Economic Modeling Study:

Exploring an Innovative Market Scheme to Advance Sustainable Transport and Fuel Security

Draft Final Report

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1 Introduction

The 48 regional members of the Asian Development Bank (ADB) represent a large and diverse group of countries, comprising 25% of the world's land area, 56% of humanity, and 29% of the global GDP. Beginning the century with relatively low average income, the region is projected to continue relatively high growth rates over the coming decades. This will happen as Asia's large emerging internal markets (China, India, and the Association of Southeast Asian Nations) see rising consumer demand succeed the historic export led growth model, offering opportunities for more stable, diversified, and inclusive economic activity around region. This projected growth, considering historical middle class emergence in the West and the large population of the region, will translate into substantial energy requirements and has the potential to contribute to further global warming.

To respond effectively these opportunities and challenges, both policy makers and private stakeholders need better understanding how demand patterns in regional energy markets will grow and change. One area of special importance is the rapidly expanding vehicle market of the region, as increased vehicle fleets will lead to increased energy demands and pollution. This study aims to project the future vehicle demand for the Asia and Pacific Region in to better prepare global energy markets achieve sustainable development.

The objective of this report is to assess the potential economic benefits and wider market implications of more determined policy approaches to efficient regional transportation services. Because indirect effects can far outweigh direct or negotiated trade effects, a GE assessment gives a more complete picture of the inclusive benefits of such cooperation. More comprehensive assessment such as this implicates a much larger universe of economic actors, and provides essential evidence to inform both the policy agenda (integration, inclusion, etc.) and supporting investments needed from public and private stakeholders.

In support of the Sustainable Fuel Partnership (SFP), this project will develop long term estimates of energy use patterns and price dynamics, globally and for specific countries. The SFP is a collaborative policy initiative comprising the Asian Development Bank (ADB), International Energy Agency (IEA), and Oxford Environmental Change Institute (OECI, Transport Studies Unit), formed with the intent to promote more sustainable transport development, particularly in Asia, with concomitant reductions conventional fuel demand growth and other co-benefits.

By elucidating the market consequences of alternative scenarios for energy and transport policy, technology innovation, diffusion, and adoption, SFP can influence the course of public and private behavior. More specifically, it is hoped that better understanding of future benefits will promote mechanisms to facilitate sustainable energy policies and private investment, such as a proposed Fuel Security Credit (FSCs). To this end, SFP has developed baseline and counterfactual scenarios for patterns of transport system development and technology deployment over the period 2010-2050. These scenarios are to be used as inputs to long term forecasting models that can predict resulting trends in future energy use and prices. A report on these estimates, including analysis of the significance of uncertainty in the underlying baseline (especially oil prices) might affect the forecasts, will be the primary output of the present activity.

More specifically, this project assesses how policy mechanisms like FSC can be expected to alter the trends and volatility of global conventional energy prices, regional fuel payments, and subsidies. The latter policies are very important to ADB developing member countries, for reasons of social safety and growth promotion, yet they may have unintended consequences for technology choice and energy use. As motorization in the region accelerates, and energy prices continue their historic ascent, these policies have also become a major fiscal burden, diverting ever-greater public resources and challenging their sustainability. The evidence developed from this study will improve visibility for policy makers seeking to make most efficient use of public funds and promoting more sustainable growth and development patterns.

