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China's Energy Dilemma

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Abstract:

PRC's energy dependence is growing and has become a major concern for both economic and national security policymakers in that country. The ambitious goal of modernization of the economy along the lines of the other newly industrialized economies(NIEs) of Asia has succeeded only too well, and it is difficult to reorient economic priorities.

If examined rigorously, such an economic strategic assumption can be seen to entail the goal of creating further technological capabilities. In particular, China seems to be firmly committed to the creation of a largely self-sustaining innovation system as part of a knowledge-based economy of the future . Such innovation systems, called *positive feedback loop innovation systems* or POLIS have been created by advanced countries, and NIEs such as South Korea and Taiwan are proceeding to create these as well. But this will add to its energy burden and further dependence on the US as the power which controls the key sea lanes. Only a strategic reorientation to building a self-sustaining POLIS and appropriate regional cooperation institutions can lead to the way out of the current dilemma for China.

1. **Introduction:**

China's remarkable growth during the last twenty five years has led to a rapid increasae in energy demand, and its hunger for energy is apparently insatiable. There are of course both economic and ecological aspects of this insatiable demand for energy. There are also security issues that exercise the Chinese leadership increasingly. In this paper I examine the measures that China is taking to achieve energy security and the motivations behind these measures. I also look at China's investment in overseas oil exploration and development projects, interest in transnational oil pipelines, plans for a strategic petroleum reserve, expansion of refineries to process crude supplies from the Middle East, development of the natural gas industry, and gradual opening of onshore drilling areas to foreign oil companies. The key question is: can China hope to achieve both equitable growth and energy security over the next two decades? I suggest the kind of mathematical modeling and political economy analysis that may be necessary to answer this two-pronged question rigorously.

China faces at least two pressing sets of energy policy challenges. The first is a problem of short run efficiency and therefore relates to the immediate need to improve management and coordination of the nation's energy supply. During the last five years economic growth has been close to 8% per annum. At the same time, energy demand grew by about 15% annually while oil imports grew at 30% per year. In today's China, electrical power shortages are widespread, and transport bottlenecks constrain the ability of the industry to move both coal and oil to where they are needed.

There are also longer term energy policy challenges.   These concern the continuing inability of China's government to formulate a coherent energy policy which could provide the basis for the effective management of the energy sector and its environmental consequences for the next fifty years and beyond.

China's entry into the WTO has already had and in the future will have diverse consequences for its economy and energy. The best overall assessment from the Chinese perspective is that although the short run adjustment costs--- for example, the increase in unemployment in the agricultural sector--- may be high, the long run economic benefits from integration into the world trading system are likely to be considerable. In particular, it is assumed that the export-led growth will continue and will also lead to the modernization of the economy along the lines of the other newly industrialized economies(NIEs) of Asia. If examined rigorously, such an assumption can be seen to entail the goal of creating further technological capabilities. In particular, China seems to be firmly committed to the creation of a largely self-sustaining innovation system as part of a knowledge-based economy of the future (Simon,1996; Simon and Goldman,1989; Lu, 2000). Such innovation systems, called positive feedback loop innovation systems or POLIS(Khan, 1998; 2003; 2004a) have been created by advanced countries, and NIEs such as South Korea and Taiwan are proceeding to create these as well.[1] Can China do the same? And will China's entry into the WTO help or hinder such efforts? While the answers here are not clear, it is reasonable to say that its WTO membership[2] will open the way towards diversification of energy import sources. However, I will argue that much depends on US-China bilateral relationship also. Furthermore, as I will show, the current strategy of indiscriminate growth only without regards to sustainability or equity will make China's growth is deeply problematic even in an open economy context of rules-based trading in the WTO framework.

In what follows, I will begin by identifying the most important aspects of the energy demand and supply aspects in order to ascertain China's energy dependence. This will enable us to look at both economic welfare and sustainability issues as well as security issues which are discussed in section 3. In conclusion I draw attention to the real dilemma faced by the ambitious Chinese leaders and suggest that multilateralism and regional cooperation are the best strategic responses available to China.

