Structural change and climate policy in developing countries

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(Preliminary and incomplete)

Abstract

It has been argued that developing countries cannot make the same degree of carbon emission reductions as developed countries without doing serious harm to their economic development. However, most analyses of the cost of carbon policy omit the potential impact structural change; that is, the transition from industry to services as an economy develops. This may be important because services are much less carbon intensive than industry. I use a 2-sector nonbalanced growth model to study the impact of structural change on carbon intensity and cost to GDP of increasing carbon prices in China. I find that structural change does play an important role in reducing carbon intensity and also lowers output losses when carbon prices are increased.

1 Introduction

International negotiations to secure a climate treaty to avoid potentially disastrous climate change have been ongoing for two decades. The first significant agreement to be ratified was the Kyoto Protocol adopted in 1997; however, this treaty has been largely unsuccessful as most countries have failed to meet the non-binding greenhouse gas (GHG) emissions targets therein. One major shortcoming of the Kyoto Protocol was that it did not include developing countries. As a result, some developed countries were hesitant to make emissions cuts while countries like China and India grew their emissions rapidly. In fact, China is now the world leader in carbon emissions and it is widely agreed that rapidly-growing developing countries will be the major source of future emissions (see table 1). Thus, to keep GHG concentrations within safe levels, developing countries must significantly reduce emissions compared to a business-as-usual scenario (Stern, 2007).

Table 1: Current and future CO_2 emissions.

Country	CO_2 Emissions in 2008	Projected Future Emissions (Weyant et al., 2006)
China	7.0 Gt	180% increase from 2000-2050
U.S.	5.5 Gt	56% increase from 2000-2050
E.U.	4.2 Gt	30% increase from 2000-2050
India	1.7 Gt	200% increase by 2030 (Indian gov't)

While developing countries have been central in more recent climate negotiations, some argue that developing countries cannot make the significant GHG commitments needed without doing serious harm to their economic development. The basis for this argument is that the economies of developing countries are much more carbon intensive (see below). Thus it is important to understand the potential economic costs and benefits of enacting emission-reducing policies such as a carbon tax in developing countries. One important aspect of cost-benefit analyses of climate policy is the transformation of developing economies toward less carbon-intensive activities. For example, as countries develop we see industries like retail and finance grow relative to heavy industry and resource extraction. In this paper I study how this transition impacts carbon emissions and how it can reduce output losses from an increasing price on carbon.

Carbon intensity is emissions per unit of GDP, or alternatively, emissions is equal to carbon intensity times GDP. With GDP growth, the only way to stabilize emissions is to lower the carbon intensity. Consider the following decomposition of carbon intensity:

$$\frac{C}{Y} = \sum_{sector} \frac{C_s}{Y} = \sum_{sector} \frac{C_s}{Y_s} \frac{Y_s}{Y}$$

Carbon intensity can be reduced either by lowering sectoral carbon intensities $\frac{C_s}{Y_s}$ (efficiency gains), or by decreasing the sectoral weights, $\frac{Y_s}{Y}$, on carbon-intensive industries. Developing countries have higher carbon intensities as a result of being less energy efficient and producing more carbon-intensive energy, usually coal burning. Both of these factors are partially attributable to the industrial makeup of developing economies, as industrial sectors form a larger share of GDP in developing economies and industry requires a large amount of fossil fuels as inputs (especially heavy industry like steel and cement).

Structural change is a shifting of importance of various sectors in the economy (see Kuznets (1957), Baumol (1967), Duarte & Restuccia (2010)). Broadly, the literature documents a shift from agriculture to industry to services as an economy develops. Structural change impacts carbon intensity because industry is more carbon intensive than services. The Euro Area went from about 50% services in 1970 to nearly 70% services in 2000 (World Bank, n.d.). If, for example, industry is twice as carbon intensive as services, then the structural change alone would account for a 15% reduction in emissions intensity over the 30-year period.

Today, services make up 45% of China's GDP, so if structural change follows the pace of the Euro Area over the next 30 years then this could lead to considerable emissions savings. To omit this factor in policy analysis could lead to overstating the cost of reducing emissions. This paper will examine whether structural change is important for reducing emissions intensity in China. I quantify the contribution of structural change to lowering emissions given emissions scenarios including those from China's Copenhagen Accord commitment. For a given carbon price path, I also determine the reduction in carbon intensity as a result of structural change. The contribution of structural change to lowering carbon emissions is relevant for China because without properly accounting for structural change, a conservative target may be chosen even though a more aggressive target is easily achievable. From an international perspective, developed countries could push China to take on greater reductions in emissions knowing that cheap savings are on the way in the form of structural change. However, it must be noted that improvements in carbon efficiency (mostly through energy efficiency) also lower a country's carbon intensity.

I use a 2-sector non-balanced growth model to study how structural change impacts carbon emissions. The model is based on the non-balanced growth model of Acemoglu & Guerrieri (2008). The service sector grows more rapidly than the industrial sector creating structural change toward services. In addition to capital and labour, emissions are an input to production with the industrial sector being more emission-intensive. I calibrate the model to the Chinese economy. I consider five different price paths for carbon to see how the price of carbon affects the role of structural change in lowering carbon intensity. I use index methods from the empirical literature to quantify the impact of structural change on the reduction of carbon intensity. I also consider parametrizations of the model that do not allow for structural change and compare the impact on output and emissions of increasing the price of carbon.

