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Energy Saving Technology Diffusion via FDI and Trade: A CGE Model of China*

Michael Hübler

Abstract:

This paper introduces intra- and inter-sectoral technology diffusion via FDI and imports into a recursive-dynamic CGE model for climate policy analyses. It analyzes China's accession to a Post Kyoto emission regime that keeps global emissions from 2012 on constant. Due to ongoing energy efficiency gains, partly stemming from international technology diffusion, China will become a net seller of emission permits and steadily reduce emissions, possibly below their 2004 level until 2030. This will reduce the world CO2 price significantly. The impact of supporting foreign firms and of reducing import tariffs on Chinese welfare will not significantly change when China joins the Post Kyoto regime.

Keywords: Technology diffusion, technology transfer, trade, FDI, climate change, China

JEL classification: F18, F21, N75, O33

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1 Introduction

The Chinese economy is expected to keep on growing and to be the world's main emitter of greenhouse gases, since it strongly relies on carbon intensive coal as an energy source. In 2004 China's carbon intensity[1] was more than three time that of Germany (World Bank 2008b). According to IEA (2007) projections, China's energy demand will more than double between 2005 and 2030, and China will be the world's biggest energy consumer soon after 2010. Asadoorian et al. (2008) even find a positive feedback mechanism between temperature and energy consumption in China, which would exacerbate the climate change problem. It seems absolutely necessary that China cuts greenhouse gas emissions to prevent at least the most severe impacts of climate change. A Chinese commitment to reduce emissions would encourage the USA and developing countries to make commitments on emissions reductions as well. Moreover, it is well known that China's economic growth causes tremendous local hazards for human health and the environment.

China is highly integrated into the world economy. It is worldwide one of the largest recipients of foreign direct investment (FDI) and plays a central role in global commodity trade. China's global economic integration strongly affects its growth and thus also the resulting environmental impacts. At the same time, economic integration promises an opportunity that is currently frequently present in the political debate as well as in the literature: international technology diffusion (summarized by IPCC 2000, OECD 2002, World Bank 2008a). In particular, financial and technical assistance of the industrialized countries for the developing countries was one of the postulations of the 2007 Bali conference on climate change. Furthermore, the World Bank initiates a global technology fund that to ease the access to emission saving technologies for developing countries. In general, technology diffusion can be a key to improve the energy efficiency of production and private consumption and to decarbonise energy generation.

But the right gateways for applying the key have not yet been clearly identified. A better theoretical and quantitative understanding of the economic effects and the underlying economic interactions is essential for opening up and supporting the right channels of technology diffusion. A better understanding of international technology diffusion could also ease China's decision to join an international climate negotiation. In the words of Popp (2006): "Diffusion of energy technologies, particularly across countries, is a fruitful avenue for further research."

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[1] Carbon intensity means CO_2 emissions in kg per 2005-PPP-Dollar of GDP.

Approaches for modeling endogenous technological progress are common in the CGE climate policy literature (for overviews see Grubb et al. 2002, Löschel 2002, Weyant und Olavson 1999). But despite the importance of international technology diffusion in the context of emission savings, there are probably no climate policy CGE models taking international technology diffusion explicitly into account. (Implicitly, international technology diffusion is modeled in form of a global knowledge stock, see for instance Buonanno, et al. 2003.) This paper fills this gap by introducing an approach that can be found in a similar way in a few CGE models in the field of development economics (van Meijl and van Tongeren 1999, Diao et al. 2002, 2005, 2006). The model specification and calibration follow the broad empirical literature on technology diffusion via trade and FDI. Following the empirical literature, the specification captures intra- and inter-sectoral technology spillovers. A contribution of this paper is to transfer this mechanism of general technology diffusion to energy specific technology diffusion.

We apply the methodology to the examination of China's accession to a hypothetical worldwide Post Kyoto emission regime. The aim is to assess China's capability to reduce emissions and the resulting influence on the global CO_2 price (not to assess certain Post Kyoto regimes currently discussed). Furthermore, the paper deals with the question whether the impact of supporting foreign owned firms and of reducing import barriers on Chinese welfare changes in the presence of international technology diffusion and an emission restriction. Leaving out international technology diffusion would lead to an underestimation of such policy effects. A sectoral CGE model including technology diffusion is able to estimate the overall effect of FDI and trade on output and emissions consisting of output expansion, sectoral changes and productivity improvements (compare Antweiler et al. 2001).

It turns out that China will reduce emissions below the 2004 level until 2030 and might become a net seller of emission permits. Energy efficiency gains in China, including FDI and trade induced energy efficiency gains, will significantly reduce the global CO_2 price. The role of supporting foreign firms and of reducing import tariffs for Chinese welfare does not significantly change when China has joint the Post Kyoto regime.

The paper is structured as follows: Section 2 briefly reviews the related literature. Section 3 gives an overview of the underlying version of the DART model. Section 4 describes how international capital movements are modeled. Section 5 explains the methodology of implementing general technology diffusion through FDI and trade, while section 6 transfers this methodology to energy specific technology diffusion. Section 7 examines welfare effects of China's accession to a global Post Kyoto climate regime and of FDI and trade policy linked to climate policy. Section 8 concludes.

2 Literature Background

FDI directly improves productivity in the destination country, when the foreign owned enterprises are more productive than the domestic ones. FDI indirectly creates productivity spillovers to local firms via product and process imitation (like reverse engineering) and demonstration effects (like on the job training and adoption of management skills) or via exchange of employees (workers, technicians, managers), via horizontal spillovers (within sectors) and vertical linkages (between sectors in the production change) (compare Saggi 2002). Imports directly improve productivity, if the imported goods have better characteristics than the domestically produced goods. Imports indirectly create productivity spillovers via imitation of the imported products and via improved application methods adopted together with the imported goods. Moreover, both FDI and trade potentially lead to productivity gains via stronger competition for domestic firms due to the presence of foreign owned firms and rivalling imports.

A broad strand of the empirical literature, covering country case studies and cross section and panel estimations, examines productivity gains and growth effects of trade and FDI – with mixed results (for overviews see Branstetter 1998, Kokko 1992, Saggi 2002, OECD 2002, Keller 2004, World Bank 2008a). Another literature strand deals with the impact of globalization on the environment using SO_2 emissions as an indicator for environmental quality (especially Antweiler et al. 2001, Copeland and Taylor 2005). Only few studies examine specifically the influence of trade and FDI on energy and emissions in the destination country (Cole 2006, Hübler and Keller 2008, for overviews see IPCC 2000, Murphy et al. 2005 and Peterson 2008).

Due to the extraordinary role of China for the world economy and for the energy and climate change challenge, several modelling attempts aim to forecast China's future economic development. For example, Garbaccio et al. (1998) set up a dynamic computable general equilibrium (CGE) model of the Chinese economy until 2032. They account for technological change, changing patterns of demand, and the dual nature of China's economy (planed and market based). The authors find a "double dividend" of pricing carbon emissions, a decrease in emissions of CO_2 jointly with a long run increase in GDP and consumption. Zhang (1998) studies the impact of Chinese emission reductions on Chinese GNP in a recursive-dynamic CGE model. A 20% emission cut in 2010 decreases GNP by more than 1.5%, while a 30% emission cut in 2010 decreases GNP by almost 2.8%. The simulations of an econometric model by Wu et al. (2004) indicate that carbon or energy taxes result in a drop of both Chinese economic growth and emissions until 2020. Higher FDI inflows or a depreciation of the Yuan raise GDP, imports and exports and increase CO_2 emissions. Soytas and Sari (2006) conclude from their VAR analysis that China can achieve long-run energy savings without hampering economic growth. IEA (2008) provides a comprehensive projection and description of Chinese energy issues until 2030. Accordingly, the Chinese energy policy can cut China's primary energy use in 2030 by about 15% compared with the reference scenario. Energy efficiency improvements and fuel switching would contribute 60% of the energy savings. Structural economic change in the economy would account for the rest of the energy savings. Blanford et al. (2008) recalibrate the inter-temporal optimization CGE model MERGE running simulations until 2030 (Manne and Richels 2005). All sources of non-price-induced changes in energy intensity are summed up in an autonomous energy efficiency index (AEEI) parameter. The model is calibrated to development patterns and energy use in emerging economies by choosing growth rates and AEEI values. Their results indicate that achieving a 450 ppmv atmospheric CO_2 goal is more costly than expected so far. Hence, climate policy must engage developing countries, especially China, and will probably require significant financial incentives given by the industrialized countries.

3 Overview of the DART Model

The DART (Dynamic Applied Regional Trade) model is a multi-region, multi-sector recursive dynamic CGE model of the world economy. For a detailed description see Springer (2002) and Klepper et al. (2003). The version of the model scrutinized here distinguishes three regions: China (*CHI*), industrialized countries (*IND*) and developing countries (*DEV*). The industrialized region encompasses the OECD countries plus Hong Kong, Macao, Taiwan, Singapore and South Korea, since they are important source countries of FDI to China (compare Tseng and Zebregs 2002, Whalley and Xin 2006). All other countries are named developing countries. The model considers four production factors: labor, capital and land and natural resources (fossil fuels), the latter as a fixed factor. The current sectoral aggregation covers 30 sectors in each region.[2]

Each commodity market is perfectly competitive. Output and factor prices are fully flexible. The model incorporates two types of agents for each region: producers, distinguished by production sectors, and consumers which comprise one representative household per region and the government. In order to analyze climate policies, CO_2 emissions are calculated based on the carbon content of the fossil fuels burned in final and intermediate consumption. Producer behavior is derived from cost minimization for a given output. The final consumer receives all income generated by providing primary factors to the production process. A fixed share of income is saved in each time period and invested into the production sectors. The disposable income (net of savings and taxes) is then used for maximizing utility by purchasing goods. The expenditure function is modeled as a CES composite, which combines consumption of an energy aggregate and a non-energy-bundle.

Factor markets are perfectly competitive and full employment of all factors is assumed. Labor is a homogenous good, mobile across industries within regions, but internationally immobile. While in the basic version of the DART model capital is also internationally immobile, in this version capital is internationally mobile between the industrialized region and China (see section 4). All regions are linked by bilateral trade flows, and all goods except the investment good are traded among regions. Domestic and foreign commodities are imperfect substitutes (Armington goods) distinguished by the country of origin.

The DART model is recursive-dynamic. It solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation. The major *exogenous* regionally different driving factors of the model dynamics are population growth, total factor productivity growth, human capital growth and investment in capital. DART also assumes constant, but regionally different growth rates of human capital taken from Hall and Jones (1999). Population growth rates and labor participation rates are taken from the PHOENIX model (Hilderink 2000) and in line with recent OECD projections.