2. China's energy dilemma: demand, supply and distributional issues

China is now the world's second largest consumer of energy, accounting for some 12% of global energy demand, but its rate of increase of demand is some four to five times that for the rest of the world. So what happens in China's energy sector will affect the rest of the world as well. Table 1 below gives a picture of China's actual and projected energy consumption till the year 2015.

China's energy sector displays continuing dependence on coal. China is the world's largest consumer of coal, accounting for more than 30% of global coal consumption. Further, coal provides approximately 64% of China's primary energy demand. While such dependence on coal is not necessarily a huge problem, it has two unfortunate consequences. Use of coal is characterized by low energy efficiency and pollution.

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[1] A formal and complete description of POLIS as an innovation system ,and contrasts with NIS(national innovation system) of which POLIS is both an extension and an extended critique, is outside the scope of this paper. Khan (2004a) gives a formal description and two existence theorems in topological spaces. Technically, non-linearities and multiple equilibria are at the heart of a formal proof of POLIS and its properties. Khan (2003) presents both a conceptual and concrete critique of NIS by comparing and contrasting the national innovation system (NIS) with POLIS in the context of Taiwan.

[2] For welfare aspects of China's entry into WTO see Khan, Haider A., "China's Entry into the WTO: ICT Sectors, Innovation, Growth and Distribution", July (2002b) - (Website address: http://www.e.utokyo.ac.jp/cirje/index.htm)

The intrinsic energy value of a unit weight of coal is known to be less than that for oil and gas.The recovery rates for many of China's coal mines are also low, meaning that much of the country's coal resource is left in the ground, never to be recovered. Table 1 below confirms this. Furthermore, the efficiency of appliances which use coal in China continues to be substantially lower than the average in OECD countries. Progress has been slow in enhancing the efficiency of consumer electrical appliances and implementing building codes which reduce heat losses. Finally, the continuing low level of end-user prices has failed to provide consumers with incentives to save energy.

Table 1

Primary Energy Consumption in China (quadrillion Btu)

Year	Coal	Natural Gas	Petroleum	Total
1980	12.5	0.6	3.8	17.3
1985	16.9	0.5	4.0	22.2
1990	20.7	0.6	4.9	27.0
1995	27.5	0.7	7.2	35.2
2000	22.7	1.2	9.7	36.7
2005	26.4	2.2	11.2	43.2
2010	33.3	3.4	14.2	55.3
2015	40.1	5.3	17.9	69.1

SOURCE: Energy Information Administration (EIA), *International Energy Database*, Washington, D.C., 2002.

NOTES: Totals may not sum because of other fuels and rounding. Figures for 2005–2015 are EIA projections, reference case.

From table 1 above it is clear that China's energy consumption will be 4 times what it was in 1980 by the year 2015.The share of oil during the same period will be on the increase also.China shifted from being net oil exporter to net oil importer in 1993.What explains the increasing dependence on oil? Table 2 below is an input-output decomposition of China's energy use. Scrutinizing table 2 below we can see that it is intimately related to final demand shift. Within the final demand shift, both household and investment needs are responsible for the lion's share. Thus, China's industrialization strategy and the increasing prosperity of households can explain its increasing dependence on energy imports. This is not likely to change in the near future.

Table 2

	Coal	Oil&Gas	Electricity	Petroleum	Coke
Total change	5.78	14.09	36.55	12.65	37.24
Technical change	-30.42	-38.55	-42.24	-46.21	-48.64
Energy technical change	-40.16	-47.84	-55.91	-48.97	-59.29
Non-energy technical change	9.75	9.29	13.67	2.77	10.65
Final demand shift	36.19	52.63	78.78	58.86	85.88
Level	61.35	61.35	61.35	61.35	61.35
Distribution	4.73	6.84	0.18	4.26	-3.62
Composition	-29.9	-15.55	17.26	-6.75	28.15
Sources of Final demands shift					
Household Consumption	20	24.39	39	22.67	40.42
Government consumption	2.7	4.86	3.4	5.2	2.28
Investment	15	35.96	42	36.9	52.25
Export	23.4	12.87	28	22.4	42.93
Import	-23.6	-45.8	-32	-38.17	-33.68
Others	2.6	2.4	1.7	1.9	1.6