Studies of the impact of climate change or climate change policy can be carried out at a global or national level. Global models do not account for structural change as regional interactions are the focus of those studies. At the national level, the literature offers more detailed sectoral modelling. Empirical literature suggests that structural change can play an important role in emissions and energy intensity reductions (a review is given in section 2). As a result, a few studies have attempted to account for structural change in examining Chinese climate policy. Zhang (1998a) and Hübler (2011) use sector-specific TFP growth rates to achieve structural change over time. Fisher-Vanden & Ho (2007) and Vennemo et al. (2009) exogenously vary share parameters over time. However, the structural change in these models depends on parameter assumptions not needed for the model I present here. Furthermore, the CGE models used in the studies above are static in the sense that choices are made accounting only for the current period. My model is fully dynamic and thus more appropriate to study a dynamic problem such as structural change.

I find that in the baseline scenario, aggregate emissions intensity is decreased by 55% after 30 years, with structural change making roughly half the contribution of efficiency gains. I also find that a higher price of carbon diminishes the impact of structural change as the substitution from emissions toward value added becomes a more dominant mechanism. Furthermore, I find that the long-run level of output is decreased by less than 5% for a doubling of the price of carbon (compared to baseline), but that increases to over 11% when structural change is shut down.

2 Literature

2.1 Economics of climate change for developing countries

The literature on the economics of climate change contains many cost-benefit analyses, as nations must understand the tradeoffs of enacting climate policy and negotiating international treaties. There are two common approaches to cost-benefit in climate change economics: 1) Calculate the decrease in output due to climate change and compare with the decrease from enacting a mitigation policy such as a carbon tax; 2) Compare different policy options looking only at the cost side. The former is typically applied to global models whereas the latter approach is generally taken for more detailed single-country analyses. Studies have generally found that for a warming of 2° to 3°, global GDP losses are 1%-2%, with developing countries being harmed more severely (Tol, 2009).

Carbon emissions are a global "public bad", meaning that emissions in one country affect the entire world, and emissions from the rest of the world affect each country. Therefore, in single-country analyses, an examination of only the cost side of a carbon policy is the typical approach. However, there is also a great deal of uncertainty regarding climate change and its effects, and hence cost-side approaches are sometimes adopted in global studies. For example, Whalley & Wigle (1991) used a multi-region model to examine the cost side only of different carbon taxation schemes. They found that when the revenues are collected and dispersed on a national level, the "developing and planned" economies experience a loss in Hicksian equivalent variation of 7% of GDP for a reduction in emissions of 50%. For India, Fisher-Vanden et al. (1997) found that to stabilize emissions at 1990 levels would result in a 6% loss in GDP by 2030, whereas stabilizing at three times 1990 levels would result in virtually no loss.

Most work on developing economies and climate change has focused on China. This reflects China's size and growth; China recently surpassed the U.S. to become the world's largest emitter of GHGs. Rose et al. (1996) simulated various emission reduction policies and found that significant reductions can be made with very minor cost to growth via mandated conservation, interfuel substitution and technological change. They found that only relying on a change in the sectoral mix would be very costly. However, this was a linear programming input-output model that did not have price responses. Zhang (1998a,b, 2000) investigated scenarios where Chinese emissions are cut by 20% and 30% compared to a 2010 baseline scenario (using a carbon tax). This resulted in 1.5% and 2.8% decreases in 2010 GNP, respectively. Garbaccio et al. (1999) introduced plan and market institutions side-by-side and as a result found that emission reductions of 5%, 10% and 15% lead to an *increase* in GDP because the carbon tax alleviates non-market inefficiencies.

Liang et al. (2007) studied how the carbon tax schemes of different Scandinavian countries would affect China. The schemes differ in their treatment of energy-intensive sectors and how the tax revenue is distributed. They found that the cost to GDP of a carbon tax is small (less than 1%) in all cases[1]. Fisher-Vanden & Ho (2007) compared the impact of

[1] Also of note, the model distinguished urban and rural households, the only paper on climate policy in China to do so.

a carbon tax in China with and without market reforms. They found that a tax-subsidy interaction effect dampens the responsiveness to a carbon tax in the non-reformed case. However, for small levels of emission reductions, the carbon tax can be welfare-improving as it alleviates inefficiencies, as was found by Garbaccio et al. (1999). Two papers incorporated damage feedback into their climate-energy-economy models. Aunan et al. (2007) found that emissions could be reduced by 17.5% relative to a baseline scenario without incurring a welfare loss. Vennemo et al. (2009) found that number to be 33%. Wang et al. (2009) modelled the Chinese economy with endogenous technological change. They found that the GDP cost of reducing emissions is 6.19% for a 50% reduction in 2050, but a subsidy for research and development lowers the loss to 3.87%. Dai et al. (2011) simulated the Chinese economy under China's actual climate policy. They found that the cost will be small, and that the policy will drive down the share of coal in electricity generation in favour of oil and gas. Finally, Hübler (2011) considered technology diffusion in China via FDI and imports. He found that the impact of climate policy on welfare depends on whether China could sustain high growth without substantial technological improvements. If yes, then welfare losses due to climate policy can reach up to 4%. If no, then there can be a net benefit due to the technology diffusion.

Gertz (2011) compared the loss in GDP level across developed and developing countries for an emissions reduction of 50%. The study found that while developed countries lose 2% of GDP, India and China lose 10% and 12%, respectively.