Review of Related Modeling Work

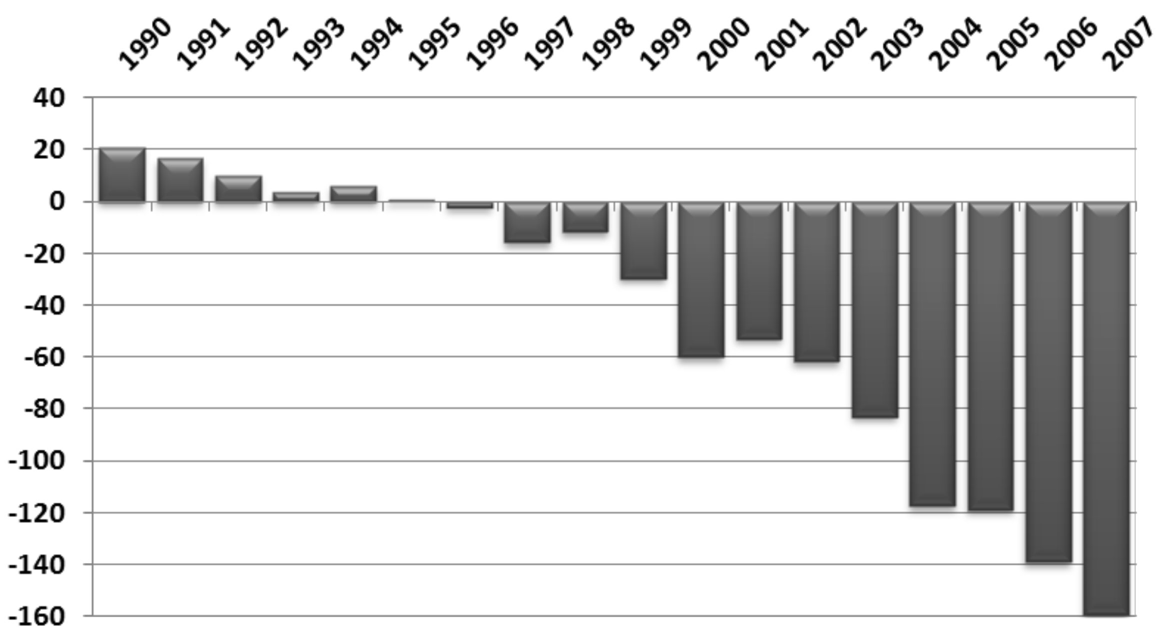
In an important empirical contribution to ADB's interest in regional energy futures, researchers at the Canadian Energy Research Institute (CERI) produced a study (Al-Qudsi et al: 2007) of oil price trends to 2030. Under a variety of scenarios for regional vehicle deployment and fuel demand from another study (Econoler: 2007), the authors estimated long term oil price levels and volatility.

While this study was a very diligent and capable application of available data and the methods chosen by the authors, it needs to re-assessed with respect to three considerations: changing energy markets, changing vehicle demand, partial equilibrium analysis.

Energy Market Fundamentals

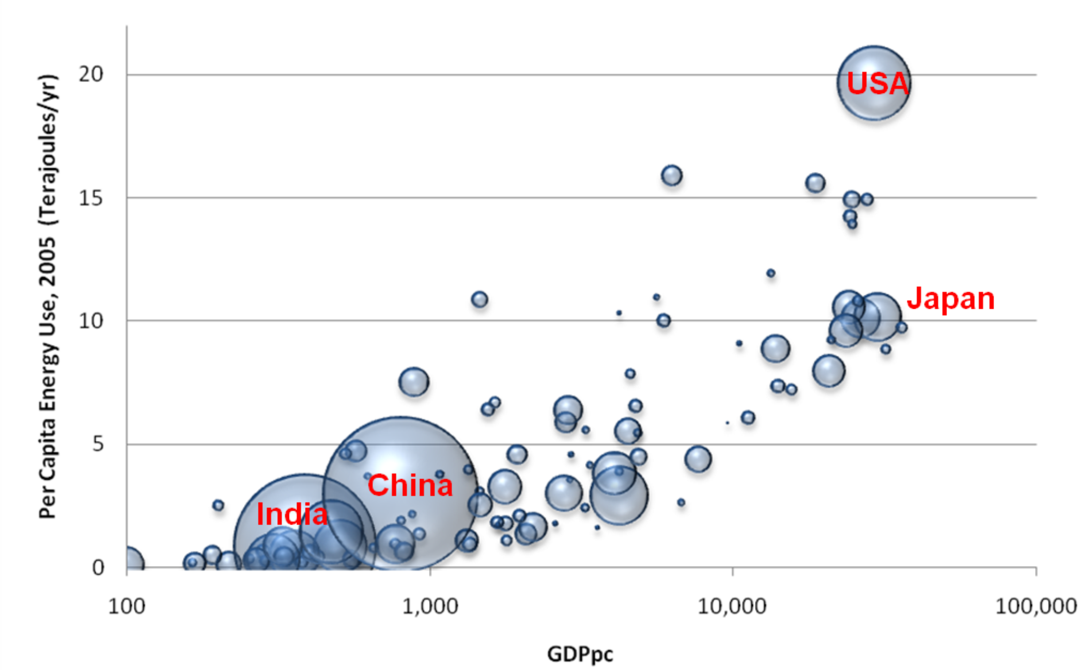
Over the last two decades, the fundamental global market determinants of commodity prices, including energy and particularly oil, have changed in what appear to be profound and perhaps lasting ways. The primary impetus for this has been accelerating demand from emerging economies. This is particularly true for those with rapidly growing middle classes, whose consumption increases in its energy- and other resource-intensity with rising incomes. For example, partly to meet growing export capacity (foreign demand) and domestic demand, China has gone over this period from being a small net exporter of oil to the world's second largest importer (Figure 1).