Table 3

Primary Energy Production in China (quadrillion Btu)

Year	Coal	Natural Gas	Petroleum	Total
1980	12.6	0.6	4.5	18.1
1985	17.7	0.5	5.4	24.3
1990	21.9	0.6	6.0	29.4
1995	28.3	0.7	6.4	35.4
2000	18.4e	1.1e	7.0	27.8e
2005	n.a.	n.a.	6.7	n.a.
2010	n.a.	n.a.	6.6	n.a.
2015	n.a.	n.a.	6.5	n.a.

SOURCE: EIA, *International Energy Database*, Washington, D.C., 2002.

NOTES: Totals may not sum because of other fuels and rounding. Petroleum includes crude oil, natural gas liquids, and refinery processing gain. Figures for 2005–2015 are EIA projections, reference case. Total is primary energy only.

e = estimated.

n.a. = not available.

Although domestic production figures have not been projected till 2015 in table 3 above, simple extrapolation would show that import dependence is here to stay. Thus the conclusion that follows from the evidence presented in tables 1 and 2 seems to be that China's import dependence will be a policy problem for at least till 2025, if not for even a longer period. The vulnerability is great as shown in table 4.

Table 4

Summary of GDP Effects, "Severe" Disruption (percentage)

Year	Oil Consumption	Import Cost	Fuel Substitution	Total
2005	(7.4)	(0.1)	3.7	(3.8)
2006	(6.5)	(0.5)	2.9	(4.1)
2007	(5.8)	(0.3)	2.6	(3.5)
2008	(5.6)	(0.4)	2.2	(3.8)
2009	(5.2)	(0.5)	1.9	(3.8)
2010	(5.0)	(0.4)	1.7	(3.7)
2011	(4.8)	(0.4)	1.6	(3.6)
2012	(4.8)	(0.4)	1.4	(3.8)
2013	(4.6)	(0.3)	1.3	(3.6)
2014	(4.4)	(0.3)	1.3	(3.4)
2015	(4.4)	(0.3)	1.1	(3.6)

SOURCE: Tables 6.8–6.11.

NOTES: Oil consumption effect is the average of Tables 6.8 and 6.9. Numbers in parentheses are negative.

Table 4 which is taken from the scenarios run by the EIA and the RAND corporation shows the effects on GDP when prices shift unfavorably affecting supply and production. In the appendix, I outline a model that looks at the distributional impacts of such disruptions in a linear approximation scenario. In particular, poverty impacts are derived. The preliminary results suggest strongly that almost all of Chinaa's growth induced poverty reduction gains can be destroyed through disruptions in the energy markets alone. For China's policy makers this must be a sobering thought. What options are available to them? In the next section, I review and assess the steps taken and suggest a strategy most likely to succeed.

3. China's energy dilemma: strategic moves

China's energy dilemma has renewed concerns about long term energy security. Several decades ago, the same concerns existed but the solution was also clear and simple--- to increase domestic production. Our analysis indicates that this is no longer a viable option.[3] Discovery of large reserves is unlikely. Thus oil is seen as a source of vulnerability in Beijing. Since plans for building a POLIS depend crucially on oil, it could make China vulnerable to foreign pressures. Many years of debate within the state council has not resolved this difficult problem. Policy makers have been divided over whether domestic production should be increased or explore for oil abroad. In practice both the paths are being followed. I will argue that neither is going to reduce vulnerability to a large extent soon. In the medium to long run, however, there is a third option available; but it will require both rethinking development priorities at home and reorienting diplomacy towards greater regional cooperation. But let us look at the existing divided strategy.