Most studies do not explicitly model structural change, and those that do incorporate structural change use different sectoral TFP growth rates (e.g. Zhang (2000), Hübler (2011)) or time-varying share parameters (e.g. Fisher-Vanden & Ho (2007), Vennemo et al. (2009)). I will explicitly model structural change to determine its impact on carbon intensity and the response to carbon prices.

2.2 Impacts of structural change on intensity

There have been many empirical studies of the impact of structural change on improvements in energy intensity.[2] The results indicate that the significance of structural change depend upon the country and the time period in question.

Howarth et al. (1993) examined the change in energy intensity across sectors for the U.S. between 1973 and 1988. They found that residential intensity decreased by 28%, manufacturing intensity decreased by 32%, other industry intensity decreased by 12%,

[2]Note that carbon intensity is highly correlated with energy intensity. Fan et al. (2007) found that 99% of carbon intensity gains in China from 1980-2003 were due to energy intensity gains (remaining 1% due to fuel mix changes).

services intensity decreased by 27%, passenger transport intensity decreased by 14% and freight transport intensity decreased by 1%. This indicates that efficiency gains are not necessarily equal across sectors.

Many empirical studies seek to decompose energy intensity gains into a structural change component and a sectoral efficiency gain component (for a review of the decomposition of energy intensity, see Ang & Zhang (2000)). Some have examined the decrease in the U.S. energy intensity between the early 1970s and 1990s (Rose & Chen (1991), Schipper et al. (1990)). They found that efficiency gains are the primary driver in the energy intensity decrease over that time. However, Wing (2008) examined a larger period from 1958-2000 and found that structural change is the more important factor (accounting for 2/3 of the decrease), but that efficiency gains were more important from the 1970s onward. Price effects (the oil shocks) drove technological change. Popp (2002) also found that prices drove efficiency gains over that period.

Schäfer (2005) decomposed energy intensity for six regions of the world between 1971 and 1998. For most developed areas, structural change lowered energy intensity by 3%-6%. For developing countries, the effect of structural change was mixed, putting a small upward pressure on energy intensity in Asia while reducing energy intensity by 5% in Latin America and 27% in eastern Europe. Nagata (1997) found that 41% of the difference between the U.S. and Japanese energy intensities is due to factors other than efficiency (prices, geography, climate, etc.). Gardner (1993) examined Ontario industry between 1962 and 1984 and found that aggregate intensity fell 1.5% per year with approximately equal contributions from structural change and efficiency improvements. Furthermore, efficiency improvements dominated from 1962-1972 while structural change dominated from 1973-1984. Diakoulaki & Mandaraka (2007) examined the impact of structural change on total emissions for countries in Europe between 1990 and 2003. They found that structural change reduced emissions in Ireland (-29%), Finland (-29%) and France (-12%) but increased emissions in the Netherlands (+17%), Belgium (+12%) and Germany (+9%).

There have been a few studies about energy intensity and structural change in China, although typically for small time windows. Fisher-Vanden et al. (2004) found that sectoral shifts accounted for 17.6% of the decrease in energy intensity from 1997-1999. Liao et al. (2007) found that the energy intensity increase from 2003-2005 was driven by the expansion of high-energy sub-sectors of the economy. Zhang (2009) found that of the 76% energy-related CO_2 intensity improvement from 1992-2006, 70% was due to efficiency gains.

It is clear that structural change can play a significant role in reducing energy intensity and hence carbon intensity; however depending on the location and time-frame considered, efficiency gains may dominate. My study will assess the relative importance of structural change in decreasing China's emissions intensity over the next 30 years.

3 The Model

The model is a 2-sector non-balanced growth model where one sector represents industry (which includes agriculture) and the other represents services. The model builds on the non-balanced growth model of Acemoglu & Guerrieri (2008). Each sector uses labour, capital and emissions as inputs to production. The production function for each sector has the same functional form but the parameters may differ which allows for differences in the rate of growth and emissions intensity. Goods produced by each sector are aggregated into a final good. Consumers maximize utility by choosing consumption and investment.

The intermediate goods are aggregated using a CES function:

$$Y(t) = A[\gamma Y_I(t)^{\frac{\epsilon-1}{\epsilon}} + (1-\gamma)Y_S(t)^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}} \tag{1}$$

Here, $Y(t)$ is the final good output at time t, $Y_I(t)$ is the industrial intermediate, $Y_S(t)$ is the services intermediate, A is a constant to adjust the level of output, γ is a share parameter and ϵ is the elasticity of substitution. The final good is used for consumption and investment:

$$\dot{K}(t) + \delta K(t) + C(t) = Y(t) \tag{2}$$

Here, $K(t)$ is the capital stock, $C(t)$ is consumption and δ is depreciation. Intermediates are produced using Cobb-Douglas technology[3]:

$$Y_i(t) = A_i(t)K_i(t)^{\alpha_i}L_i(t)^{\beta_i}Z_i(t)^{1-\alpha_i-\beta_i},\ i \in (I, S) \tag{3}$$

$L_i(t)$ is labour demanded at time t, $Z_i(t)$ is emissions demanded, $A_i(t)$ is the total factor productivity, and α_i and β_i are the share parameters. The profit function for the intermediates is:

$$\pi_i(t) = p_i(t)Y_i(t) - R(t)K_i(t) - w(t)L_i(t) - p^Z(t)Z_i \tag{4}$$

Here, $p_i(t)$ is the price of good i, $R(t)$ is the rental rate of capital, $w(t)$ is the wage and $p^Z(t)$ is the price of emissions. Note that the price of inputs is the same across sectors. The quantity or price[4] of emissions chosen in equilibrium is given by $p^Z(t)Z_i(t) = (1-\alpha_i-\beta_i)p_i(t)Y_i(t)$. The household receives payment for the right to emit carbon.