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[2] Agriculture and food (AGR), textile, apparel and leather (TEX), beverages and tobacco (BEV), business services (BUI), chemicals, rubber and plastic (CRP), culture and recreation (CUS), coal (COL), communication (COM), construction (CON), crude oil (CRU), electrical equipment (ELM), electricity supply (ELY), ferrous metals (FEM), financial intermediation (FIN), gas (GAS), machinery (MAC), metal products (MET), minerals (MIN), non-ferrous metals (NFM), non-metallic mineral products (NMM), other manufacturing (OTM), paper products and publishing (PAP), petroleum and coal (OIL), trade and wholesale (TRD), public services (PUB), real estate (REE), transport machinery (TRM), transportation (TRN), water supply (WAT), wood (WOO). (Garbaccio et al. 1998 distinguish 29 sectors within the Chinese economy).

The static part of the DART-Model is currently calibrated to the GTAP 7 database (Narayanan and Walmsley 2008) that covers global production and trade data for countries and regions, commodities and primary factors for the benchmark year 2004. The model runs under GAMS MPS/GE.

4 International Capital Mobility in a Multi-Sector CGE Model

Although international capital mobility is not a standard feature in CGE models, several "international trade models" also include international capital mobility. Islam (1999) reviews methodologies for implementing capital mobility in CGE models. He distinguishes mobility of capital and mobility of savings, mobility within borders and across borders and mobility within periods and across periods. Goulder, Shoven and Whalley (1983) distinguish 'capital as a service' and 'capital as a good.'

According to the standard neoclassical theory, the investment to capital ratio increases with Tobin's q and is slowed down by adjustment costs. The adjustment costs create a gap between the capital price and the investment price.

The modeler needs to find a realistic simplification of the classic theory in a recursive-sequential model. Van der Mensbrugghe (2005) pre-determines international capital flows exogenously. A straight forward approach is to assume that the relative capital flow between two regions is determined by the capital price differential between these regions and an elasticity parameter (described by Islam 1999). In Mai (2004) the demand of domestic and foreign capital is determined by the related capital prices and additionally by residual influences such as state interventions. In the MIRAGE model (Bchir et al. 2002) savings are allocated across sectors and regions as a function of the initial savings pattern, the present capital stock and the sectoral rate of return to capital with a certain elasticity. Springer (2002) evaluates different degrees of capital mobility from perfect mobility over mobility of capital savings to mobility of capital stocks on a global scale with the DART model. While perfect mobility does not seem to be a realistic assumption (Feldstein and Horioka 1980), both of the latter assumptions lead only to small changes in international capital movements and little impacts on CO_2 emissions in Springer's assessment.

In the following part, section 4.1 explains the methodology of capital accumulation and international capital mobility of the current model. Section 4.2 describes the calibration.

4.1 Methodology

In the DART model, capital[3] is perfectly mobile within boarders (across sectors) and imperfectly mobile across boarders (in both cases within periods). Investments increase the capital endowments across periods. Investments are produced in form of an investment good, which requires production factors as inputs as any other kind of production.

Investment in a region I_R^t is set equal to savings S_R^t. Savings are a constant fraction of total income Y_R^t depending on the regional savings rate s_R (given by the GTAP 7 data):

$$I_R^t = S_R^t = s_R \cdot Y_R^t \qquad (1)$$

Note, that I_R^t, S_R^t and Y_R^t are measured in benchmark year prices of investment, i.e. in real values. At the end of every year *t*, investment is added to the existing stock of capital K_R^t, which is also measured in real values, i.e. in the benchmark period's price of investment. It depreciates at a rate δ_R:

$$K_R^{t+1} = (1 - \delta_R) \cdot K_R^t + I_R^t \qquad (2)$$

In the current model, capital is internationally mobile between the industrialized region (*IND*) and China (*CHI*) following the portfolio approach by Goulder and Eichengreen (1989), applied by Springer (2002) (like the approach described by Islam 1999, mentioned above). *IND* is the source region of FDI directed to *CHI*. We assume rigid international mobility of capital and home bias. This means, investors have a higher preference for holding capital assets at home in *IND* rather than in *CHI*, for instance because of transaction costs, uncertainties concerning the Chinese business environment or the fear of revealing knowledge to rivalling Chinese firms. (The latter aspect can be especially important due to the requirement of joint ventures of foreign with Chinese firms.) As a consequence of the imperfect mobility of capital, there is in general a price differential between the return rate on capital invested in *IND* and the return rate on capital invested in *CHI*. Due to home bias (home preference) of asset holding, the main part of new capital investment that is added to the existing value of capital is kept at home in *IND* in accordance with Feldstein-Horioka (1980).

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[3] The DART model uses values of capital *services* for calibration and calculation. This implies a multiplication of all capital stock values by a constant factor, i.e. a constant scaling of all capital values in the model (stock to flow conversion). For simplicity, we use the term "capital" instead of "capital services" throughout the paper.

Equation (3) is a CET function written in terms of capital prices. The return rates to capital are measured relative to the benchmark period, where all prices are set to one. Supply of capital, represented by the return rate r_{IND}, is diverted into domestically used capital, denoted by $r_{IND,IND}$ and foreign direct investment into *CHI*, denoted by the price of foreign capital $r_{IND,CHI}$.

$$r_{IND} = \left(\nu \cdot r_{IND,IND}^{\;1-\varepsilon_{KIND}} + (1-\nu) \cdot r_{IND,CHI}^{\;1-\varepsilon_{KIND}}\right)^{\frac{1}{1-\varepsilon_{KIND}}} \tag{3}$$

ν is the share of capital invested in *IND,* owned by the representative consumer in *IND* in the benchmark year. It indicates the home bias of asset holding in the portfolio. The benchmark share of capital invested in *CHI* owned by the representative consumer in *IND* is denoted by $(1-\nu)$. When the return on capital rises in *CHI*, the share of capital in the portfolio diverted to China will also increase. A higher elasticity of transformation ε_{KIND} means that the decision to invest at home or abroad reacts more sensitively to changes in the return rates on capital at home and abroad. The return on foreign direct investment is transferred from China back to *IND*. In the benchmark situation, the same value of foreign capital is subtracted from the current account surplus in *IND* and added to the current account surplus in *CHI*. This implies that a certain part of the current account surplus in each region is now explicitly treated as returns from FDI. All other values do not change in the benchmark year.

Figure 1 shows the main production structure in China (which is also valid in *IND* and *DEV* except the foreign capital input, i.e. there is only one kind of capital used in production in *IND* and *DEV*). The production structure principally follows the MIT EPPA model described by Paltsev et al. (2005).[4] The lower right nest combines the production factors capital, labor, land and energy. In China capital consists of foreign capital originating from *IND* and domestic capital combined with an elasticity of substitution ε_{KCHI}. Foreign and Chinese capital basically differ in terms of embodied technologies. The higher ε_{KCHI} the more equal are both kinds of capital. The capital-labor-land-energy composite is then combined with an intermediate input aggregate in form of a Leontief function. A CET function diverts output into a domestically sold and an exported part.

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[4] The nest structure is simplified compared to the original DART model, so that the solver can handle the more complex model including technology diffusion.

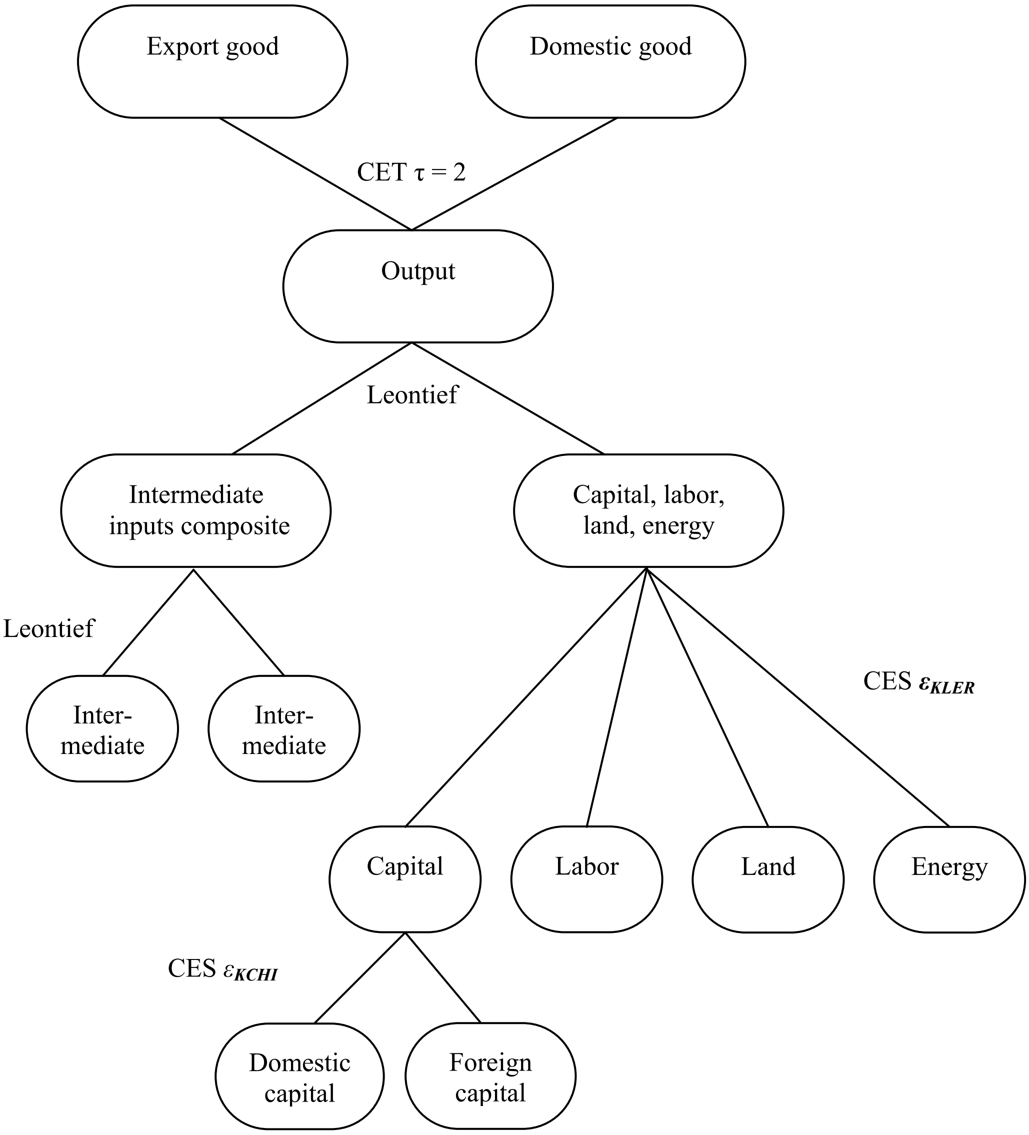

Figure 1: Main production structure (without foreign capital input in *IND* and *DEV*)

4.2 Calibration

The GTAP 7 data do not contain benchmark quantities of *foreign* capital. Hence, the benchmark quantities of foreign capital are derived from the China Statistical Yearbooks (2006, 2007). The total value of foreign capital in *CHI* originating from *IND* is computed as:

$$K^{i}_{IND,CHI} = \kappa_{IND,CHI} K_{CHI} \tag{4a}$$

$\kappa_{IND,CHI}$ is the total share of foreign capital relative to *all* foreign capital in China in the benchmark year, being 9.7%. $\kappa_{IND,CHI}$ is approximated by the sum of total investment in fixed assets by foreign funded economic units and by economic units with funds from Hong Kong, Macao and Taiwan divided by total investment in fixed assets. The data are taken from the China Statistical Yearbook (2007).[5] The underlying assumption is that capital investment shares are a good approximation for capital stocks. Given a time invariant investment share $\kappa_{IND,CHI}$, the validity of the same share for capital stocks is a logical consequence of the capital accumulation process. K_{CHI} is the benchmark value of all capital in China given by the GTAP 7 data.[6] Knowing $K^{i}_{IND,CHI}$ and the value of total capital in *IND*, we can also determine the parameter ν in equation (3).

