3, investment demand and government spending increases are expansionary, but in this case, they result faster growth and higher inflation due to the fact that the increase in domestic price will no longer drag the aggregate demand down via net exports reduction. Energy productivity (ξ_E) does not change in both scenarios, the change in labor productivity (ξ_L) and the change in energy-labor intensity (E/L) are equal due to: 1. Fixed input-output coefficient between energy and industry sector; and 2. Fixed ratio between imported intermediates and output because import elasticity was set to zero.

The 10% devaluation is contractionary rather than expansionary when industry sector's export is insensitive to foreign-domestic price ratio ($\epsilon P_i^*/P_i$). Contractionary devaluation occurs here primarily because the increase in foreign price pushes the cost of imported intermediates ($m_3\epsilon$) up in the industry sector, but the propensity to import stays the same because of zero trade elasticities, as the result the industrial value-added share v_3 shrinks resulting negative real GDP growth. Unlike the contractionary effects of wage increase exhibited in the first set of results in table 3, contractionary devaluation here is deflationary rather than inflationary. The explanation can be found in the industry cost composition equations (14) and (15) where v_3 is an important component in industry output cost. The increase of foreign intermediate cost contracts the domestic value-added share via equation (4), which in turn exerts downward pressure on energy and industrial prices. Although the increase of foreign intermediate cost also generates upward pressure

on price via the last item in equations (14) and (15), but the latter force is not strong enough to dominate the earlier force.

Contractionary devaluation results the deterioration of private and public balances due the fall of real income. External balance also deteriorates as the result of declining industry terms of trade. Unemployment and underemployment emerges due to the contraction, and the labor productivity fall with real GDP via the augmented Kaldor-Verdoorn equation. Despite of the economic contraction, the pattern of energy consumption in industry sector still worsens with increasing energy intensity and declining energy productivity. Conceptually, this is the worst-case scenario with simultaneous economic contraction and energy use intensification. Conversely, one can imagine that a "Green Growth" path emerges in this scenario with currency appreciation. However, it is important to emphasize that the aforementioned scenarios depend on zero trade elasticities, and trade elasticity is not really a policy parameter. Thus one should view these results as results of theoretical construct, to a large extent.

Finally, let's turn to the effect of wage increase. Wage increase in this setting is still contractionary; however, it is not nearly as severe as in the first set of results. This is again due to the fact that industrial export is now completely insulated from the effect of domestic cost-push inflation led by wage increase. Given the degree of export-dependence of the Chinese economy, such result is not surprising. However, what remain to be explained is, why consumption-led expansion did not occur with wage increase in this setting? If we pay attentions to the change of all the endogenous variables after the 10% industry wage shock, we would realized that while wage increase raises households' disposable incomes, it also generates rapid inflation in both industry and agriculture sectors. The industrial inflation is due to cost-increase, whereas the agricultural inflation is because of fixed output. In other words, agriculture supply constraint drives inflation, and the high consumption floor makes a shift away from agriculture difficult. Essentially, what we observed here is called "forced saving" – a common developing country phenomenon involving price inflation "forcing" households to consume less and save more in real terms. It is also evident from the improved private balance as the result of wage shock.

IV. Conclusion and Policy Implications

In this paper we examine the impact of China's structural change on a number of important variables -- most importantly on the use of energy in relation to both output and labor. Methodologically, we follow the general approach of structuralist economic theory. In order to examine the key issues for China, we construct a structuralist computable general equilibrium (SCGE) model based on a 3- productive activities -- agriculture, energy and industry – captured consistently in relation to factorial and household incomes and expenditure, transfers, capital account and external trade etc. by the social accounting matrix for China. Four simulation exercises are conducted using this model--- industrial investment demand increase, industrial wage increase, exchange rate depreciation, and government spending increase in industry. Our results show that

structural change associated with raising industrial labor productivity and employment share are likely to result in simultaneous intensification of energy-use and slight reduction of energy productivity in China. Industrial wage increase creates cost-push inflation and output contraction caused by a decrease in exports, and devaluation is expansionary. Furthermore, when industrial output is insulated from foreign-domestic relative price effects, devaluation becomes contractionary and wage increase results in a slight contraction in real GDP due to the "forced saving" effect. Essentially our model illustrates some of the challenges China faces in its attempt to achieve "green growth" objective with high level of employment.

From a policy perspective, we can conclude that the current growth strategy can be both ecologically and socially burdensome. Natural capital is being depleted while the quality of life for the great majority suffers. Furthermore, the already existing inequalities can worsen if a green growth strategy is not combined with a distribution-sensitive approach. Thus policy moves for wage-led growth and energy productivity increase need to be pursued in tandem. In this context, it is important to emphasize that moving towards green energy and away from fossil fuels requires explicit directives in the state sector and moral suasion plus price and other incentives for the private sector. (Khan, 2010) An across-the-board privatization will lead to further instabilities and distributive inequalities.