[3] I have developed a version of the model with CES technology between value added and emissions, however the results are preliminary and will not be presented here.

[4] I will switch between one and the other being exogenous.

Household preferences are represented by

$$\int_0^\infty \exp(-(\rho - n)t)\frac{c(t)^{1-\theta} - 1}{1-\theta}dt, \tag{5}$$

where ρ is the discount rate, n is population growth, $c(t)$ is per capita consumption and $1/\theta$ is the intertemporal elasticity of substitution. For an interest rate of $r(t) = R(t) - \delta$, the household problem gives the following Euler equation:

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\theta}(r(t) - \rho) \tag{6}$$

Finally, the transversality condition is:

$$\lim_{t\to\infty} \left[K(t) \exp\left(-\int_0^t r(\tau)d\tau\right)\right] = 0 \tag{7}$$

4 Constant growth path

As in Acemoglu & Guerrieri (2008), a constant growth path (CGP) is defined such that the growth rate of consumption is asymptotically constant.

$$\lim_{t\to\infty} \frac{\dot{c}(t)}{c(t)} = g_c^* = g_C^* - n \tag{8}$$

By equation (6), this means that the interest rate is also asymptotically constant. Furthermore, the final good must grow at the rate of consumption, $g^* = g_C^*$, otherwise the transversality condition is violated. By differentiating (1), we can obtain the growth rate of the final good:

$$g(t) = \frac{\dot{Y}(t)}{Y(t)} = \frac{\gamma Y_I(t)^{\frac{\epsilon-1}{\epsilon}} g_I(t) + (1-\gamma)Y_S(t)^{\frac{\epsilon-1}{\epsilon}} g_S(t)}{\gamma Y_I(t)^{\frac{\epsilon-1}{\epsilon}} + (1-\gamma)Y_S(t)^{\frac{\epsilon-1}{\epsilon}}} \tag{9}$$

Thus, the final good asymptotic growth rate, g^*, is equal to the the minimum ($\epsilon < 1$) or maximum ($\epsilon > 1$) of the sectoral growth rates (g_I^*, g_S^*). In order to be consistent with the stylized fact that the service sector increases its share of output with time, I impose $g_S^* > g_I^*$

and $\epsilon > 1$. Subsequently the asymptotic growth rates can be derived:

$$
\begin{aligned}
g_S^* &= g^* = g_C^* \\
n_S^* &= n \\
g_{K_S}^* &= g_K^* = g^* \\
g_{Z_S}^* &= g_Z^* \\
n_I^* &= n_S^* + \frac{\epsilon - 1}{\epsilon}(g_I^* - g_S^*) \\
g_{K_I}^* &= g_{K_S}^* + (n_I^* - n_S^*) \\
g_{Z_I}^* &= g_{Z_S}^* + (n_I^* - n_S^*)
\end{aligned}
$$

Thus, asymptotically, the service sector and its inputs grow at the rate of the overall economy while the industrial sector and its inputs grow at a slower rate. Furthermore, since the capital stock grows at the same rate as output, the capital-output ratio is constant in the limit. Since the interest rate is constant in the limit, the capital share is also asymptotically constant. Thus the "Kaldor facts" are preserved by this model in the limit.

Asymptotically, the TFP growth rate of the service sector is related to the growth rate of the overall economy:

$$a_S = (1 - \alpha_S)g^* - \beta_S n - (1 - \alpha_S - \beta_S)g_Z^* \tag{10}$$

Equation (10) is useful because the TFP growth rate is determined by exogenous parameters of the model. Futhermore, the following condition on the TFP growth rate of the industrial sector ensures that the service sector grows faster:

$$a_I < (1 - \alpha_I)g^* - \beta_I n - (1 - \alpha_I - \beta_I)g_F^* \tag{11}$$

Note that carbon intensity has been decreasing in developed countries and China for many decades. In standard models without structural change, a constant price of emissions will generate a constant intensity. However, with a constant emissions price in this model, the intensity can decrease in the short run due to the shifting of importance from a carbon intensive sector to a non-carbon intensive sector. In the long run, carbon intensity is constant when the price is constant.

5 Experiments

Numerical simulations of the model calibrated to the Chinese economy are used to quantify the impact of structural change on carbon intensity and output. First, I consider a set of five different carbon price paths. Note that in the long-run carbon intensity will decrease if the price is increasing. Thus I consider price paths with different non-negative growth rates for the carbon price to be consistent with policy objectives and the stylized fact that carbon intensity decreases with development. Across these scenarios I use index methods to quantify the contribution of structural change to lowering carbon intensity.

Next, I consider a calibration of the model that does not allow for structural change. I do this in two ways. First, I set the elasticity of substitution between industry and services very close to one. As a result, relative price changes offset the changes in relative quantities being produced in the two sectors. Second, I make the two sectors identical, in essence creating a one-sector model. I then calculate the emissions reduction and loss of output from a doubling of the carbon price (compared to the baseline). I compare the reductions with structural change to those in the two non-structural change calibrations of the model. This shows how structural change affects output losses from an increase in the price of carbon.

5.1 Data and calibration

I calibrate the model to the Chinese economy using economic data from the Chinese Statistical Yearbook (CSY, National Bureau of Statistics of China (2007)) and emissions data from the World Development Indicators (World Bank, n.d.). Sectoral-level data is from the most recent (2007) input-output table in the CSY.