In the next step $K^{i}_{IND,CHI}$ is distributed across Chinese sectors based on the benchmark sectoral shares of foreign capital κ^{i}_{SEC}:

$$K^{i}_{IND,CHI} = \kappa^{i}_{SEC}\kappa_{IND,CHI}K_{CHI} \tag{4b}$$

κ^{i}_{SEC} is the share of foreign capital in sector *i* in *all foreign* capital in China.[7] We approximate the foreign capital shares of the sectors agriculture, manufacturing, construction etc. by inter-sectoral shares of actually utilized investment values. Within the industrial sector, the foreign capital shares (for manufacture of transport equipment etc.) are given by inter-sectoral shares of *total assets* of enterprises with Hong Kong, Macao, Taiwan and foreign funds.

However, there are data accuracy problems as pointed out by Whalley and Xin (2006). FDI inflow data reported by the National Bureau of Statistics China differ from FDI figures reported by individual investing countries. Moreover, so-called round-tripping capital, originating from Mainland China and returning through Hong Kong possibly amounts to up to 20% of foreign capital (Dees 1998). And overall round-tripping capital possibly accounts for up to 40% (Xiao 2004). This insight contradicts expectations of large technology spillovers associated with capital imports. On the other hand, Whalley and Xin (2006) explain that the share of wholly foreign-owned enterprises increased between 2000 and 2004 from 46.9% of accumulated FDI to 66%, which may accelerate technology diffusion. The reason is that multinational enterprises are likely reluctant to transfer their most advanced technologies to joint venture affiliates, because they fear giving away their technology based competitive

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[5] Due to restricted data availability on investment in fixed assets for 2004, the *share* of foreign investment in total investment is computed as an average value over the years 2005 and 2006.

[6] Hong Kong, Macao, Taiwan, Singapore and South Korea are added to the group *IND* of industrialized source countries of FDI, because they play an important role for FDI to China (compare Tseng and Zebregs 2002, Whalley and Xin 2006).

[7] The China Statistical Yearbook sectoral data are aggregated in order to match the GTAP data. Due to restricted data availability on investment in fixed assets for 2004, the *shares* of foreign capital in specific sectors relative to all foreign capital in China are computed as averages over the years 2005 and 2006.

advantage to rivals. Finally, economic activities are unevenly distributed across China, most economic activities taking place in the Eastern costal region (see for instance Groenewold et al. 2008). Nevertheless, taking round-tripping capital and the spatial dimension of technological progress and spillovers within China into account is beyond the scope of our CGE analysis.

ε_{KIND} is set to 2. Thus, there is a home bias of holding capital; and holding capital at home and in China are relatively good substitutes. ε_{KLER}, the elasticity of substitution between the production factors, is set to 1, which is the standard Cobb-Douglas form following Popp (2004). ε_{KCHI} is also set to 1. Therefore, foreign and domestic capital are not perfect substitutes. This difference between domestic and foreign capital in China occurs due to different embodied technologies.

Table 4 in the Appendix gives an overview of sectoral indicators in the benchmark situation.

5 General Productivity Gains via FDI and Imports

This section describes the implementation of general productivity gains via FDI and imports in the DART model. There are few methods for implementing international technology diffusion in CGE models, and there is no standard approach. An easy way to incorporate international technology spillovers is to introduce a global knowledge stock and to insert it into local production functions as an additional production factor (for instance Buonanno, et al. 2003). This approach leaves open through which channels technologies spread worldwide. While international technology diffusion, explicitly driven via FDI and trade, is a new issue in climate policy modelling, it has been included in a few CGE models in the fields of agricultural, international trade and development economics. Bchir et al. (2002) simply assume that total factor productivity at the sectoral level grows in line with the share of FDI in total investment and an elasticity of five percent. Van der Mensbrugghe (2005) links productivity increases to economic openness defined as the export to output ratio. Van Meijl and van Tongeren (1999) assume that productivity growth increases with import intensities of intermediate goods. It also rises with a higher human capital level of the destination country compared with the source country and with a higher structural similarity (e.g. land to labor ratios) between the destination and source country.

Within the field of development economics, Diao, Rattsø and Stokke suggest several variants of implementing technology spillovers through trade and FDI in CGE models, in most cases referring to Thailand's economy. Diao et al. (2005) link labor augmenting and land augmenting productivity growth rates to the level of international trade. In Diao et al. (2002) productivity growth rates in the sectors agriculture, exportables, importables and non-tradables are Cobb-Douglas type functions of imported (and domestically produced) intermediate inputs multiplied by imported capital, each divided by total labor supply. In Diao et al. (2006) intermediate input and capital import values are measured relative to GDP instead, and additionally multiplied by the relative distance to frontier based on Nelson and Phelps (1966). While van Meijl and van Tongeren (1999) assume that the spillover strength is highest when the two regions are most similar, the Nelson and Phelps methodology rather assumes that technology diffusion is faster the larger the technology gap between the regions (for a detailed discussion see Hübler 2009). Rattsø and Stokke (2005) write productivity growth in the modern and traditional sector as a non-linear function of the investment to GDP ratio plus the trade to GDP ratio, the latter multiplied by the distance to frontier.

The specification used in this paper is similar to the methodologies described above. It is described in section 5.1. Section 5.2 describes the calibration of the approach introduced in 5.1.

5.1 Methodology

The following implementation of general productivity gains via FDI and imports is based on Nelson and Phelps (1966), Findlay (1978), Aitken and Harrison (1999) and Javorcik (2004). It combines elements from the CGE models designed by van Meijl and van Tongeren (1999) and Diao, Rattsø and Stokke. For more theoretical and empirical details see Hübler (2009).

The basic relation based on Nelson and Phelps (1966) and Findlay (1978) reads:

$$\dot{A}^t = \phi(\varphi,k,m)[T^t - A^t] \;\Leftrightarrow\; \frac{\dot{A}^t}{A^t} = \phi(\varphi,k,m)\left[\frac{T^t}{A^t} - 1\right]$$

$$\frac{\partial\phi(\varphi,k,m)}{\partial h} > 0;\; \frac{\partial\phi(\varphi,k,m)}{\partial k} > 0;\; \frac{\partial^2\phi(\varphi,k,m)}{\partial h\partial k} > 0;\; \frac{\partial\phi(\varphi,k,m)}{\partial m} > 0;\; \frac{\partial^2\phi(\varphi,k,m)}{\partial h\partial m} > 0 \tag{5}$$

A^t is the technology (total factor productivity) in practice in the destination country, in our case China *(CHI)*, changing over time *t*. Technological progress via technology diffusion is expressed as the time derivative of A^t, denoted by $\dot{A}^t$. T^t is the level of the exogenous technology frontier in the industrialized region *(IND)*. We assume that capital and goods transferred from *IND* to *CHI* embody technologies up to this frontier level. Technologies stemming from *IND* are not immediately available throughout production processes in *CHI*. They rather need time to diffuse into and through *CHI* described by the differential equation (5). Technology diffusion rises with the *IND-CHI* technology gap, T^t minus A^t. The intuition is simple: The larger the technology gap the less of the newly arriving technologies are already known in *CHI*. Hence, more of the newly arriving technologies can be beneficially adopted. This results in a convergence process of the technology level in *CHI* towards the technology frontier in *DEV*.[8] Φ is the spillover strength, which increases with human capital (educational attainment) φ in *CHI*. φ can be interpreted in a broader sense, including other determinants of the host economy that influence technology diffusion, like property rights, telecommunication possibilities, infrastructure etc. We assume that Φ increases with the foreign capital intensity k and the import intensity m. φ, k and m are complements, they enhance each other.

This technology diffusion mechanism is supported by empirical evidence. For instance, World Bank (2008b) data describe that the spread of personal computers, of internet access and of broadband subscriptions in China increased strongly after the introduction and levelled off until 2005.[9] Moreover, there is evidence for the capability of FDI "to close the technology gap" and for sectoral differences. Moreover, Young and Lan (1997) present survey results from the city of Dalian in Northeast China indicating that the source of FDI and the sector matter for technology diffusion. For example, on average, 39% of FDI are reported to involve a technology gap of at least 10 years compared with the technology in practise in China. 68% of this share are in turn reported to be to some extent or completely transferable.

The following part explains how relationship (5) is implemented in the current CGE model. We additionally take forward and backward spillovers across industries explicitly into account as frequently motivated by the empirical literature (referring to China by Young and Lan 1997 and Liu 2002 and 2008). The implementation of vertical linkages introduced here, is similar to the empirical specification by Javorcik (2004). (For an implementation of inter-sectoral R&D spillovers see Lejour et al. 2006.) Most studies dealing with China identify backward linkages as the most significant spillover channel as in the general literature.

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[8] The World Bank (2008a) confirms the hypothesis of technological convergence of some, but not all developing countries.

[9] The diffusion speed of old technologies is in general slower than the diffusion speed of new technologies, World Bank (2008a).