The centerpiece of the current strategy seems to be an ambitious scheme of investment in overseas oil projects together with continuing domestic exploration. The state owned oil companies of China are the key players in both arenas.During the 1980s China launched three large oil companies. The China National Offshore Oil Corporation(CNOOC) has controlled most of the offshore oil businesses since its founding in 1982. The China National Petrochemical Corporation (Sinopec) was founded in 1983 and is responsible for refining and marketing. The China National Petroleum Corporation (CNPC) was founded in 1988 by the ministry of petroleum industry. In 1998 the government reorganized CNPC and Sinopec and created two vertically integrated oil companies.However, CNPC is still China's dominant upstream oil company and Sinopec the main downstream company in the industry.

Initially, the government maintained a two-tiered pricing policy that required CNPC to sell to its industrial customers at a fraction of the market price. The resulting cash flow constraint led to limited exploration. In 1993, the government relaxed the pricing policy increasing the first tier crude price. CNPC was the main beneficiary, as indeed was the

[3] See also Christoffersen (1998) for an analysis of the situation particularly with respect to China's relations with Russia and Central Asia in historical perspective.

intention. CNPC officials knew that unless the money was quickly invested it would be confiscated. The coincidental appointment of Zhou Yongkang who favored foreign investment led to overseas expansion of investment.[4] Since this time, views of top CNPC officials have mattered a great deal in China's foreign energy investments. However, they are chosen ultimately by the Communist Party leadership. Hence it can be rightly said that the Party is the final arbiter.

Among other things CNPC has invested from Canada to Kazakhstan. In 1997 it pledged over $8 billion for oil concessions in Canada, Venezuela, Iraq and the Sudan. Such activities underline the high priority attached to these projects. They can also lead to increasing tension between China and the US. For example, in 1997, CNPC acquired a sixty per cent stake in Kazakhstan's Aktyubinskmunaigaz Production Association. CNPC beat out Texaco, Amoco and Russia's Yujnimost by agreeing to pay $320 million bonus to the Kazakh government and to conduct a feasibility study on the construction of an 1800 mile pipeline to Western China. This was estimated to cost $ 3.5 billion.In September 1997, CNPC followed similar tactics to defeat Petronas, Unocal and Amoco to win a controlling interest in Uzen, Kazakhstan's second largest oilfield with reserves of 1.5 bb.

In June 1997, a consortium of Chinese oil companies signed a 22-year production sharing contract with Iraq to develop half of the Al-Ahdab field after thhe lifting of UN sanctions. Al-Ahdab is the country's second largest oilfield.Prior to the US invasion of Iraq, CNPC was negotiating for rights to develop three other Iraqi fields. These are Halfaya, Luhais and Suba.

However, the US invasion of Iraq and the subsequent occupation has put these plans in great jeopardy.The global energy situation is now marked by even more uncertainty and the Chinese must feel more vulnerable than ever. It is always possible that US imperialism will fail like all imperialist powers to ultimately control the middle eastern oil or even the sea routes permanently. But the realists in China must know that the current situation is one of US dominance. Apart from its domestic snafus reflected in the facts such as that Kazakhstan-China pipeline plans were shelved in 1999, the US preeminence as a military power and its willingness to use this power for various purposes including protecting control over overseas oil, China's energy dependence seems logically to lead to dependence on the US hegemony. What is the way out? I suggest that rethinking development strategy and increasing regional cooperation offer the best hope for China.

Strategically, Chinese development path has been so far marked by the East Asian model.According to this model heavy state involvement together with the promotion of market led industrialization through export promotion is the best strategy for development. As an industrialization strategy, this can succeed up to a point. However, as

[4] For a detailed description see, Kenneth Lieberthal and Michel Oksenberg . 1998. Policy Making in China: Leaders, Structures, and Processes , Princeton: , Princeton University Press.

the Asian financial crisis demonstrated, there are risks as well (Khan1997, 1998, 2004 a and b).The Chinese strategy has led to high growth and a lopsided distribution together with energy dependence. Following this path further without qualification, as the current leadership seems to have grasped, will exacerbate the negative aspects with the inevitable growth slowdown. However, there is an alternative which I have developed in detail elsewhere. Here I will merely sketch the main outline.

