Greening Capital while Greening Energy: Capital Deepening, Biased Technical Change and Energy Transition in China

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If climate change is a consequence of capitalism, energy economists would need to increase our knowledge on the relationship between capital deepening and energy transition in a developing economy. Capital deepening, usually measured by the capital-labor ratio, can indicate the stages of economic development, reflect the comparative advantages of competing energy technologies, and determine the biased technical change which leads to capital-intensive modern energy.

Every stage of the energy life cycle - exploration, extraction, conversion and consumption - is underpinned by the technologies which correspond to different types and grades of fuels (Chakravorty, Roumasset, and Tse 1997). Energy production technology is linked to the capital intensity of the economy as advanced energy technologies tend to only be adopted by energy suppliers in an economy with relatively high capital intensity, due to the requirement for skilled labor and infrastructure. Several examples in historical literature illustrate this assertion. The first one is Cugnot's Fardier. In 1770, a French inventor Nicolas-Joseph Cugnot built a high-pressure steam engine and installed it on a vehicle, but this technology was not successfully used until the invention of rails, the capital-intensive infrastructure, developed in British coal mines (Allen 2009, 153). The second example is Jacques de Vaucanson's automated silk loom, which was never used commercially since it was too capital-intensive (Doyon and Liaigre 1967). It is well documented that China Sichuan province was using natural gas as far back as the Han dynasty (200 BCE). However, large-scale use of natural gas did not occur until capital-intensive technologies like turbines, compressors and pipes were developed in high capital intensity economies, such as Europe and the USA after World War II (Smil 2010, 37).

We have gained the knowledge of energy production that different forms of energy require different combinations of factor inputs. In the view of energy system evolution, energy transition from one form of energy to another would not have happened without a change in input proportions between labor and capital (Kander, Malanima, and Warde 2014, 411). For instance, labor demand in coal mining per unit of energy is usually higher than that in nuclear power plants; likewise, the capital intensity of solar power production is relatively higher than that in generating energy from fuelwood. This phenomenon is due to the attributes of each primary energy source including scarcity, power intensity, energy density, safety, the flexibility of use, and cost of conversion (Stern 2010).

However, technical change in energy production is not neutral but tends to use more capital than labor (Acemoglu 2002). This biased technical change can be driven either by relative factor price changes (the price effect) or by relative factor quantity change, i.e., capital intensity increase (market size effect). The relative factor price change will create incentives to develop advanced technologies using the more expensive factor that is – capital – rather than labor. The relative factor abundance change will promote technological progress by using the more abundant factor, that is, capital. In a competitive electricity market, the prices of different sources of electricity will be converging eventually given the electricity is a kind of homogeneous goods. Thus, in this context, an increase in capital intensity will induce technical change directed to modern energy which is capital intensive. Acemoglu's model implies that technical change in energy transition may be biased towards modern energy (i.e., capital-intensive energy) when there is capital accumulation relative to labor in a developing economy.

China's energy transition during the past four decades shows that the relative production of non-coal electricity and coal electricity is in line with the increase in capital intensity of the country, see Figure 1. There exists a linear relationship between energy transition and capital deepening especially after the year 1984 which is the start of 'High Wave of Reform'. That is, China's economic reform had an underlying

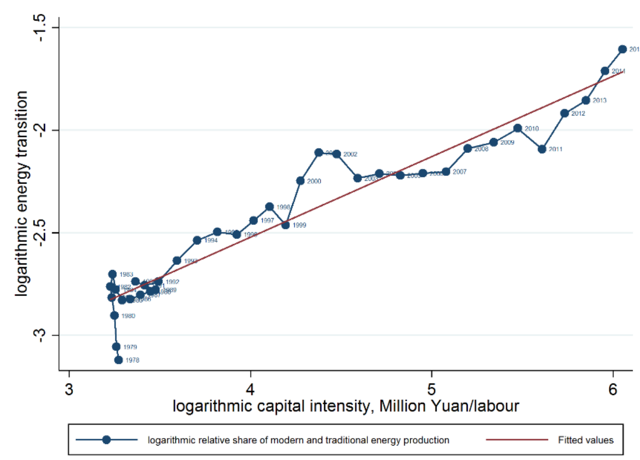

Figure 1 Energy transition and capital deepening in China

transition in 1984. The central government launched the reform in urban area and adopted the decision on 'planned commodity economy' which was starting the process of market liberalisation. Overall, we can see from Figure 1., with an increase in capital intensity, the relative production share of modern energy and traditional energy increases. This pattern implies the structure of energy mix shifting towards capital-intensive modern energy.

In our recent research, we conduct an empirical model is based on China's national level time series from 1978 to 2015 (Wang, Mugera, and White 2019). The results show that the long-run equilibrium relationship and short-run dynamic effects between the energy transition and capital deepening are both significant. The Granger causality test suggests that capital intensity indeed causes energy transition but not *vice versa*.

The results from time series modeling further show that the increase in capital intensity has a long-run effect on China's energy transition and the dynamical adjustment period is around five years which is in line with the National Five-year Plan.

Our results imply that the shift in China's energy mix, from tradition to modern energy, is in line with capital deepening in the long run. With an increase in capital intensity, technical change in the energy sector is biased towards capital as modern energy tends to be capital intensive.

The policy implications of our results are that both capital-enhancing policies and price-regulations can be used to promote energy transitions. However, price-regulation solutions may distort efficient resource allocation, and feed-in tariffs can be inefficient leading to an increase in social cost. In terms of policy recommendations, we favor measures that include tax relief, technology standardization and foster financial security and fair competition between technologies. The industrial policy would be better at reducing the market frictions related to investment in modern energy sector. The appropriate policy instruments may be an inclusion of tax relief, information asymmetry reduction, technology standardization, financial security and rules of fair competition. In so doing, modern energy innovation and factor capital intensity increase will promote the adoption of modern energy technology and gradually displace the traditional energy. In the long run, this will promote the wide-scale adoption of modern energy technology and displace polluting traditional energy. We refer to this process as 'Greening capital while greening energy'.

There are many researches on the relationship between energy and capital adopts the derived demand approach to investigate the inter-factor substitution between these two inputs. The policy insights from this approach may be confined by the assumption that the output level is constant. On the other hand, it would be helpful for many developing countries, if future study could take capital deepening, especially the dynamic condition of capital and labor, of the whole economy into energy transition policy design. Put it differently, beyond factors like GDP per capita, energy prices and scarcity of resources, capital deepening is another critical factor for energy transition. In addition, the dynamical evolution between energy transition and capital intensity needs to be explored further. For example, researchers might need to explore whether there exists a 'threshold' or 'optimal path' of energy transition given the corresponding conditions of capital intensity of an economy. Our study attempts to open a discussion room for this debate.

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