The following function relates the relative change in total factor productivity (in other words the rate of technological progress) $\Delta A_{CHI}^{it} / A_{CHI}^{it}$ in a certain Chinese sector *i* in year *t* to the foreign capital and import shares in that sector and year and to vertical linkages to other sectors:

$$\frac{\Delta A_{CHI}^{it}}{A_{CHI}^{it}} = \varphi_{CHI}^{t} \mu_{CHI} \left(\mu_K \frac{K_{IND}^{it}}{K_{CHI}^{it}} + \mu_M \frac{M_{IND}^{it}}{Y_{CHI}^{it}} + \mu_B \sum_{b,b\neq i} \frac{K_{IND}^{bt}}{K_{CHI}^{bt}} \frac{D_{CHI}^{bit}}{Y_{CHI}^{it}} + \mu_F \sum_{k,k\neq i} \frac{K_{IND}^{ft}}{K_{CHI}^{ft}} \frac{D_{CHI}^{ift}}{Y_{CHI}^{it}} \right) \left(\frac{\dfrac{Y_{IND}^{it}}{L_{IND}^{it}}}{\dfrac{Y_{CHI}^{it}}{L_{CHI}^{it}}} - 1 \right) \quad (6)$$

$$+ a_{CHI}$$

φ_{CHI}^{t} is the human capital level in China that is shown to influence productivity spillovers in China by Lai et al. (2006) and Xu et al. (2008) (but questioned by Wei 1993). Its multiplicative interaction with the sources of growth is motivated by the use of interaction terms in the econometric literature (for example by Lai et al. 2006). The human capital level improves over time exogenously in the different regions. Total factor productivity a_{CHI} increases exogenously as well. Exogenous total factor productivity growth is the only source of technological progress in the regions *IND* and *DEV*, since technology diffusion is modeled only in China. $K_{IND}^{it} / K_{CHI}^{it}$ denotes the share of foreign capital originating from *IND* relative to Chinese capital in each sector. The higher the foreign capital intensity in a sector, the higher the technology diffusion speed (compare Findlay 1978 and the empirical literature described before). $Y_{IND}^{it} / L_{IND}^{it}$ over $Y_{CHI}^{it} / L_{CHI}^{it}$ is the relative difference in labor productivities (output value divided by the labor force size) between *IND* and *CHI* in each sector, representing the gap between the technologies in practise.[10] Since L_{IND}^{it} is not directly given by the GTAP 7 data, we compute it in the following way:

$$L_R^{it} = \frac{l_R^{it}}{l_R^{total,t}} L_R^{total,t} \quad (7)$$

$l_R^{it} / l_R^{total,t}$ denotes the labor input value in sector *i* relative to the total labor input value in region R (*CHI, IND, DEV*) at time *t*. $L_R^{total,t}$ is the size of the total labor force in that region at time *t*. In other words, equation (7) expresses the number of workers in a sector $L_R^{total,t}$ as the

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[10] The results by Branstetter and Lardy (2006) support the choice of labor productivities as a productivity and technology measure.

labor input value in that sector l_R^{it}, divided by the average wage $l_R^{total,t} / L_R^{total,t}$ in region *R*. This enables us to use the GTAP 7 data.

μ_{CHI} is a constant parameter that determines the general spillover strength in China. μ_K is the spillover strength with respect to foreign capital relative to μ_{CHI}, which can be normalized to one. μ_M is then the spillover strength stemming from imports relative to the import strength stemming from foreign capital. Technology diffusion associated with μ_K and μ_M describes *horizontal* technology spillovers across firms within a sector *i*. Technology diffusion associated with μ_B and μ_F describes *vertical* technology spillovers across firms between sectors in the production chain. μ_B is the spillover strength with respect to backward linkages through intermediate good inputs, and μ_F with respect to forward linkages through intermediate goods supplied to downstream sectors. $M_{IND}^{it} / Y_{CHI}^{it}$ describes the import value to output value ratio in each sector. This implies that only newly imported commodities bring about additional knowledge. $K_{IND}^{bt} / K_{CHI}^{bt}$ denotes the foreign capital share in a backward upstream sector *b*. $D_{CHI}^{bit} / Y_{CHI}^{it}$ is the value of intermediate goods transferred from the backward sector *b* to sector *i* divided by the output value of sector *i*.[11] In the same way, $K_{IND}^{ft} / K_{CHI}^{ft}$ denotes the foreign capital share in a forward downstream sector. $D_{CHI}^{ift} / Y_{CHI}^{it}$ is the value of intermediate goods transferred from sector *i* to the forward sector *f* divided by the output value of sector *i*. Summing up over all upstream and downstream sectors captures all inter-sectoral vertical spillovers.

A, K, D, M, *L* and *Y* are endogenous variables; *φ* increases exogenously; the *μ* parameters and *a* are exogenous parameters that we need to calibrate.

5.2 Calibration

Several data sources help us calibrate the model. We calibrate it in an iterative process in order to match all information as close as possible. However, there are uncertainties in the choice of parameter values. Thus, we will change the strength of technology diffusion in

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[11] Note that the model does not distinguish, whether the intermediate goods have been produced at home or abroad. Thus, also intermediate goods imported by Chinese firms and traded to other Chinese firms create forward linkages. In the same way, intermediate imports bought from Chinese firms, which in turn imported these intermediate goods, create backward linkages.

alternative scenarios in order to examine the sensitivity of the model results to changes in the parameter values.

(1) The general literature on productivity spillovers finds elasticities of total factor productivity (or output) with respect to FDI (intensities of inflows or equity shares) and import (intensities) in the range of 0.03 to 0.1, many elasticities being around 0.05.[12]

Many econometric studies specifically examine the Chinese economy, because of its important role within the world economy and as a major emitter of greenhouse gases. Wei (1993), for example, finds a 1.3 percentage point higher growth rate for a one percent increase in the absolute size of FDI inflows, while the FDI share does not lead to significant effects. Following Berthélemy and Démurger (2001) the coefficient for the impact of FDI relative to GDP on the growth rate is 0.037; following Sun and Parikh (2001) it is 0.358 to 0.818 or even higher for some Chinese regions. Liu (2008) estimates that a one percentage point increase of the foreign equity share in a sector raises total factor productivity by about 0.037% (horizontal linkage). The corresponding effect of the foreign equity share in downstream sectors is about 0.070% (backward linkage). The influence of the foreign equity share in upstream sectors has a similar magnitude as the intra-industry spillover, but it is statistically not significant.[13] According to Kuo and Yang (2008), the elasticity of growth in Chinese regions with respect to FDI stocks is 0.021.[14] While this relationship is not robust and differs across provinces, the authors find statistically and economically more significant effects of imports on growth, in particular a growth elasticity of 0.041 to 0.066.

In our model, the marginal effects of FDI and trade on productivity are determined as follows. The human capital endowment φ^t_{CHI} is derived from Hall and Jones (1999) and equals 1.019 in the benchmark year. The average relative distance to frontier over Chinese sectors (the last term in parentheses in equation 6) is 13.113 in the benchmark year. Thus, setting μ_{CHI} = 0.0005 and $\mu_K = \mu_M =$ 1 yields an overall coefficient of about 0.0067 for $K^{it}_{IND} / K^{it}_{CHI}$ (horizontal linkage) and also for $M^{it}_{IND} / Y^{it}_{CHI}$. This magnitude is conservative compared with the econometrically estimated coefficients described before. The magnitude of $K^{it}_{IND} / K^{it}_{CHI}$ is similar to the magnitude of $M^{it}_{IND} / Y^{it}_{CHI}$ computed as averages across Chinese sectors. (In the

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[12] Coe and Helpman (1995), Coe et al. (1997), van Pottelsberghe de la Potterie and Lichtenberg (2001), Aitken and Harrison (1999), Hejazi and Safarian (1999), Xu and Wang (2000), Keller and Yeaple (2003), Ciruelos and Wang (2005), Lee (2005), Zhu and Jeon (2007) are a few examples.

[13] Note that Liu (2008) finds positive growth spillovers, but negative level spillovers for all linkages.

[14] They find no statistically significant relationship in their fixed effects estimation.

alternative scenario „Zero“ we set μ_{CHI} = 0, and in the alternative scenario „Double“ we set $\mu_{CHI} = 0.001$.) Since technology diffusion via imports is assumed for less sectors than for technology diffusion via FDI, the impact of imports on technology diffusion is potentially smaller than the impact of FDI (see below and Appendix, Table 4). The average of $D_{CHI}^{bit} / Y_{CHI}^{it}$ over Chinese sectors is 0.25. μ_F is set to 4 giving forward linkages a similar magnitude as horizontal linkages. We assume $\mu_B = 8$ resulting in a dominant role of backward linkages based on the empirical literature.

(2) Furthermore, we look at dynamic indicators for technological progress. The sectoral development of output, labor productivity, energy productivity and the foreign capital share can be computed from China Statistical Yearbook for the last years. Moreover, World Bank (2008b) data show that between 1980 and 2006 China's GDP rose on average by 9.87% per year, labor productivity grew on average by 7.19% per year and the foreign capital share by 8.41% per year, the latter being volatile and often negative.[15] Chinese GDP grew by 10.1% in 2004. Historical simulations by Mai et al. (2003) yield yearly rates of productivity improvement amounting to 6.2% in agriculture, 2.1% in mining, 10.1% in light manufacturing industries, 6.5% in "pillar" manufacturing industries and 2.9% in services.

The Chinese growth rate of labor productivity in 2004 resulting from our model simulation is less than 8% in accordance with the empirical evidence. The resulting growth rate of Chinese GDP for 2004 is ca. 10.2%, which is about the growth rate computed from World Bank (2008b) data.

(3) Moreover, there is empirical evidence for the share of economic growth associated with inward FDI. As reported by Tseng and Zebregs (2002), FDI contributed 2.5 percentage points of China's GDP growth during the 1990s via positive spillovers from foreign enterprises and 0.4 percentage points of GDP growth via enhanced capital accumulation. Similarly, Whalley and Xin (2006) find that FDI contributed to 3.4 percentage points of China's GDP growth in 2003 and 2004, including 1.6 percentage points stemming from technologies embodied in foreign capital. Thus, foreign invested enterprises contributed to over 40% of China's economic growth. Sun and Parikh (2001) estimate that FDI accounted only for 7% of growth in the coastal region. Lai et al. (2006) find an influence factor of foreign R&D on Chinese growth via FDI of about 0.24 (ca. 0.11 when multiplied with Chinese human capital). The analogue effect stemming from imports is only between 0.057 and 0.072 (ca. 0.01 when

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[15] Very high foreign capital share changes in 1981, 1992 and 1993 have been removed as outliers.

multiplied with human capital). These results suggest that in China the productivity spillover effect of inward FDI is about three to ten times higher than that of imports. Similarly, Rattsø and Stokke (2003) estimate that trade (imports plus exports) over GDP explains 30% of total factor productivity growth, while FDI over total investment explains 40% of growth referring to Thailand's industry sector between 1975 and 1996. On the contrary, in the agricultural sector the trade share explains over 80% of total factor productivity growth.

Although we set the single spillover strength values of horizontal FDI, vertical FDI and imports rather low, the sum of all technology diffusion effects is rather high, but in accordance with the empirical evidence. In our model, international technology diffusion contributes about 4 percentage points of growth or 40% of total growth. (While the growth share of 40% reported by Whalley and Xin (2006) includes only technology diffusion via FDI, our share also includes technology diffusion via imports.)