The industry sector includes all types of manufacturing, chemical processing, construction, agriculture and mining. The service sector includes all other sectors, including electricity and transportation. It could be argued that the latter two sectors belong with industry, however it is customary to include them with services. In addition, it would be expected that electricity and transportation will grow at the rate of the service sector because household electricity consumption and vehicle purchases will likely increase with development. The initial shares in output of industry and services are calculated by summing the value added of the respective sub-sectors.

The share parameters for labour are calculated by summing "employee compensation" across appropriate sub-sectors and dividing by the corresponding value added. The capital share is 1 minus the labour share. I assume that emissions are linear in fossil fuels, and thus the share of emissions is the same as that of fossil fuels. However, the English version

	Industry	Services
Initial output share	0.57	0.43
Capital (α)	0.479	0.639
Labour (β)	0.418	0.343
Emissions ($1-\alpha-\beta$)	0.103	0.018

Table 2: Shares by sector: Initial shares of output and parameters calibrated to capital, labour and emissions shares of output.

$g^* = 6\%$	$g_z^* = 3.3\%$	$n = 0.3\%$
$\rho = 2\%$	$\delta = 5\%$	$\theta = 4$
$\epsilon = 5$	$\gamma = 0.51$	

Table 3: Parameter values

input-output table does not have fossil fuels disaggregated from mining[5]. Therefore I use half of the mining sector as a proxy for the fossil fuels/emissions input. The labour, capital and emissions shares are then normalized to sum to one.

The initial level of total output is China's 2007 GDP in RMB, total labour is employment in 2007 and total emissions is in kt CO_2 in 2007. The initial capital stock is taken to be 1.72 times output (Bai et al., 2006). The initial ratio of the *quantity* of output produced in each sector is taken to be the same as the ratio of the value of output produced in each sector. The initial allocations of capital, labour and emissions across sectors are then determined by the equations in the model,[6] as is the share parameter in the CES function, γ, aggregating industry and services.

Population growth is taken to be 0.3% from Vennemo et al. (2009).[7] Standard values are chosen for the discount rate (2%), depreciation (5%) and inter-temporal elasticity of substitution (0.25, or $\theta = 4$). The long-run growth rate (which determines TFP growth for the service sector) is taken to be 6%. This number is chosen because as China approaches the income levels of developed countries, it would be unprecedented to maintain growth rates near 10%. However, it was still desirable to simulate the rapid-growth character of China's economy over the transition path so a higher long-run growth rate than we see for

[5] I have recently had the Chinese version of the input-output table translated and will be able to use actual fossil fuel shares in the next version of the paper.

[6] Note that the actual allocation of labour was approximately 32% to services and 68% to industry in 2007, whereas the model gives 38% and 62%, respectively.

[7] According to the United States Census Bureau (n.d.), the current population growth rate of China is 0.5% and the population is expected to peak in 2026. However, the work force is expected to peak by 2016.

developed countries is used.[8] The TFP growth for industry is chosen to be the same as that of services.[9]

The elasticity of substitution between industry and services is chosen so that the share of services follows a path similar to that of the Euro Area from the 1970s onward. The Euro Area had a service share near 50% in the early 1970s and increased steadily to around 70% after 30 years (World Bank, n.d.). The labour share went from approximately 50% (of men) employed in services in 1990 to approximately 60% in 2010. The service shares for China begin and thus end slightly lower.

Finally, in the baseline scenario, a total emissions growth rate of 3.3% is taken from the International Energy Agency (2007).

5.1.1 No structural change calibration

In order to assess the economic savings from structural change in the face of an increase in the price of carbon, the baseline scenario is compared to parametrizations where structural change does not take place. I consider two ways of shutting down structural change. For the first, I use all of the parameters above except for the elasticity of substitution between industry and services, which is set to 1.01. For the second alternate calibration, I use all of the parameters given above except the shares of capital, labour and emissions are calculated for the entire economy and used for both sectors. The values are 0.548, 0.386 and 0.066, respectively. The former calibration of the final good production function is nearly Cobb-Douglas while the latter is exactly Cobb-Douglas. Since shares remain constant with a Cobb-Douglas production function, there is no structural change.

5.2 Numerical simulations

The calibrated model described above is simulated over a 500-year period, although I focus on the behaviour of the first 100 years where most of the dynamics take place. The differential equations are discretized using the Euler method and a shooting algorithm is used to solve for the time path of the model.

The "Kaldor facts" are stylized facts about economic growth asserting that the growth rate, interest rate and capital share are all relatively stable. Figure 1 shows time-path for these variables in the simulated model. Although the overall growth rate and interest rate are stable, the capital share increases slowly. This is due to the fact that services are

[8] In a future version of the paper I will conduct robustness checks on the growth rate.

[9] The growth rate of services is nonetheless higher because it is more capital intensive and capital grows more rapidly than labour and emissions.

much more capital intensive in the Chinese economy (0.64 to 0.48) and so the transition to services requires more capital. For the United States, I used the NIPA tables (Bureau of Economic Analysis, n.d.) to calculate the respective capital shares and found values of 0.36 for services and 0.34 for industry. Thus it is not surprising that the capital share does not increase as the service share increases in the United States, but this may not be the case in China.