Consistent with the above point, Chinese geo-economics and geopolitics for further oil and gas acquisition needs to be changed (Khan, 2010; Christoffersen, 1998) in the direction of moving away from fossil fuel use and more regional cooperation. Some steps have already been taken in moving in the direction of green growth with increased regional cooperation. If the above policy directions are to be formulated in a detailed manner for implementation throughout the economy consistently, then issues of growth, energy use and distribution need to be integrated in a more disaggregated model that can be used for detailed macro, meso and micro policies. (Khan, 2010, 1997b; Khan and Sonko, 1994). Furthermore, linking the financial sector to the real sectors including energy sectors in a disaggregated structuralist CGE model (Khan, 2003, 2004) also looms as an urgent task for the policy-relevant research agenda.

In People's Republic of China in particular, given the history of unequal and ecologically harmful growth, it has to be recognized that energy productivity increase requires all around cooperation between engineers, economists, managers and workers. In effect, this points to a knowledge-technology based social democratic institutional arrangement with continual learning mechanisms. For this to occur China does have to evolve into more of a sharing economy than it is today. The change in this strategic orientation and the task of building institutions that can create sustainable growth with equity must be the highest priority of China in the next few decades.

References

Energy Informational Administration. "International Energy Database." Washinton, DC: EIA, Various Years.

Aziz, J., and X. Li. "China's changing trade elasticties." *IMF Working Paper*, no. 266 (July 2007).

Center for Climate and Energy Solutions . *CCESO International Key Countries Policies*. October 2015. http://www.c2es.org/international/key-country-policies/china (accessed November 12, 2015).

Cheung, Y., M. Chinn, and E. Fujii. "China's current account and exchange rate." In *China's Growing Role in World Trade*, by R. Feenstra and S. Wei, 231-271. Chicago, IL: University of Chicago Press, 2010.

Christoffersen, G. "China's intentions for Russian and Central Asian oil and gas." *NBR Analysis* (The National Bureau of Asian Research Analysis) 9, no. 2 (1998): 11-12.

Imb, J., and I. Mejean. *Trade Elasticities: A Final Report for the European Commission* . Economic Papers, Economic and Financial Affairs, European Commission, Brussels: European Commission, 2010.

Ke, J., et al. "Consumption trends and impacts of the top-1000 enterprises energy-saving program and the ten key energy-saving projects." *Energy Policy* 50 (2012): 562-569.

Khan, H. "China's development strategy and energy security." In *The Rise of China and India: Development Stratehies and Lessons*, by A. Santos-Paulino and G. Wan. Palgrave/Macmillan, 2010.

—. "China's entry into the WTO: ICT sectors, innovation, growth and distribution." *CIRJE, Faculty of Economics, University of Tokyo* . 2002. http://www.cirje.e.u-tokyo.ac.jp/research/dp/2002/2002cf157.pdf (accessed 11 12, 2015).

—. "Choice of technology in the energy and textiles sectors in Korea." *World Employment Programme Working Paper*, 1982.

—. "Choice of technology, energy and income distribution: a macroeconomic framework." *PhD dissertation.* Ithaca, NY: Cornall University, 1983.

—."Creating socia capabilities in POLIS." In *Technology and Modernity*, by T. Misa, P. Brey and A. Feenberg. Cambridge, MA: MIT Press, 2003.

—."Ecology, inequality and poverty: the case of Bangladesh." *Asian Development Review* 15, no. 2.

—. "Energy, technology and income distribution: a social accounting matrix for energy modelling." *Paper prepared for the Applied Simulation and Modelling Conference.* Calgary, 1982.

—. *Global Market and Financial Crisis in Asia: Towards a Theory for the 21st Century.* Basingstoke: Macmillan, 2004.

—."Innovation and growth in a Schumpeterian model." *Oxford Development Studies* 30, no. 3 (2002): 289-306.

—. *Innovation and Growth in East Asia: The Future of Miracles.* Basingstoke: Mamillan, 2004.

—."Macro-modeling of poverty and the dual-dual model." In *Poverty Strategies in Asia: Growth Plus*, by H. Khan. Cheltenham: Edward Elgar, 2006.

—. "Managing global risks and creating prosperity: the role of the IMP and regional financial architectures." Tokyo: Graduate School of Economics, University of Tokyo, 2002.

—. *Technology, Development and Democracy: The Limits of National Innovation Systems in teh Age of Postmodernism.* Cheltenham: Edward Elgar, 1998.

—. *Technology, Energy and Development: The South Korean Transition.* Cheltenham: Edward Elgar, 1997.