(4) Point (3) indicated sectoral differences in technology spillovers via FDI and trade. Sectoral differences are also identified in India: Chakraborty and Nunnenkamp (2008) describe that the growth effects of FDI differ between sectors. In particular, they are mainly found in production sectors, only to some extent in the service sector and less likely in the agricultural sector. In general, most of the econometric studies cited at the beginning of this section use industrial production data. Hence, the empirical evidence is strongest for the industry sector.

We follow the empirical evidence when including sectors into technology diffusion via FDI and trade. Table 4 in the Appendix shows that in our model, FDI increases productivity in all sectors except culture and recreation, petroleum and oil, public services and real estate. Imports are assumed to improve only productivities in machinery production sectors and in agriculture (e.g. via the imitation and implementation of imported advanced grain types and related production methods).

(5) Furthermore, the OECD provides country (or region) specific GDP forecasts until 2030. According to OECD (2008), China's GDP will be 6.372 trillion US-$ in 2030. China's GDP growth rate will average around 7.2% between 2005 and 2010, 4.9% between 2010 and 2020 and 4.1% between 2020 and 2030.

We choose the exogenous rates of yearly total factor productivity improvements $a_{CHI} = 0.0105$, $a_{IND} = 0.0086$ and $a_{DEV} = 0.013$ such that the GDP values for 2030 generated by the model match those predicted by the OECD for 2030. The resulting GDP growth rate declines from 4.1% in 2020 to 2.7% in 2030.

(6) Finally, the IEA (2008) provides forecasts of regional future emissions distinguished by fossil fuel sources.

We calibrate the resulting CO_2 emissions from burning fossil fuels accordingly. In Scenario I we consider only general technological progress and no energy specific technological progress. The elasticities[16] of coal, oil and gas supply for China and the other regions are chosen so that the Chinese emissions and the world wide emissions stemming from coal, oil and gas come close to the *Reference Policy Scenario* with high emissions for 2030 estimated by the IEA (2008). (Different to the IEA, our simulations yield higher emissions stemming from oil.)

Appendix, Table 4 gives an overview of sectoral indicators in the benchmark situation. All parameter values are reported in Appendix, Table 5.

6 Energy Efficiency Gains via FDI and Imports

This section transfers the methodology of implementing general international technology diffusion to energy specific international technology diffusion. In general, there is no reason to believe that energy technologies diffuse in a different way than other technologies. Usually, energy saving characteristics are connected to other technological advances in the same product such as a machine or a car. Therefore, it is straightforward to assume that general productivity advancements and energy specific advancements diffuse jointly. Consequently, the model framework developed in section 5.1 can be transferred to energy specific technology diffusion.

Section 6.1 describes the methodology of modelling international diffusion of energy saving technologies. 6.2 explains the calibration of the methodology derived in 6.1.

6.1 Methodology

Lin and Polenske (1995) and Garbaccio et al. (1999) show that changes in subsectoral intensities explain the main part of the decline in China's energy intensity, which supports the implementation of a sectoral diffusion model. The following equation (9) differs from

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[16] The elasticities of coal, oil and gas supply link the fixed resource input factor to the other input factors in the related energy production function. In our simulation, CO_2 emissions stemming from oil are higher than in IEA (2008).

equation (6) in three respects. First, in equation (6) technology diffusion enhances total factor productivity, i.e. the output quantity given certain input quantities. Now, technology diffusion reduces the ceteris paribus necessary energy input quantity to produce a certain output quantity; thus equation (9) has a negative sign. Second, labor productivities as efficiency measures are replaced by energy productivities. Herein, it is important to note that the simulations yield energy inputs in value form, which depend on energy prices that differ significantly across regions. In order to derive an inter-regionally comparable measure, we compute "real" energy input E_R^{it} in a region *R* (*CHI, IND, DEV*), in a certain sector *i* at time *t* in the following way:

$$E_R^{it} = \frac{e_R^{it}}{e_R^{i,2001}} \rho_R^{2001} \qquad (8)$$

$e_R^{it} / e_R^{i,2001}$ denotes the ratio of the energy input value in year *t* relative to the energy input value in the base year 2004. ρ_R^{2001} is the physical energy input (in Giga Joule) in 2004 given by the GTAP 7 data.[17]

The μ parameters in equation (6) are renamed by corresponding η parameters. We are now able to rewrite equation (6) expressing a relative reduction in energy input:

$$\frac{\Delta E_{CHI}^{it}}{E_{CHI}^{it}} = -\varphi_{CHI}^{t} \eta_{CHI} \left(\eta_K \frac{K_{IND}^{it}}{K_{CHI}^{it}} + \eta_M \frac{M_{IND}^{it}}{Y_{CHI}^{it}} + \eta_B \sum_{b,b \neq i} \frac{K_{IND}^{bt}}{K_{CHI}^{bt}} \frac{D_{CHI}^{bit}}{Y_{CHI}^{it}} + \eta_F \sum_{k,k \neq i} \frac{K_{IND}^{ft}}{K_{CHI}^{ft}} \frac{D_{CHI}^{ift}}{Y_{CHI}^{it}} \right) \left(\frac{\frac{Y_{IND}^{it}}{E_{IND}^{it}}}{\frac{Y_{CHI}^{it}}{E_{CHI}^{it}}} - 1 \right) \qquad (9)$$

$$+ b_{CHI}$$

Now b_{CHI} represents autonomous energy efficiency improvements. (Again, we consider only exogenous energy efficiency improvements without international technology diffusion in the regions *IND* and *DEV*.)

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[17] This method corrects for regional differences in energy prices in the base year, but it does not take regional differences in future energy price increases into account. If one corrects for future energy price changes, one will also need to correct for future output value changes or even other factor price changes, which will be very difficult in practise.

6.2 Calibration

This sub-section deals with the parameterization of equation (9) based on the parameter values used for equation (6). As before, we assume that FDI inflows cause efficiency gains in most sectors, while imports only lead to efficiency gains in production of machinery and agriculture (compare Appendix, Table 4).

In contrast to the broad empirical evidence on general productivity spillovers, empirical evidence on energy specific technology diffusion is limited (compare the review by Peterson 2008). Only few empirical studies have examined energy specific technology spillovers via FDI and trade – without strong evidence. On an aggregate level based on observations for 20 developing countries and a simplified regression, Mielnik and Goldemberg (2002) conclude that the FDI intensity has a strong energy intensity reducing impact on recipient developing countries. Hübler and Keller (2008) cannot confirm this result in general. Cole (2006) examines the impact of trade intensity on energy use in 32 developed and developing countries. According to Cole, energy use falls in countries with low capital to labor ratios in response to trade liberalization, whilst it rises in countries with high capital to labor ratios.

Another difficulty occurs, when measuring and comparing different kinds of technological progress. While we use labor productivity as a general productivity measure in equation (6), we now use energy productivity (output value divided by physical energy input). These measures have different units. Moreover, suppose a certain amount of FDI leads to a 50% increase in labor productivity within 5 years. Then it is not clear whether the same amount of FDI improves energy productivity to the same, a smaller or a larger extent. It is not clear, either, how long it takes to improve energy productivity by say 50%. One aspect neglected in the model, is that the bias of technological progress towards certain production factors also depends on (relative) factor prices (Acemoglu 2002). If energy will become more costly in the future due to climate policy, firms will engage more in energy saving R&D.

Since the factor bias of technological progress and of technology transfer via FDI and trade is exogenous in our model, we try to calibrate it so that it is in line with the empirical evidence and existing forecasts. We also consider different assumptions on the strength of energy efficiency improvements relative to labor productivity improvements in alternative scenarios.

Our new Scenario II includes exogenous and endogenous energy specific technological progress additional to the general technological progress derived in section 5 (Scenario I with default values). There is some information that helps us calibrate the model:

(1) Foreign ownership of firms is correlated with better energy efficiency. Eskeland and Harrison (2003) estimate a decrease in the energy to output ratio through foreign ownership of 0.036 percentage points for selected manufacturing sectors in Mexico and 0.085 percentage points in Cote d'Ivoire. Fisher-Vanden et al. (2004) find a relative decline in the energy intensities of Chinese companies by foreign ownership amounting to 35.3% and by Hong Kong, Macao and Taiwan funded enterprises amounting to 45.1%. Furthermore, it is a well known fact that Chinese coal fired electricity power plants, which account for 75% of electricity generation, are about 5 to 10% less efficient than power plants in industrialized countries (Blackman and Wu 1998, for an analysis of carbon emission in the Chinese power sector see Zhang et al. 2006).

These studies show that foreign owned firms indeed bring about energy efficiency gains (in China). Unfortunately, they do not directly yield the parameter values for equation (9). Therefore, we mainly rely on the evidence for general technology spillovers via FDI and trade as reported in section 5.2. In general, the spillover strength parameter η_{CHI} differs from μ_{CHI}. We determine the energy specific spillover strength η_{CHI} in the following way: The average relative distance to frontier over sectors concerning energy productivities is 2.117. We set η_{CHI} to 0.02. As a result, the coefficient of $K_{IND}^{it} / K_{CHI}^{it}$ is 0.0431. This value is in accordance with the average spillover elasticity of general productivity gains with respect to FDI and trade of about 0.05 estimated in the empirical literature (compare the coefficients described in section 5.2). (We set $\eta_{CHI} = 0$ in the alternative scenario „Zero", and we set $\mu_{CHI} = 0.04$ in the alternative scenario "Double".) In the current parameterisation of the model, the other relative spillover values η are assumed to be equal to the corresponding μ values, because there is no energy specific information available.

(2) Van der Werf 2007 provides estimations of rates of energy specific technological change. The rates vary between 1.27% and 2.75% in high-income European countries. Blanford et al. (2008) suggest a rate of autonomous energy efficiency improvements of 1% for industrialized countries. They point out, that it is not clear whether energy intensities rise or fall in developing countries.

Based on this information, we set the rates of autonomous energy efficiency improvements in the three regions to $b_{CHI} = 0.01$, $b_{IND} = 0.01$ and $b_{DEV} = 0$.

(3) We use the IEA (2008) forecasts of future CO_2 emissions stemming from coal, oil and gas in section 5.2 to calibrate the elasticities of coal, oil and gas supply in Scenario I.

We keep these elasticities in Scenario II that we derive here. We then calibrate the strength of energy specific technology diffusion in China together with exogenous energy specific technological progress such that the Chinese emissions in 2030 come close to the emissions in 2030 in the IEA (2008) *Alternative Policy Scenario* with low emissions. (Different to the IEA, our simulations yield higher emissions stemming from oil.)

(4) Some studies give us insights into the factor bias of technological change in China. The estimation results by Fisher-Vanden et al. (2006) show that imported technologies are labor and energy saving and capital and materials using, whereas internal technology development in Chinese firms is capital and energy saving and labor and materials using. Moreover, the World Bank (2008b) data reveal that the yearly improvement of energy productivity in China was slightly higher than the yearly improvement of labor productivity between 1980 and 2001, namely above 6% p.a. On the contrary, the Chinese energy productivity dropped by 3.38% in 2003 and by 5.36% in 2004. It improved again by 1.75% in 2005. Furthermore, the China Statistical Yearbook (2007) reports the ratio of the growth rate of energy production to the growth rate of GDP. The ratio averages around 0.6 between 1990 and 2006, resulting in the observed decline in the average Chinese energy intensity.