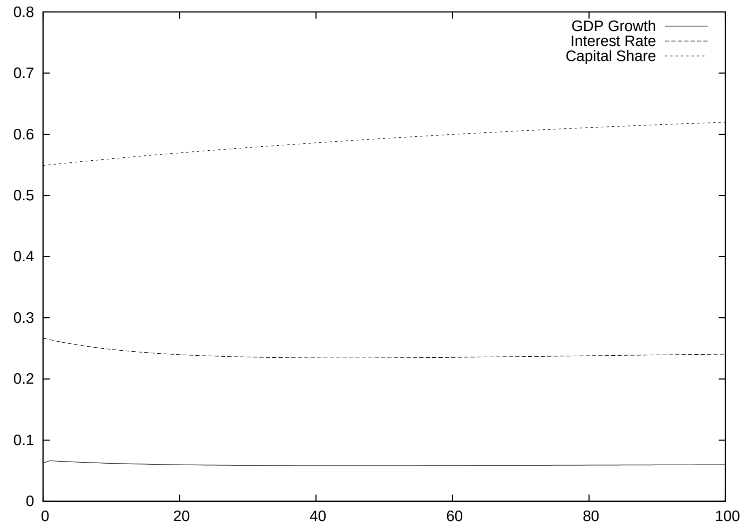

Figure 1: The Kaldor facts: The growth rate and interest rate are fairly stable. The capital share increases slowly with time.

Figure 2 shows the reallocation of resources toward services over time, and as a result services' increasing share of output. Note that after 30 years, the services share of output is around 63% compared to 43% at the beginning of the simulation. Labour goes from 38% to 57% services. This is similar to the transition in the Euro Area over 1970 to 2000 (see section 5.1).

Figure 3 shows the carbon intensity by sector over time. Initially the total intensity is closer to that of the industrial sector, but over time it is pulled closer to the intensity of the service sector as it begins to dominate. After 100 years, the total intensity is almost equal to that of the service sector.

5.2.1 Contribution of structural change

Having established the behaviour of the baseline scenario, I now consider several other emission price paths. The five scenarios are:

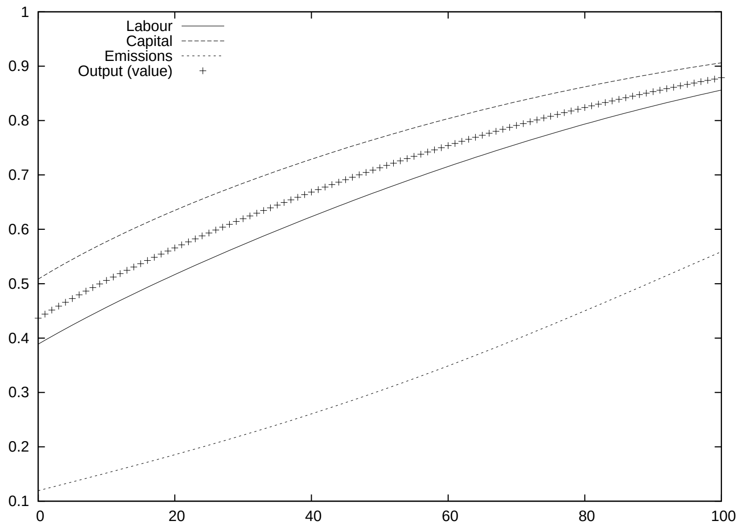

Figure 2: Structural change: The service sector shares of output, capital, labour and emissions increase over time (baseline scenario).

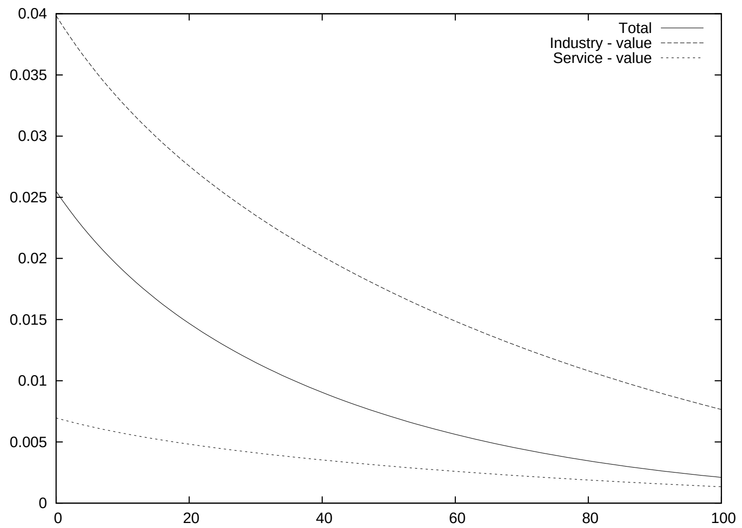

Figure 3: Carbon intensity by sector (baseline scenario).

1. High price scenario

2. 45% target

3. Baseline scenario
4. 40% target
5. Constant price

The 40% and 45% target scenarios correspond to price paths such that China's stated emission intensity reduction target is achieved. That is, a 40-45% reduction in carbon intensity by 2020 over 2005 levels. The constant price scenario is a constant price of emissions relative to the numeraire good (final good). The high price scenario yields an arbitrary carbon price path that is higher than the other scenarios. The price paths can be seen in figure 4. The corresponding intensity paths are shown in figure 5.

