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Can technological innovation help China take on its climate responsibility? An intertemporal general equilibrium analysis

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HIGHLIGHTS

- ▸ We examine the effect of China's technological innovation to curb its carbon emissions.
- ▸ A mechanism of R&D-induced technical change is incorporated into an intertemporal CGE model.
- ▸ Private R&D efforts and public R&D intervention are insufficient to achieve climate target.
- ▸ A carbon tax is indispensable to achieve climate target but at the cost of output losses.
- ▸ Induced technical change can partially mitigate the deadweight loss incurred by carbon tax.

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ABSTRACT

This paper examines the effectiveness of China's indigenous R&D and technological innovation to curb its carbon emissions. The mechanism of endogenous technical change (TC) is incorporated an intertemporal computable general equilibrium (CGE) model. R&D investments and knowledge creations are modeled as the endogenous behaviors of private firms. The accumulated stocks of knowledge are applied in the production process to affect the rate and bias of TC. Simulation results show that: (1) while China's indigenous R&D efforts play a significant role to curb carbon emissions, sole dependence on R&D may be far from sufficient to achieve pledged climate target, with complementary policies being required to reinforce existing climate actions; (2) innovation policies can strengthen R&D investment and cut emissions further, but the complementary effect is relatively minor; (3) carbon taxation can generate significant carbon-saving benefits and fulfill climate target, but this achievement is at the cost of economic losses. The induced technical improvement, however, can partially mitigate the deadweight loss incurred by carbon tax distortion.

1. Introduction

Since launching the "open-door" policy in the late 1970s, China has experienced a profound transformation from a rural agricultural-based to an urban industrial-focused society. As one of the fastest growing economies, China is expected to continue its growth trend and overtake the U.S. to become the world's largest economy by 2030 (World Bank, 2011). While China's rapid growth has created tremendous wealth and prosperity, its development trajectory – with enormous resource depletion and environmental degradation – is becoming unsustainable, putting China at the center of international debates on energy governance and climate mitigation (International Energy Agency (IEA), 2010; Energy Information Administration (EIA), 2010).

While a country's economic size generally reflects its energy demand and carbon emission, China's appetite for energy and emission is unsurprisingly mammoth. During the period 1990–2005, China's total primary energy demand grew by 4.7% annually from 874 to 1742 Mtoe, and its CO_2 emissions grew by 5.6% per year from 2244 to 5101 Mt (International Energy Agency (IEA), 2007). In a global context, China had overtaken the U.S. in 2010 to become the world's largest carbon emitter, and its emissions will continue to rise rapidly in line with its industrialization and urbanization. Reportedly, China has accounted for nearly three quarters of world emission growth in recent years, and its emission levels are projected to rise to about 28% of the world's total in 2020 (International Energy Agency (IEA), 2010; British Petroleum (BP), 2011). Without regulations, this growth trend is likely to offset climate mitigation efforts elsewhere. In the global efforts of tackling climate change, there is no disagreement that China needs to take on a growing responsibility of carbon abatement.

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To stabilize the rising emission trend, China would have set a daunting challenge of cutting its carbon intensity given a large demographic base and rapidly rising consumption levels (Kaya, 1990; IPCC, 2000). In the minds of the leadership in Beijing, the key to handling this challenge is the decoupling of carbon emissions from economic growth through technological innovation. This is true for China where the growth story, beyond the role of global manufacturing engine, is increasingly about innovation. In the course of building a ‘‘harmonious society’’ through ‘‘scientific development’’, Beijing has begun to raise awareness of the pivotal role that scientific development and innovation play in sustaining long-term quality growth and addressing major social challenges.[1]

In a changing landscape of global innovation, the emergence of innovation hubs in China is underpinned by the strong growth of R&D investments in indigenous innovation. While the U.S. and Japan remain leaders in science and technology innovation, they face increasing competition from emerging markets, notably China—the world's third leading R&D investor at $100 billion in 2010 (OECD, 2010). R&D spending in China grew by about 20% per year over the last decade. Average R&D investments in G7 markets, by comparison, have grown by 3.2% annually during the same period. R&D intensity remained flat across G7 markets over the past decade at 2.1%. In China it has double as a share of GDP since 1999, reaching 1.5%, leaving room for potential improvement by international standards (OECD, 2008, 2010). In a transition to the innovation-oriented society, Beijing is expected to boost future investments in indigenous innovation. This is reflected by the government's spending target of 2.5% of GDP on R&D by 2020, translating into a tripling of China's R&D investment over the next decade to $300 billion (Ministry of Science and Technology (MOST), 2006b).

In a context where climate mitigation and technological innovation are intrinsically interconnected, it is vital to explore the effectiveness of China's R&D efforts to achieve its carbon reduction commitment. We thus aim to address the following issues: (1) how substantially can R&D-induced TC drive China's carbon emissions below projected baseline levels; (2) can emission cuts driven by R&D efforts guarantee the achievement of Beijing's pledged climate target; (3) do public R&D intervention with the aim of correcting for innovation market failure provide significant aid to cut emissions; (4) is it needed to introduce carbon tax to complement technology policy in order to achieve the climate target.