In our model, the Chinese growth rate of energy productivity in 2004 resulting from the calibration above is about 2.3%. This is close to the actually measured growth rate in 2005 of 1.75.[18]

The remaining parameter values for equation (9) are the same as for equation (6). All parameter values are reported in Appendix, Table 5.

7 Simulation Results

This section presents the results of the CGE simulations running from 2004 until 2030. Figures 2a and 2b in the Appendix plot GDP, emissions, labor productivity and energy productivity for Scenario I with the default values derived in section 5.2. Since we do not assume autonomous energy efficiency improvements in any region in this scenario, nor energy specific technology transfer to China, the Chinese energy productivity improves only slightly over time (Figure 2b). All simulations yield a decline of the average foreign capital intensity (value of foreign capital to the value of domestic capital) over time in China from

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[18] A comparison with the negative growth rates of energy productivity in 2003 and 2004 would be misleading, because the worsening of energy productivity was probably a temporary phenomenon. One would not expect energy productivity to improve forever with the same high rate as at the end of the 20th century, either.

more than 13% in 2004 to more than 6% in 2030. This result seems plausible because of the declining GDP growth rate of the Chinese economy. However, the value of foreign capital in China steadily increases over time in absolute terms.

Section 7.1 provides a welfare analysis for different scenarios in order to assess the sensitivity of the results for different parameter assumptions. It introduces a hypothetical Post Kyoto regime that keeps global emissions from 2012 on constant. Emission permits are traded across regions. The purpose of this simplified scenario is to examine whether and to what extent China will reduce emissions below the 2012 level and how this affects Chinese welfare and the global CO_2 price. This scenario implies medium emission reductions that are probably not sufficient to avoid a temperature increase of more than 2°C. Our simplified scenario has the advantage to show clearly in how far China is able to reduce emissions below the 2012 level and how this affects the global CO_2 price.

Section 7.2 addresses two particular policy instruments: A subsidy on foreign capital in China and a reduction of all import tariffs in China. The main question of interest is, whether the role of these policy instruments will change in the presence of a climate regime including China with respect to China's welfare. Leaving out international technology diffusion would lead to an underestimation of the policy effects.

7.1 Climate Policy Analysis

Table 1 distinguishes Scenario I with general technology diffusion to China and Scenario II with additional energy specific technology diffusion to China. Within Scenario I all regions have a constant exogenous rate of general technological progress. The endogenous part of general technological progress in China stemming from international technology diffusion is varied between zero in Scenario „Zero", the default value derived in section 5 in Scenario "Default", and twice the default value in Scenario "Double". There is no exogenous or endogenous energy specific technological progress within Scenario I.

Scenario II is based on Scenario I, „Default". Additionally, in the „Default" Scenario there is exogenous energy specific technological progress in *CHI* and *IND* and endogenous technological progress stemming from international technology diffusion in China as described in section 6. Energy specific international technology diffusion to China is varied between zero in Scenario "Zero", the default value derived in section 6 in Scenario "Default" and twice the default value in Scenario „Double".

We run each of these six scenarios twice: At first, we assume a hypothetical Post Kyoto regime with a worldwide emission cap excluding China. This means, worldwide emissions are kept constant at their 2012 level, while China can emit without any restriction as a free rider. The regions *IND* and *DEV* can trade permits with each other. The results are shown in the first row of Table 1 in form of Chinese welfare. At second, we assume that China joins the hypothetical worldwide post Kyoto regime. Now *CHI, IND* and *DEV* can trade emission permits with each other. The regions that take part in emissions trading receive their emission volumes in 2012 as their initial endowments with emission permits in both cases. The results are shown in the second row of Table 1. Chinese welfare is in all cases expressed as Hicks equivalent variations accumulated over the period 2013 to 2030, discounted at a rate of 2% p.a.

"Welfare change row" reports the welfare change compared with the first scenario in the row. "Welfare change column" reports the welfare change due to China's accession to the worldwide climate regime.

The results of Scenario I show that general technology diffusion substantially increases Chinese welfare. The results of Scenario II show that energy specific technology diffusion increases Chinese welfare, no matter with or without the climate regime. (Compare Scenarios *D*, *E* and *F* with Scenario *B* in the first row, and Scenarios *J, K* and *L* with *H* in the second row.) The welfare gains in Scenario I are slightly lower in the case when China has joint the climate regime than in the case when it has not. The stronger international technology diffusion, the higher the welfare loss stemming from the climate regime. The reason is that the climate regime indirectly restricts output, so that international technology diffusion cannot achieve its full potential. Thus, the higher the output value without a climate regime, the higher the welfare loss due to the introduction of the climate regime. On the other hand, the higher the assumption of energy specific technological progress in Scenario II the lower the welfare loss due to the introduction of the climate regime in China. The intuition is simply that energy specific technology diffusion eases achieving the emission target. The relative welfare losses stemming from the introduction of the climate regime in China are in all Scenarios relatively low. This is in accordance with Soytas and Sari (2006) stating that China can achieve energy savings without hampering economic growth. Nevertheless, even when China has joint the climate regime, the additional welfare gain of energy specific technology diffusion (Scenarios *K* and *L* compared with *H*) is relatively low.

Figures 3a and 3b in the Appendix visualize the outcomes of Scenario II, „Default“, where China has joint the post Kyoto regime (Scenario *K* in Table 1). It turns out that China becomes a net seller of emission permits and steadily reduces emissions reaching an emission level lower than in 2004 until 2030. This outcome is possible because China is able to more than double its energy productivity between 2004 and 2030 as shown in Figure 3b. It confirms China’s high capability to reduce carbon emissions at low costs in accordance with the literature (for example Garbaccio et al. 1998, Wu et al. 2004 and IEA 2008).

	Scenario I			Scenario II		
Technology diffusion	General			Energy specific (additional to Scenario I Default)		
Strength	Zero	Default	Double	Zero	Default	Double
Scenario	*A*	*B*	*C*	*D*	*E*	*F*
	2012 CO_2 level cap in *IND, DEV*			2012 CO_2 level cap in *IND, DEV*		
Welfare CHI 2013-2030	2819.68	3979.54	5045.57	4074.34	4208.54	4246.22
Welfare change row	0.00	0.41	0.79	0.44	0.49	0.51
Scenario	*G*	*H*	*I*	*J*	*K*	*L*
	2012 CO_2 level cap in *CHI, IND, DEV*			2012 CO_2 level cap in *CHI, IND, DEV*		
Welfare CHI 2013-2030	2797.91	3942.83	4998.31	4049.28	4199.68	4241.39
Welfare change row	0.00%	40.92%	78.64%	44.73%	50.10%	51.59%
Welfare change column	-0.77%	-0.92%	-0.94%	-0.62%	-0.21%	-0.11%

Table 1 Accumulated discounted welfare under different assumptions on technology diffusion and under different climate policy regimes

The industrialized countries also sell emission permits, while the growing developing countries buy emission permits. The price of one ton of CO_2 steadily increases up to about 30 US-$ in 2030. Under the assumption of no exogenous or endogenous energy specific technological progress in any region (Scenario *J*), the price of one ton of CO_2 rises up to 40 US-$ in 2030. This outcome shows the strong impact of (energy specific) technological progress in China on the global CO_2 price and hence on the world economy.

7.2 FDI and Trade Policy Analysis

While FDI was prohibited in China until 1979, Chinese policy has thereafter followed a strategy of opening China for international investment and trade and actively supporting FDI, for example via better access to financial sources offered to foreign firms than offered to indigenous firms. Due to its market power and attractiveness, China has been able to require that foreign investors form joint ventures with local firms. This policy aims to maximize technology diffusion (World Bank 2008). The requirements for FDI have been gradually relaxed over time. Consequently, FDI inflows to China were steadily increasing during the 1980s and 1990s. Moreover, China’s WTO accession in 2001 was an important milestone, and the related effects of the reduction of import barriers has been investigated in a number of CGE analyses (for example Wang 2002).

Accordingly, we will apply the methodologies derived in this paper to the analysis of two policy instruments: At first, a 10% value added subsidy on the returns to foreign capital in China financed by the Chinese representative agent. At second, a 20% reduction of all import tariffs. (Import tariffs are given by the GTAP 7 data for 2004, for an overview of import barrier reductions see Wang 2002.) Both policy instruments are applied from 2004 on and are based on the Scenarios defined in section 7.1.

	Scenario I			Scenario II		
Technology diffusion	General			Energy specific (additional to Scenario I Default)		
Strength	Zero	Default	Double	Zero	Default	Double
Scenario	*A*	*B*	*C*	*D*	*E*	*F*
	2012 CO_2 level cap in *IND, DEV*			2012 CO_2 level cap in *IND, DEV*		
Welfare change	-0.366%	0.089%	0.231%	0.071%	0.069%	0.053%
Scenario	*G*	*H*	*I*	*J*	*K*	*L*
	2012 CO_2 level cap in *CHI, IND, DEV*			2012 CO_2 level cap in *CHI, IND, DEV*		
Welfare change	-0.352%	0.089%	0.224%	0.072%	0.082%	0.064%

Table 2 Analysis of a subsidy on foreign capital: Accumulated discounted welfare gain due to the subsidy under different assumptions on technology diffusion and under different climate policy regimes[19]

Table 2 shows the relative welfare effects of introducing the foreign capital subsidy in China. Again, welfare is accumulated from 2013 to 2030 and discounted at a rate of 2% p.a. While the subsidy reduces welfare in Scenarios *A* and *G* without any international technology diffusion, the subsidy generates welfare gains in all other Scenarios through international technology diffusion. Nevertheless, the welfare gains are relatively small compared with the welfare losses due to the introduction of the climate regime in China as reported in Table 1. The welfare gain via the subsidy is smaller under *I* than under *C*. The reason is that on the one hand, the emission cap limits the productivity gains from international technology diffusion, because it indirectly restricts output. On the other hand, within Scenario II the productivity gains via the subsidy are higher when China has joint the climate regime than when it has not. This means, the energy efficiency gain (technique effect) dominates the production expansion (scale effect, following Antweiler et al. 2001).[20] Nevertheless, the additional welfare benefit

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[19] The welfare gain can be smaller under Scenario II than under Scenario I, „Default", because different to Scenario I, Scenario II assumes autonomous energy efficiency improvements in *IND* which re-allocates resources from *CHI* to *IND*.

[20] The welfare gain of the subsidy is in *E* high than in *F*. The intuition is that in *F* technology diffusion is already higher than in *E* per parameter assumption. Thus, the subsidy has a smaller additional effect on enhancing technology diffusion.

of the subsidy in the presence of the climate regime in China is rather small (Scenarios *K* and *L* compared with *E* and *F*).