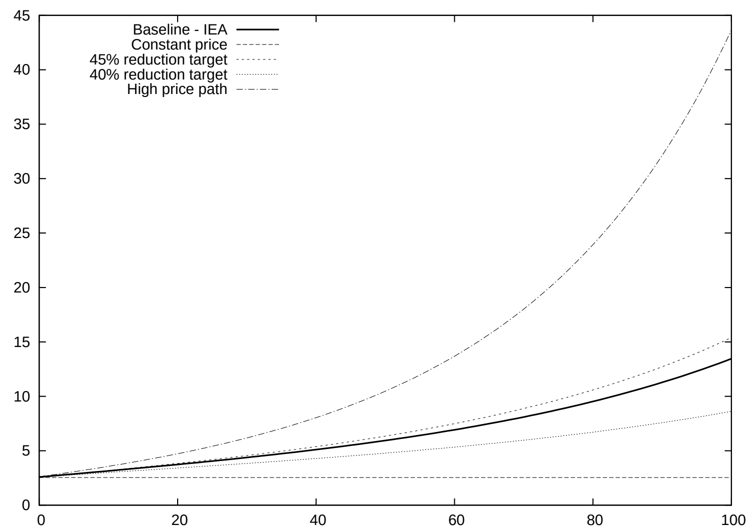

Figure 4: Carbon price paths.

The impact of structural change can also be quantified by using indices from the empirical literature on energy/carbon intensity and structural change (see Ang & Zhang (2000)). The breakdown of contributions to the decrease in carbon intensity using the Laspeyres multiplicative index is given in table 4. Structural change is makes a significant contribution to the reduction in carbon intensity, accounting for about 6/10 the contribution of efficiency gains in the baseline scenario. Furthermore, it is clear that the contribution of structural change increases as the carbon price decreases, to the point where structural change accounts for all of the intensity reduction in the constant price scenario. This is expected because for a higher carbon price the substitution of value added for emissions becomes more important.

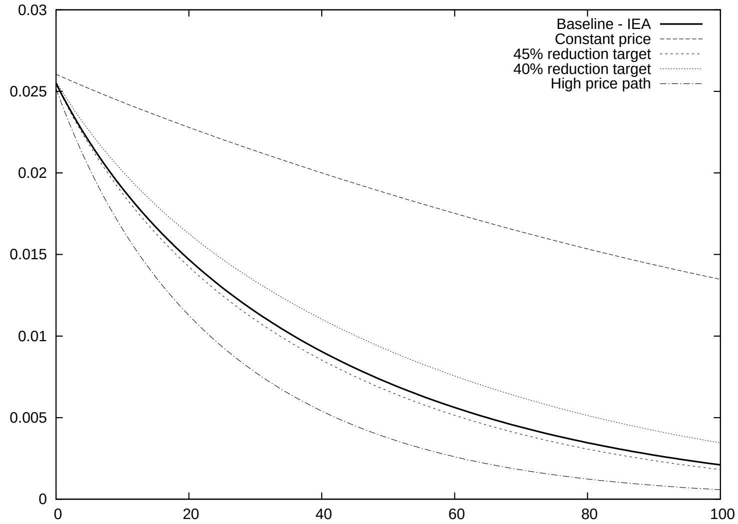

Figure 5: Carbon intensity by scenario.

Table 4: Contributions to reduction in carbon intensity over 30 years by scenario.

@ 30 years	Total reduction	Efficiency component	Structural component	Ratio S / E
High price	69%	58%	27%	0.47
45% target	57%	43%	24%	0.56
Baseline	55%	41%	24%	0.59
40% target	48%	33%	22%	0.67
Constant price	18%	0%	18%	∞

5.2.2 Impact on output and emissions

Having established that structural change could play an important role in lowering emissions intensity, I now examine the potential economic ramifications. Here, I calculate the reduction in emissions and output from a doubling of the carbon price compared to the path used for the baseline scenario above. I compare the results to two simulations where there is no structural change. In the first of those two simulations I set the share parameters to be equal for both sectors. This is exactly equivalent to a Cobb-Douglas production function for the final good. I label this simulation CD-1. In the second simulation the elasticity of substitution is set close to 1 so that the final good production function is approximately Cobb-Douglas. As a result, the shares of each sector must remain roughly constant. I label this simulation CD-2.

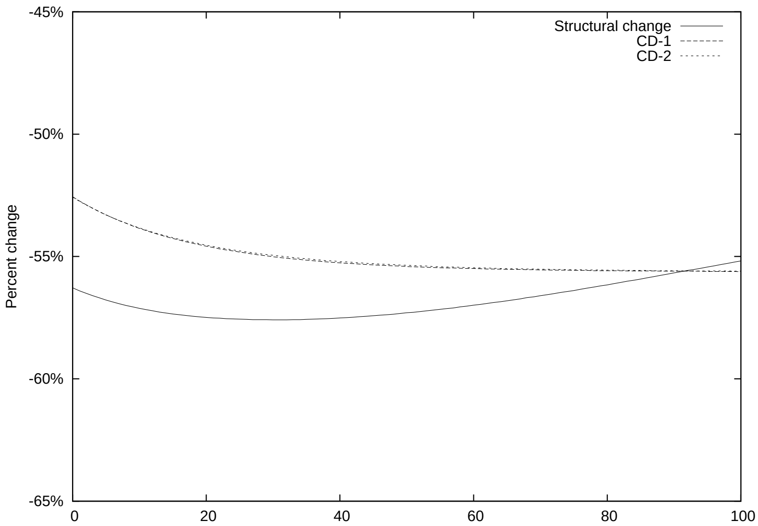

Figure 6: Reduction in emissions from doubling carbon price.