In my development of an alternative strategy(Khan 1983, 1982a and b, 1997,1998, 2002, 2003, 2004 a and b; Khan and Sonko 1994) based among others on an extension of Schumpeterian theory of innovation and Sen's capabilities, the key is a distributionally sensitive approach with clear recognition of ecological constraints.The main idea is to moderate the growth rate and hence short term dependence on fossil fuels and minimize consequent ecological problems.With a proper poverty reduction strategy---called 'growth plus'strategy[5]--- the adverse distributional consequences from moderate growth can be avoided. In fact, with a properly moderate 'growth plus'strategy, the capabilities of the great majority of the poulation caan be enhanced along with the productive capacity. This will lead to the creation of a domestic market for commodities that are produced in a much more ecologically sustainable manner. Furthermore, the goal of a transition to a relatively non-fossil fuel based knowledge and information economy will be facilitated and the transition will occur more quickly and smoothly under the proposed POLIS strategy.

The question of domestic market creation leads also to considerations of cooperation in Asia. For reasons of regional financial stability, reciprocal exporting and energy security greater cooperation in each of these spheres is an urgent necessity. China along with the other countries in Northeast Asia must proceed to diffuse tensions and build up regional institutions. Given the historic hostilities this will be no easy task. Yet the enlightened self-interests of the countries together with imperatives of regional peace and prosperity lead logically towards cooperation. There is much here to learn from European integration experience, particularly about the role of enlightened leadership. No doubt, there are special Asian features and special Asian roadblocks that might require particular Asian approaches to negotiation and conflict resolution at times. But China's energy dilemma is one compelling reason for that country to take the initiative and start a dialogue. There is no time to lose.

4. Conclusions and Future Directions

In this paper I have sketched the energy dilemma for China in this century. As long as the current geopolitical situation persists the pursuit of present development strategy of China will further increase its energy dependence.For both political and economic reasons China needs to rethink its development strategy. I have sketched such an alternative strategy that relies much less on fossil fuels and emphasizes regional cooperation. This POLIS strategy will ultimately lead to a sustainable economy based on growth with equity. A transition to a non- fossil fuel based knowledge and information economy will also be easier to effect under the proposed strategy.

[5] This is discussed in detail in chapter 1 of Khan and Weiss, forthcoming.

However, time is of the essence. Given the path dependence of development unless strategic disengagement from the existing path followed by a strategic engagement with the alternative strategy is begun within the next five years, it may well be too late. The stakes are indeed very high. A more detailed strategy paper based on the key ideas from the alternative strategy outlined here with concrete quantitative scenarios and feasibility studies along the lines of models sketched in the appendix (and other, more detailed models) will go some distance towards giving the appropriate analytical foundations for the policy makers.

Appendix 1: Growth Impacts of the energy sectors--- A simple SAM-based Model

Fixed Price Modeling in a SAM-based Framework:

In this section the Social Accounting Matrix is presented as a data gathering framework as well as an analytical tool for studying the effects the energy sectors on growth. Appendix two presents the methodology for estimating the impact of growth generated by the energy sectors on poverty alleviation. The origins of social accounting can be traced as far back as Gregory King's efforts in 1681, but more recent work stems from the attempts by Richard Stone, Graham Pyatt, Erik Thorkbecke and others. [6]

In the methodological framework of this study the SAM is used for mapping production and distribution at the economy wide level. In this section, first a general SAM is described. Then it is shown how the method for studying the effect of growth within this framework follows logically from its structure. The model used is a simple version of a class of SAM-based general equilibrium models.[7] It summarizes succinctly the interdependence between productive activities, factor shares, household income distribution, balance of payments, capital accounts, etc. for the economy as a whole at a point in time. Given the technical conditions of production the value added is distributed to the factors in a determinate fashion. The value added accrued by the factors is further received by households according to their ownership of assets and the prevailing wage structure. In the matrix form the SAM consists of rows and columns representing receipts and expenditures, respectively. As an accounting constraint receipts must equal expenditures.