Table 3 reports the welfare effects of the 20% reduction of all import tariffs in China. Again, the welfare effects are rather small. Different to the subsidy on foreign capital, the tariff reduction yields lower welfare gains in the presence of the climate regime in China than without the regime. This means the scale effect dominates the technique effect. This is not surprising, because we assumed energy efficiency gains through imports only in machinery production sectors and in agriculture in accordance with the empirical evidence. Energy efficiency gains through FDI, on the contrary, cover most sectors.

	Scenario I			Scenario II		
Technology diffusion	General			Energy specific (additional to Scenario I Default)		
Strength	Zero	Default	Double	Zero	Default	Double
Scenario	*A*	*B*	*C*	*D*	*E*	*F*
	2012 CO_2 level cap in *IND, DEV*			2012 CO_2 level cap in *IND, DEV*		
Welfare change	0.163%	0.119%	0.106%	0.117%	0.118%	0.117%
Scenario	*G*	*H*	*I*	*J*	*K*	*L*
	2012 CO_2 level cap in *CHI, IND, DEV*			2012 CO_2 level cap in *CHI, IND, DEV*		
Welfare change	0.148%	0.106%	0.095%	0.108%	0.111%	0.112%

Table 3 Analysis of a 20% reduction of all tariffs: Accumulated discounted welfare gain due to the tariff reduction under different assumptions on technology diffusion and under different climate policy regimes

In summary, neither a subsidy on all foreign capital nor a reduction of all tariffs seem to be effective policy instruments for achieving given emission goals in a welfare enhancing way. Thus, according to the simulations, the role of these policy instruments from the point of view of a policy maker who maximizes Chinese welfare will not significantly change when China joins the Post Kyoto regime.

8 Conclusion

This paper introduces international technology diffusion via FDI and imports explicitly into a recursive-dynamic multi-region, multi-sector CGE model for climate policy analyses.

The methodology is used to examine the welfare effects of China’s accession to a worldwide emission restriction regime allowing for inter-regional emission trading. China will become a net seller of emission permits. China will be able to reduce its carbon emissions steadily and possibly reach an emission level that is lower than the 2004 level until 2030. This is possible due to ongoing energy efficiency gains, partly stemming from international technology diffusion. This result confirms China's high potential for reducing emissions efficiently.

Excluding exogenous or FDI and trade driven energy efficiency gains in any region leads to a CO_2 price of about 40 US-$ per ton of CO_2 in 2030. Including exogenous energy efficiency gains in the industrialized region and in China plus FDI and trade driven energy efficiency gains in China leads to a CO_2 price of only 30 US-$ per ton of CO_2 in 2030. Herein, FDI and trade induced energy efficiency gains in China contribute significantly and should not be neglected in climate policy analyses. This outcome shows the strong influence of China's energy efficiency gains on the global CO_2 price and hence on the world economy.

A subsidy on foreign capital in China or an import tariff reduction in China, on the other hand, do not yield significantly different effects on Chinese welfare when China has joint the climate regime than when it has not. Supporting any FDI and imports leads to a bunch of sectorally different output increasing and energy efficiency improving effects. The overall effect does not promise achieving emission goals in a welfare maximizing way.

This result confirms the necessity of formulating clear requirements for emission savings when supporting international technology diffusion. Such requirements are present in the Clean Development Mechanism (CDM) and will be present in a technology fund governed by the World Bank. It also suggests sectoral measures that support technological progress and restrict emissions in certain sectors depending on sectoral emission intensities and the potential to reduce the emission intensities.

However, like in other climate and energy policy analyses there are uncertainties in the choice of functional forms and parameter values such as the technology spillover strengths, especially concerning energy specific technological progress.

Future research can combine the methodology of international technology diffusion with an approach of endogenous technological change along the lines of Acemoglu (2002) and Buonanno et al. (2003).

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10 Appendix

	Technology diffusion		Foreign capital	Imports	Vertical linkages	Labor productivity	Energy productivity	Labor productivity	Energy productivity
	FDI	Imports	% of all capital	% of output	% of output	1000 US-$ per worker	US-$ per Joule	relative gap	relative gap
China av.			9.40	12.70	26.10	4.08	3.04	13.11	2.12
AGR	x	x	1.31	6.10	9.52	2.08	4.45	40.29	1.30
BEV	x		11.98	1.52	10.15	7.19	8.00	19.19	2.22
BUI	x		15.27	7.25	31.11	3.03	10.97	15.57	2.08
COL	x		1.67	1.61	17.07	2.61	1.70	35.23	2.20
COM	x		3.66	1.46	22.06	3.95	6.28	13.80	4.44
CON	x		1.67	0.37	9.16	4.22	19.44	9.22	2.79
CRP	x		26.04	31.15	54.68	6.43	1.18	15.04	1.24
CRU	x		1.26	78.35	4.62	6.75	1.23	31.13	5.56
CUS			9.87	4.26	-	2.14	7.39	24.81	1.15
EGW	x		5.25	0.18	27.22	7.24	0.30	14.19	2.44
ELM	x	x	59.63	41.04	94.50	8.50	21.47	13.70	0.21
FEM	x		10.88	10.87	34.42	5.20	0.96	20.07	1.65
FIN	x		0.58	5.25	20.23	2.99	13.50	12.22	2.57
GAS	x		16.63	0.01	27.56	51.15	0.15	1.55	22.62
MAC	x	x	13.98	36.96	37.49	4.77	8.66	12.33	2.41
MET	x		18.24	6.91	32.26	5.38	4.60	10.06	2.85
MIN	x		1.45	37.12	40.22	2.75	2.00	33.16	0.64
NFM	x		20.29	28.27	53.56	7.29	1.08	14.28	1.75
NMM	x		20.04	3.84	26.61	3.54	0.91	19.88	2.55
OIL			22.45	10.32	-	27.86	-	48.80	-
OTM	x	x	6.81	3.36	18.49	4.50	36.18	17.90	-0.26
PAP	x		27.39	14.68	45.57	4.38	2.69	14.05	1.34
PUB			2.34	1.47	-	1.35	5.72	19.00	2.30
REE			20.28	-	-	-	-	-	-
TEX	x		17.66	10.81	27.71	5.13	6.17	17.47	1.57
TRD	x		5.50	8.46	24.10	2.87	5.61	13.21	1.94
TRM	x	x	51.28	17.22	57.14	5.62	7.62	16.98	4.81
TRN	x		3.85	4.52	21.74	2.67	1.02	21.51	0.41
WAT	x		5.97	0.88	20.82	2.29	1.03	25.04	3.82
WOO	x		4.29	5.90	14.86	4.74	10.53	12.40	0.54

Table 4: Sectoral[21] indicators of China in 2004 computed from GTAP 7 data

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[21] Sectors: Agriculture and food (AGR), textile, apparel and leather (TEX), beverages and tobacco (BEV), business services (BUI), chemicals, rubber and plastic (CRP), culture and recreation (CUS), coal (COL), communication (COM), construction (CON), crude oil (CRU), electrical equipment (ELM), electricity supply (ELY), ferrous metals (FEM), financial intermediation (FIN), gas (GAS), machinery (MAC), metal products (MET), minerals (MIN), non-ferrous metals (NFM), non-metallic mineral products (NMM), other manufacturing (OTM), paper products and publishing (PAP), petroleum and coal (OIL), trade and wholesale (TRD), public services (PUB), real estate (REE), transport machinery (TRM), transportation (TRN), water supply (WAT), wood (WOO).

The first two columns show which sectors are included in modelling international technology diffusion via the channels FDI and imports. The last two columns show relative technology gaps. The relative labor productivity gap between *IND* and *CHI* is computed according to equation (6), last term in parentheses. The relative energy productivity gap according to equation (9), last term in parentheses.

Symbol	Name	Value	Symbol	Name	Value
ρ	Welfare discount rate p. a.	0.02	a_{IND}	Rate of exogenous general technical progress in *IND* p. a.	0.0086
ξ_{G}	Elast. of subs. Armington goods from different regions	8	a_{CHI}	Rate of exogenous general technical progress in *CHI* p. a.	0.0105
ξ_{MD}	Elast. of subs. Armington goods imports vs. domestic goods	2	a_{DEV}	Rate of exogenous general technical progress in *DEV* p. a.	0.013
τ	Elast. of trans. domestic goods and exports	2	b_{IND}	Rate of exogenous energy saving technical progress in *IND* p. a.	(0) 0.01
ε_{KIND}	Elast. of transf. domestic and foreign capital assets	1	b_{CHI}	Rate of exogenous energy saving technical progress in *CHI* p. a.	(0) 0.01
ε_{KCHI}	Elast. of subs. foreign and domestic capital in *CHI*	1	b_{DEV}	Rate of exogenous energy saving technical progress in *DEV* p. a.	0
ε_{KLER}	Elast. of subs. capital, labor, land and resources	1	$\varsigma_{COL,\ CHI}$	Price elast. of demand for coal in *CHI*	0.95
μ_{CHI}	General spillover strength in *CHI*	(0) 0.0005 (0.001)	$\varsigma_{OIL,\ CHI}$	Price elast. of demand for oil in *CHI*	0.1
η_{CHI}	Energy spillover strength China	(0) 0.02 (0.04)	$\varsigma_{GAS,\ CHI}$	Price elast. of demand for gas in *CHI*	28
$\mu_{K} = \eta_{K}$	Relative general/energy saving spillover strength foreign capital	1	$\varsigma_{COL,\ IND/DEV}$	Price elast. of demand for coal in *IND* and *DEV*	0.2
$\mu_{M} = \eta_{M}$	Relative general/energy saving spillover strength imports	1	$\varsigma_{OIL,\ IND/DEV}$	Price elast. of demand for oil in *IND* and *DEV*	0.1
$\mu_{B} = \eta_{B}$	Relative general/energy saving spillover strength backward linkages	8	$\varsigma_{GAS,\ IND/DEV}$	Price elast. of demand for gas in *IND* and *DEV*	0.35
$\mu_{F} = \eta_{F}$	Relative general/energy saving spillover strength forward linkages	4			

Table 5: Parameter values[22] for the simulations

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[22] Alternative lower and higher values are written in parentheses.