In figure 6 we see that doubling the carbon price has a similar impact on emissions across scenarios, with emissions being reduced by 52%-58% each year. However, the reduction is slightly greater for the model with structural change for most of the first 100 years.[10] Notice that the percentage reduction decreases after about 30 years in the model with structural change. This is because the marginal increase in the service sector share is decreasing as the service sector grows. However, the annual percent decrease in emissions asymptotes to a constant value in all simulations (around 54% with structural change, around 56% without).

In terms of output, we can see in figure 7 that the loss from doubling the carbon price in the structural change model is much lower. For example at 30 years, the structural change parametrization gives a loss in output of 7.8% compared to over 10% for the non-structural change parametrization. In the long run the difference is even greater at a loss of less than 5% with structural change compared to over 11% without. It is clear that the structural change plays an important role in allowing the economy a mechanism to reduce the impact of a carbon price increase.

[10]Note that the cumulative effect of this difference can be very significant as carbon emissions are a stock in the atmosphere taking around 100 years to be removed.

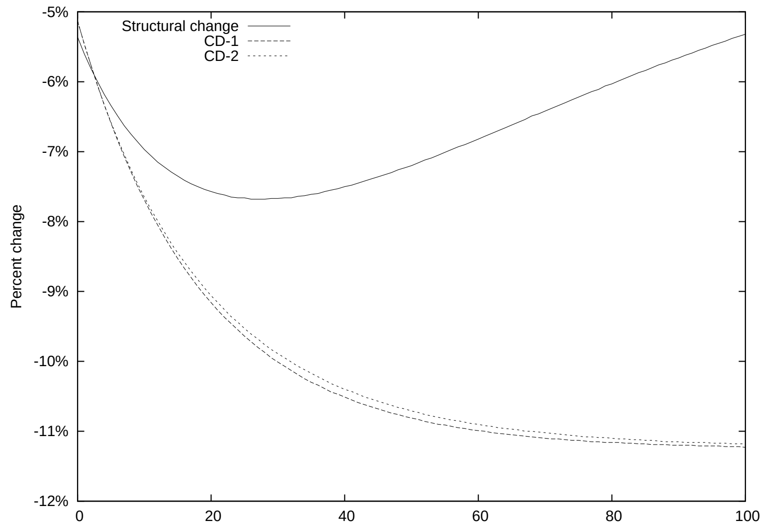

Figure 7: Reduction in output from doubling carbon price.

6 Discussion

With the growing global focus on mitigating climate change and the important role for developing countries, more studies of the economic impact of climate change and associated policies are being conducted. However, most studies do not account for structural change; in this case, the growing share of the service sector as an economy develops. This can be an important consideration because services are typically much less carbon intensive than industry. This paper has focused on how structural change affects carbon emissions and interacts with carbon prices. I use a non-balanced growth model with carbon emissions as an input to simulate the growth of the Chinese economy.

I find that structural change plays an important role in reducing carbon intensity ($\frac{6}{10}$ the contribution of efficiency gains in the baseline scenario), and that the contribution of structural change increases as the carbon price decreases. I also find that structural change reduces the loss in output from a carbon price increase. To show this I compare my model with structural change to two parametrizations without structural change where I double the carbon price and compute the resulting reduction in both emissions and output. I find that the percent reduction in yearly emissions is greater with structural change over roughly the first 90 years. In addition, the loss in output with structural change (less than 5% in long run) is significantly less than without (over 11% in long run). Thus it is clear that structural change can create significant savings for a country like China when lowering carbon emissions.

The implication of this result is significant. From the Chinese perspective, this means that for a given carbon price, the economic loss is much lower (in my example half) than what would be expected based on an analysis that does not account for structural change. The results also matter from an international perspective. Since it will be more costly for developing countries to reduce emissions (see Stern (2007)), it is likely that developed countries will have to make transfers to developing countries to offset economic losses. However, transfers may not have to be as large when structural change is taken into account.

Previous studies of the economic impact of cutting emissions in China have used more sectorally-detailed CGE models. While my model lacks this sectoral detail, it accounts for structural change and dynamics to bring fresh insights. For example, any baseline structural change in CGE models is generally driven by an exogenous savings rate; further change may come as a result of the introduction of a carbon tax. In the model presented here, forward-looking agents can adjust their savings to reach a more optimal state as a response to a higher carbon price. This may be particularly important for developing countries as there are an abundance new capital expenditures, especially in energy, to satisfy the rapid economic growth. In more developed economies, adjustment costs to the capital stock may be much more prohibitive. While a few earlier studies incorporate structural change, it was done by exogenously varying parameters over time. In the model presented here, structural change can respond endogenously to carbon prices and does not rely on uncertain assumptions about sector-specific TFP growth rates and time-varying share parameters. As a result of these differences, this paper elucidates important new facts about the impact of carbon prices, especially over the first 50-75 years where the dynamic effects are most important.

It is important to note that structural change will not have the same significant impact on all economies. For developed economies which are already 70%-80% services, there is much less scope for a transition to services lowering emissions. Even India, which already has a 56% service sector share, will not benefit to the same degree from structural change. This could result in different policy implications. For example, Nordhaus (1993) finds that the optimal carbon price policy is a steady ramp-up in the carbon price because future emissions cuts will be cheaper due to better technology. This may be the case for developed countries or even a country like India. However, for China cheaper emissions cuts may come earlier as it is relatively less costly to push the economy more rapidly toward services, implying a faster ramp-up of the carbon price.

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