As is elaborated further in Khan and Thorbecke (1988), the SAM framework can be used to depict a set of linear relationships in a fixed coefficient model. For deciding the question of determination, the accounts need to be divided into exogenous and endogenous ones. For instance, in the China SAM, there are three endogenous accounts. These are factors, households and production activities, leaving the government, capital and the rest of the world accounts as exogenous.[8]

[6] For a description of SAM as a data gathering device, see G. Pyatt and E. Thorbecke, *Planning Techniques for a Better Future* (Geneva: ILO, 1976). Khan(1997) also has a chapter on this alone.

[7] In Walrasian general equilibrium models the flexible price vector determines the equilibrium. In a Keynesian (dis)equilibrium model in the short-run the quantities vary while the price vector remains fixed.

[8] See Khan and Thorbecke, op.cit., Ch. II for more theoretical details and empirical examples. The presentations here follow the cited work closely.

Table 1: Simplified Schematic Social Accounting Matrix

				Expenditures				
				Endogenous Account			Exog.	Total
				1	2	3	4	5
Receipts	Endogenous Accounts	Factors	1	0	0	$T_{1.3}$	x_1	y_1
Receipts	Endogenous Accounts	Households	2	$T_{2.1}$	$T_{2.2}$	0	x_2	y_2
Receipts	Endogenous Accounts	Production Activities	3	0	$T_{3.2}$	$T_{3.3}$	x_3	y_3
Receipts	Exog.	Sum. Of other accounts	4	l_1'	l_2'	l_3'	t	y_x
		Total	5	y_1'	y_2'	y_3'	y_x'	

Looking at Table 2, which represents a SAM, we can see immediately that

$$y = n + x \qquad (1)$$

$$y = 1 + t \qquad (2)$$

Now if we divide the entries in the matrix Tnn by the corresponding total income (i.e. y_n), we can define a corresponding matrix of average expenditure propensities. Let us call this matrix A. We now have:

$$y = n + x = Ay + x \qquad (3)$$

$$y = (1-A)^{-1}x = Mx \qquad (4)$$

M has been called the matrix of accounting multipliers by Thorbecke, for these multipliers, when computed, can account for the results (e.g. income, consumption, etc.) obtained in the SAM without explaining the process that led to them. Let us now partition the matrix A in the following way.[9]

[9] Ibid.

$$A = \begin{bmatrix} 0 & 0 & A_{13} \\ A_{21} & A_{22} & 0 \\ 0 & A_{32} & A_{33} \end{bmatrix} \qquad (5)$$

Table 2: Schematic Representation of Endogenous and Exogenous Accounts in a SAM

		Expenditures				Totals
		Endogenous	Sum	Exogenous	Sum	
Receipts	Endogenous	T_{nn}	n	Injections T_{nx}	x	y_n
	Exogenous	Leakages T_{xn}	1	Residual Balances T_{xx}	t	y_x
Totals		$y_n/$		$y_x/$		

Source: H.A. Khan and E. Thornbecke, Choice and Diffusion of Technology in a Macroeconomic (SAM) Framework

Given the accounts factors, household and the production activities, now we see that the income levels of these accounts (call them y_1, y_2, y_3 respectively) are determined as functions of the exogenous demand of all other accounts. In this respect, what we have is a reduced-form model which can be consistent with a number of structural forms. This is quite satisfactory as far as tracing the effects of a certain injection in the economy is concerned or for prediction purposes when the structural coefficients are more or less unchanged.