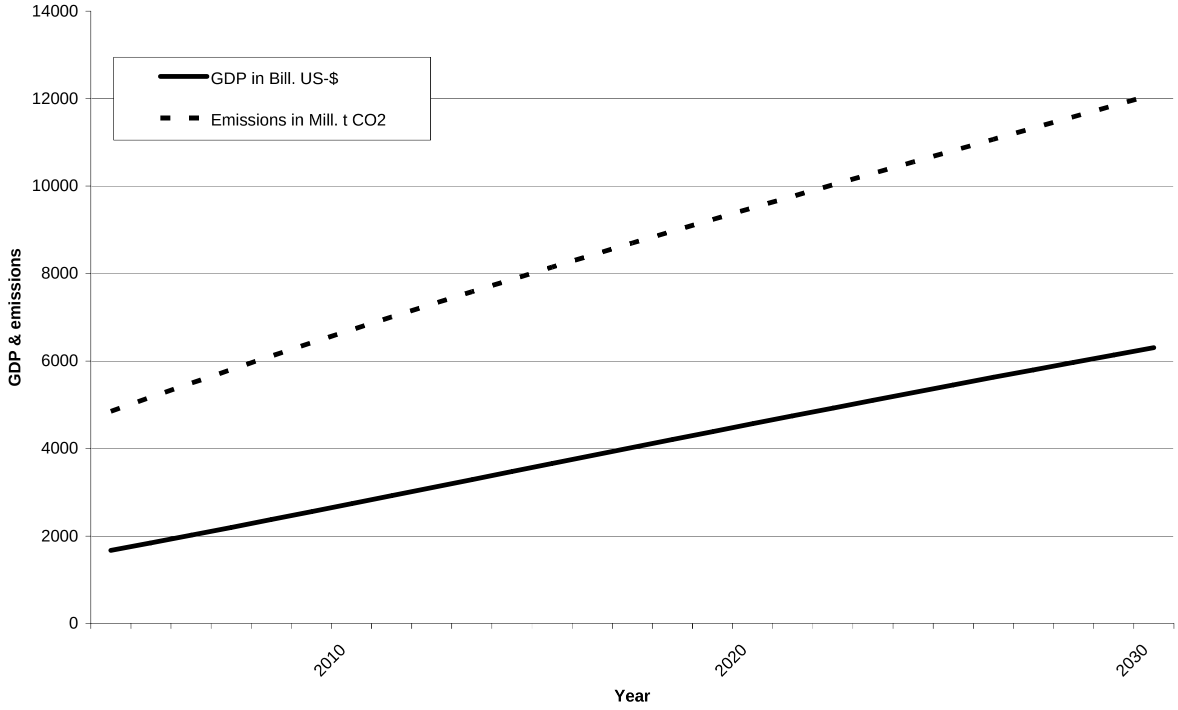

Figure 2a China's GDP and emission paths for Scenario I, Default including general technology diffusion, without energy specific technology diffusion and without restrictions on emissions in any region

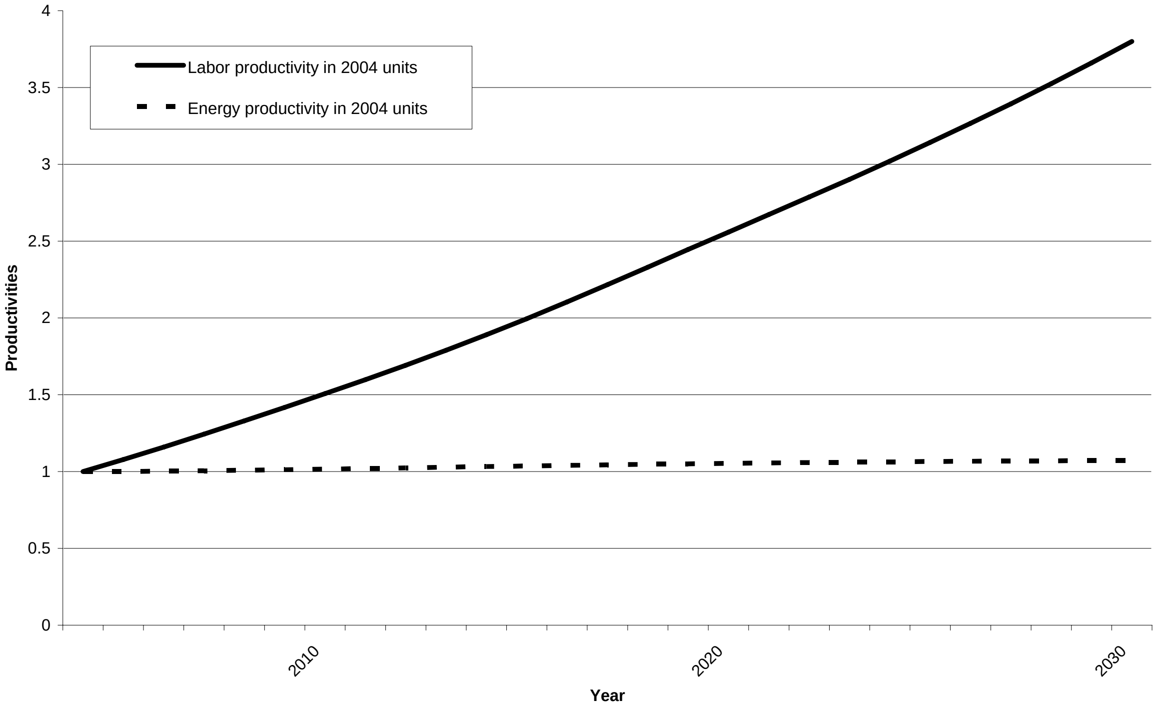

Figure 2b China's labor and energy productivity paths for Scenario I, Default including general technology diffusion, without energy specific technology diffusion and without restrictions on emissions in any region

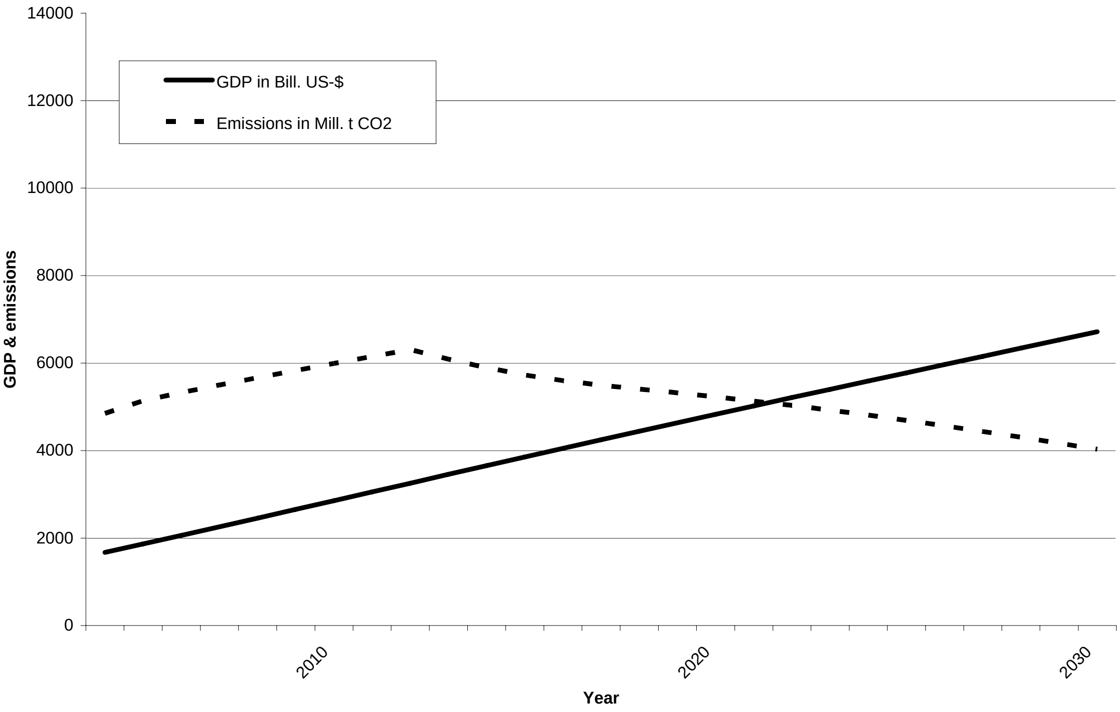

Figure 3a China's GDP and emissions paths for Scenario II, Default (*K*) including general and energy specific technology diffusion and keeping worldwide emissions from 2012 on constant

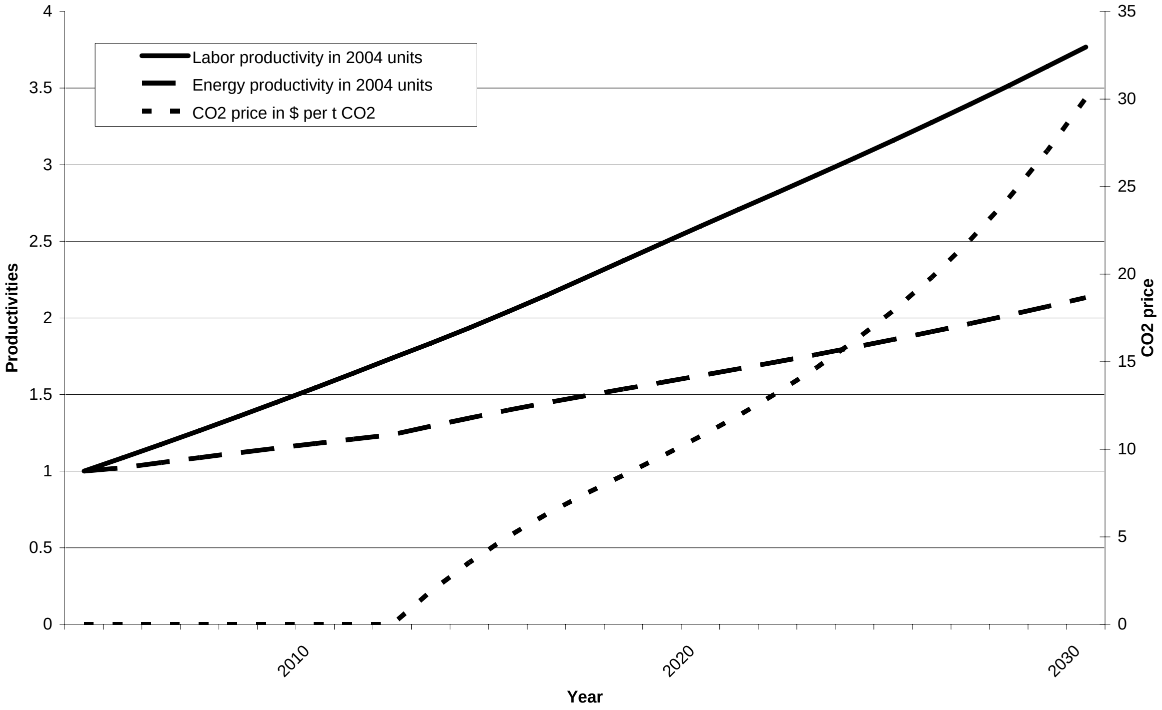

Figure 3b China's labor and energy productivity paths for Scenario II, Default (*K*) in China including general and energy specific technology diffusion and keeping worldwide emissions from 2012 on constant