Khan, H., and E. Thorbecke. "Macroeconomic effects of technology choice: multiplier and structural path analysis." *Journal of Policy Modeling* 11, no. 1 (1988).

—. *Technology Choice and Difussion in a Macroeconomic Framework.* Aldeshot: Gower, 1988.

Khan, H., and K. Sonko. "A further extenion of adjustment models: the environment and equity." In *Economic Justic in Africa: Adjustment and Sustainable Development*, by G Shepherd and K. Sonko, 189-201. Westport: Greenwood Press, 1994.

Martinez-Alier, J., and K. Schlupmann. *Ecological Economics: Energy, Environment, and Society.* Oxford: Blackwell, 1991.

Mirowski, P. *More Heat than Light: Economics as a Social Physics, Physics as Nature's Economics.* Cambridge: Cambridge University Press, 1989.

Ocampo, J., C. Rada, and L. Taylor. *Growth and Policy in Developing Countries.* New York: Columbia University Press, 2009.

People's Republic of China. " The Renewable Energy Law." *Authorized Release.* Beijing: People's Repubic of China, 2005.

Stifel, C., and E. Thorbecke. "A dual-dual model for an archetype African economy: trade reform, migration and poverty." *Journal of Policy Modeling* 25 (2003): 207-235.

Thirlwall, A. "A plain man's guide to Kaldor's growth laws." *Journal fo Post Keynesian Economics* 5, no. 3 (1983): 345-358.

von Arnim, R., and C. Rada. "Labour productivity and energy use in a three-sector model: An application to Egypt." *Development and Change* 42, no. 6 (2011): 1323-1348.

World Bank and Development Research Center of the State Council. *Seizing the Opportunity of Green Development in China.* World Bank Group, 2013.

Appendix:

Figure 1: China's Numerical SAM 2007

	A(1)	E(2)	I(3)	A-House(4)	K-House(5)	W-House(6)	Gov (G)(7)	RoW (F)(8)	Inv (I)(9)	Sum (H)(10)
A(1)	6877	71	27395	5745	0	5411	342	666	4758	51266
E(2)	883	34634	42150	568	0	3001	0	1240	−2055	80421
I(3)	12474	15234	413097	19762	0	62066	34849	93635	111509	762625
Wage (W)(4)	27182	6717	76149	0	33079	0	7276	2951	0	153353
Profit (π)(5)	1430	12067	103981	0	0	0	0	0	0	117478
Gov (G) (6)	93	4270	35589	0	16196	3186	0	−13	52075	111396
RoW (F)(7)	2328	7429	64264	0	−1622	0	124	0	0	72523
Inv (I)(8)	0	0	0	18805	69825	34809	68805	−25956	0	166288
Sum (H)(9)	51266	80421	762625	44880	117478	108472	111396	72523	166288	1515350

Figure 2: China's Symbolic SAM

	A(1)	E(2)	I(3)	A-House(4)	K-House(5)	W-House(6)	Gov(G)(7)	RoW(F)(8)	Inv (I)(9)	Sum (H)(10)
A(1)	$P_1 X_1 a_{1,1}$	$P_2 X_2 a_{1,2}$	$P_3 X_3 a_{1,3}$	$C_A P_1$		$C_w P_1$	$G_1 P_1$	$P_1 E_1$	$P_1 I_1$	$P_1 X_1$
E(2)	$P_1 X_1 a_{2,1}$	$P_2 X_2 a_{2,2}$	$P_3 X_3 a_{2,3}$	$C_A P_2$		$C_w P_2$		$P_2 E_2$	$P_2 I_2$	$P_2 X_2$
I(3)	$P_1 X_1 a_{3,1}$	$P_2 X_2 a_{3,2}$	$P_3 X_3 a_{3,3}$	$C_A P_3$		$C_w P_3$	$G_3 P_3$	$P_3 E_3$	$P_3 I_3$	$P_3 X_3$
Wage(W)(4)	$L_1 w_1$	$L_2 w_2$	$L_3 w_3$		U_{bw}		U_{gw}	U_{fw}		Y_w
Profit(π)(5)	$K_1 r_1$	$K_2 r_2$	$K_3 r_3$							Y_π
Gov(G)(6)	T_1	T_2	T_3		T_b	T_w		U_{fg}	U_{kg}	Y_g
RoW(F)(7)	$\in M_1 P_{f1}$	$\in M_2 P_{f2}$	$\in M_3 P_{f3}$		U_{bf}		U_{gf}			Y_f
Inv(I)(8)				S_A	S_b	S_w	F	D	$-U_{kg} - \sum PI$	0
Sum(H)(9)	$P_1 X_1$	$P_2 X_2$	$P_3 X_3$	Y_A	Y_b	Y_w	Y_g	Y_f	0	