To handle these issues, we incorporate the endogenous mechanism of R&D-induced TC into a multi-sector computable general equilibrium (CGE) model for climate policy analysis. The theory of R&D-induced TC has its origins in the second-generation endogenous growth literature, which highlights the key role of R&D and knowledge stock in shaping economic growth (Romer, 1990; Aghion and Howitt, 1998; Acemoglu, 2009a). In this direction, most climate policy studies represent the R&D-induced TC by adopting knowledge substitution for physical inputs, with an *innovation possibility frontier* (*IPF*) specifying the process of knowledge accumulation (Nordhaus, 2002; Popp, 2004; Sue Wing, 2006; Bosetti et al., 2008; Acemoglu et al., 2009b). As a feature, the representation of disaggregated sectors in a CGE model provides a useful platform to explore general equilibrium effect of intersectoral knowledge interactions, which facilitates examining the externality of knowledge (e.g., spillover, crowding-out) and its impacts on the timing and costs of carbon emissions reduction (Löschel, 2002; Popp, 2006; Clarke et al., 2006, 2008; Gillingham et al., 2008).

To our knowledge, few CGE studies with the R&D-induced TC have appeared in climate policy analysis literature. Goulder and Schneider (1999) investigate the attractiveness of the U.S. climate policies in the presence of induced TC. Sue Wing (2003) explores the impact of induced TC on the U.S. macroeconomic cost of carbon taxation. Wang et al. (2009) examine the role that TC could play in designing China's climate mitigation targets. Bye and Jacobsen (2011) scrutinize the welfare effects of differentiated R&D subsidies across general and carbon-saving TC on the Norwegian economic cost of carbon tax. Investigations of R&D-induced TC also include the studies on the cost effectiveness of climate policies that combine R&D subsidies with carbon constraints in the presence of technological externality by Otto et al. (2007, 2008), Otto and Reilly (2008) and Löschel and Otto (2009).

As a needed complement to existing literature, this paper contributes to advancing methods of climate policy modeling in the following ways: (1) instead of using recursive-dynamic modeling, we develop an intertemporal optimization framework to capture the time path of adjustment associated with particular climate policy shocks;[2] (2) To represent the endogenous process of innovation, we incorporate a mechanism of R&D-induced TC into CGE framework, with special treatments on innovation externalities including crowding-out, intersectoral spillovers and the dual role of R&D in knowledge absorption.

The paper is organized as follows: Section 2 describes basic modeling framework. Section 3 discusses model implementation, with an emphasis on knowledge accounting for model calibration. Simulation results and discussion under various scenarios are presented in Section 4. Section 5 concludes.

2. Model description

2.1. Basic framework

Fossil energy is an indispensable input into every industry in the energy-intensive Chinese economy. A model encompassing multiple industries and commodities is thus required to capture the full general equilibrium effect of climate policies.[3] In our modeling framework, the Chinese economy is represented by multiple economic agents, including: twelve production sectors, an investment sector (producing physical capital goods), a R&D sector (producing R&D goods), a representative household, and a government. To be relevant to climate policy analysis, the twelve production sectors consists of five energy sectors (electric utility, gas utilities, petroleum refining, coal mining, crude oil and gas extraction) and seven non-energy sectors (agriculture, forestry, mineral mining, durable manufacturing, non-durable manufacturing, transportation, services). Carbon emissions are calculated

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[1] This is reflected by a commitment to create an ‘‘innovation-oriented’’ society made by Chinese President Hu at the National Science and Technology Conference in January 2006, an occasion which also saw the unveiling of the 2006–2020 Medium to Long-term Plan for the Development of Science and Technology (Ministry of Science and Technology (MOST), 2006b).

[2] This differs from the traditional recursive-dynamic model that solves for a sequence of static equilibrium in a slow-Swan formulation, where capital stock accumulation is based on an exogenous saving rate with myopic expectations. In contrast, optimization models endogenize the intertemporal behavior of economic agents, with current decisions depending on expectation about future economic prospect (Jorgenson and Wilcoxen, 1990; Bovenberg and Goulder, 1996; McKibbin and Wilcoxen, 1999; Dixon et al., 2005). As modern macroeconomic elements (e.g., expectation, assets) play an increasingly important role in China's market-oriented economic operation, intertemporal modeling frameworks that incorporate macroeconomic elements are more applicable to our study for China.

[3] The multi-sector specification differs from Ramsey growth model where the supply side of an economy is represented as a single producer of unique final goods. The economic dynamics are captured by a social planner choosing the optimal level of inputs into an aggregate production function, e.g., R&DICE (Nordhaus, 2002), ENTICE (Popp, 2004), and WITCH (Bosetti et al., 2008).