One limitation of the accounting multiplier matrix M as derived in equation (2.2) is that it implies unitary expenditure elasticities (the prevailing average expenditure propensities in A are assumed to apply to any incremental injection). A more realistic alternative is to specify a matrix of marginal expenditure propensities (C_n below) corresponding to the observed income and expenditure elasticities of the different agents, under the assumption that prices remain fixed. The C_n matrix can be partitioned in the same way as the A matrix above. The most important difference between the two partitioned matrix is that $C_{32} \neq A_{32}$. Expressing the changes in income (dy) resulting from changes in injections (dx), one obtains,

$dy_n = C_n dy_n + dx$ (6)

$= (I - C_n)^{-1} dx = M_c dx$ (7)

M_c has been called a fixed price multiplier matrix and its advantage is that it allows any nonnegative income and expenditure elasticities to be reflected in M_c. In particular, in exploring the macroeconomic effects of exogenous changes in the output of different product-cum-technologies on other macroeconomic variables, it would be very unrealistic to assume that consumers react to any given proportional change in their incomes by increasing expenditures on the different commodities by exactly that same proportion (i.e. assuming that the income elasticities of demand of the various socioeconomic household groups for the various commodities were all unity). Since the expenditure (income) elasticity is equal to the ratio of the marginal expenditure propensity (MEP_i) to the average expenditure propensity (AEP_i) for any given good i, it follows that the marginal expenditure propensity can be readily obtained once the expenditure elasticity and the average expenditure propensities are known, i.e.,

$y_i = MEP_i/AEP_i$ (8)

$MEP_i = y_i\, AEP_i$ (9)

and $\sum_i MEP_i = 1$ (10)

Thus, given the matrix A_{32} of average expenditure propensities, and the corresponding expenditure elasticities of demand, y_i the corresponding marginal expenditure propensities matrix C_{32} could easily be derived.[10]

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[10]See Khan and Thorbecke (1988) for some examples.
See also G. Pyatt and J.I. Round, "Accounting and Fixed Price Multipliers in Social Acounting Matrix Framework," *Economic Journal* Vol. 89, Dec. 1979, p. 861.

Appendix 2: Energy Sectors, Growth, Distribution and Poverty.

Multiplier Decomposition,Growth and Poverty Alleviation Sensitivity

Since poverty in the present context is measured by identifying a poverty line in monetary terms incomes of the various household groups are the crucial variables. In particular, sectoral growth generated by the energy sectors must be linked to incomes of the various households in order to determine the exact extent of the alleviation of poverty through growth. The exact effect of income growth on poverty, of course, depends on the sensitivity of the adopted poverty measure to income. In this paper the Foster, Greer and Thorbecke (1984) P_α class of additively decomposable poverty measure is selected for this purpose. For α=0,1,n this measure becomes the headcount ratio, the poverty gap and a distributionally sensitive measure that gives specific weights to each poor person's shortfall, respectively.

If we apply Kakwani's (1993) decomposition to the P_α measure for specific sectors and households i and j respectively, the change in $P_{\alpha ij}$ can be written as follows:

$$dP_{\alpha ij} = \frac{\partial P_{\alpha ij}}{\partial y_i} + \sum_{k=1} \frac{\partial P_{\alpha ij}}{\partial \theta_{ijk}} d\,\theta_{ijk} \qquad (11)$$

Here $P_{\alpha ij}$ is the FGT P_α measure connecting sector j to household group i, y_i is the mean per-capita income of household group i, and θ_{ijk} is the income distribution parameter. Under the unrealistic but simplifying assumption of distributional neutrality:

$$d\frac{P_{\alpha ij}}{P_{\alpha ij}} = \eta_{\alpha i}\left(\frac{d\bar{y}_i}{\bar{y}_i}\right) \qquad (12)$$

where $\eta_{\alpha i}$ is the elasticity of P_{ij} with respect to the mean per capita income of each household group i resulting from an increase in the output of sector j. dy_i on the right hand side is the change in mean per capita income of household group i. This can be written as (by considering the fixed price multiplier matrix)

$$dy_c = m_{ij}\, dx_j \qquad (13)$$

where dx_j is the change in the output of sector j on a per capita basis for group j. We can now rewrite the aηverage change in poverty measure as

$$d\frac{P_{\alpha ij}}{P_{\alpha ij}} = \eta_{\alpha i} m_{ij} \left(\frac{dx_j}{\bar{y}_i}\right) \qquad (14)$$

By aggregating across the household groups we can arrive at the overall poverty alleviation effect

$$d\frac{P_{\alpha j}}{P_{\alpha j}} = \sum_{i=1}^{m} \left(\frac{dP_\alpha ij}{P_\alpha ij}\right)\left(\frac{n_i}{n}\right) = \sum_{i=1}^{m} \left(\frac{dP_{\alpha ij}}{P_{\alpha ij}}\right)\left(\frac{P_{\alpha ij}}{P_{\alpha j}}\right) \qquad (15)$$

Since we are considering a P_α measure

$$d\underline{P_{\alpha j}} = \sum^{m} \left(\underline{dP_{\alpha ij}}\right)\left(\underline{\Sigma(z-y_k)/z)^\alpha}\right) \qquad (16)$$

$$P_{\alpha j} \quad {}_{i=1} \left(P_{\alpha ij}\right) \left(\Sigma(z-y_l)/z)^{\alpha}\right)$$

where q_i is the number of poor in the ith group and the total number of poor $q=\sum_{i=1}^{m} q_i$

Let $s_{\alpha i}$ be the poverty share of household group i (naturally $\sum_{i=1}^{m} s_{\alpha i} = 1$)

$$s_{\alpha i} = \sum_{k=1}^{qi}\left(\frac{z-y_k}{z}\right)^{\alpha} \Big/ \sum_{l=1}^{q}\left(\frac{z-y_l}{z}\right)^{\alpha} \qquad (17)$$

We can further rewrite the expression for the average change in overall poverty alleviation.

$$\frac{dP_{\alpha j}}{P_{\alpha j}} = \sum_{i=1}^{m}\left(\frac{dP_{\alpha ji}}{P_{\alpha ij}}\right) s_{\alpha i} \qquad (18)$$

Combining equations 14 and 18
we now have,

$$\frac{dP_{\alpha j}}{P_{\alpha j}} = \Sigma s_{\alpha i}\eta_{\alpha i}\, m_{ij}\left(\frac{d_{xj}}{\bar{y}_i}\right) \qquad (19)$$

Thorbecke and Jung(1996) separate the income increase via the modified multiplier effect from the sensitivity of the poverty measure formally in equation (19) by defining the following two entities:

1. $m^{/}_{\alpha ij} = s_{\alpha i}m_{ij}$ gives the modified multiplier effect in terms of income of a poor group.
2. $q_{\alpha ij} = \eta_{\alpha i}(dx_j/\bar{y}_i)$ represents the sensitivity of the poverty index to the change in income. I adopt their terminology and call this the poverty sensitivity effect.

But each multiplier m_{ij} can be further decomposed:

$$m_{ij}=\eta_j d_{ij} \qquad (20)$$

where n_j gives the (closed loop) interdependency effects and d_{ij} the distributional effects of a change in demand for the product of sector j on household group i.
Thus,

$$dP_{\alpha j}/P_{\alpha j} = \Sigma^{m} m^{/}_{\alpha ij}q_{\alpha ij} \qquad (21)$$

$$= \sum_{i}^{m}(r_{\alpha ij})\,(s_{\alpha ij}d_{ij})(q_{\alpha ij}) \qquad (22)$$

The d_{ij} on the right hand side can be further decomposed by multiplicatively decomposing the total distributive effects. Given the structure of C_n matrix in section 2. $D=D_3D_2D_1$ where $D_3= (I-C_{22})^{-1}$; $D_2=C_{21}C_{13}$, and $D_1=(I-C_{33})^{-1}$
The particular element for each household i and sector j can be selected from these three matrices.

Thus the contribution of an increase in output of a particular sector j to poverty alleviation can be decomposed multiplicatively into its two components: (i) the contribution due to the change in mean income of the poor across all groups and (ii) the sensitivity of the particular poverty measure to this change in average income of the poor.

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