Figure 1: China's Net Oil Trade (MMT)



This trend can be expected to continue, as increased energy use per capita is strongly correlated with income (Figure 2), but diversity of outcomes from high income countries suggests that policy and behavioral differences can be important. The challenge for policy makers will be to find ways to flatten this growth trajectory and/or reduce the growth of conventional energy content in total energy demand.

Figure 2: Per Capita Income and Energy Use, 2006



Source: Author estimates from International Energy Agency and World Bank data. Vertical axis measures energy use per capita from all sources. Bubble diameter is proportional to population.

At the global level, energy price expectations are strongly informed by the International Energy Agency. With a wide ranging perspective and detailed supply and demand reporting from over one hundred countries, the IEA model is highly regarded, while always acknowledging substantial uncertainty in forward energy markets. Their latest forecasts (WEO, 2010), however, are following changing fundamentals and sharply revising their long term projections. In terms of expected energy availability and uncertainty, IEA forecasts have become much more pessimistic. This is clearly reflected in the following three extracts from recent public statements by Dr. Fatih Birol, IEA Chief Economist:

"The public and many governments appeared to be oblivious to the fact that the oil on which modern civilization depends is running out far faster than previously predicted and that global production is likely to peak in about 10 years – at least a decade earlier than most governments had estimated."

"…the first detailed assessment of more than 800 oil fields in the world, covering three quarters of global reserves, has found that most of the biggest fields have already peaked and that the rate of decline in oil production is now running at nearly twice the pace as calculated just two years ago."

"…we estimate that the decline in oil production in existing fields is now running at 6.7 percent a year compared to the 3.7 percent decline it had estimated in 2007 [the year of the CERI study], which we now acknowledge to be wrong."

These revised expectations are dramatically revealed in Table 1, which compares official oil price forecasts quoted in the Econoler (2007) study and their counterparts in 2010. The United States has nearly doubled its official long term , while IEA has revised upward by about three quarters. These portend dramatic increases in conventional energy costs, as well as the fiscal burden associated with any maintained fuel subsidy programs.

Table 1: Published Oil Price Forecasts (2008 USD per barrel)

Econoler:2007 (Table 6)

Source	2015	2020	2025	2030	2035
EIA-DOE	49.87	52.04	55.58	59.12	
IEA	56.50	56.0	58.47	61.0	

Most Recent (2010)

Source	2015	2020	2025	2030	2035
EIA-DOE	94.52	108.28	115.09	123.50	133.22
IEA	90.40	99.0	105.0	110.0	113.0

Difference

Source	2015	2020	2025	2030	2035

EIA-DOE	90%	108%	107%	109%
IEA	60%	77%	80%	80%

The implication of these demand and supply trends for prices is obvious, and we are already seeing it as oil sustains itself above $100/bbl. For the world's largest energy consumer, we see in Figures 3 and 4 that oil and gasoline prices appear to be lifting off from stable long term trends toward future distributions with much higher mean and variance. This is not an anomaly, and the structural nature of this price escalation is revealed in Figure 5, which shows United States national average gasoline spot and moving average prices over the last decade. Apart from a very temporary dip late in 2009 (since reversed and now over $400), these trends suggest systemic escalation of conventional fuel prices.

Figure 3: Crude Oil Prices

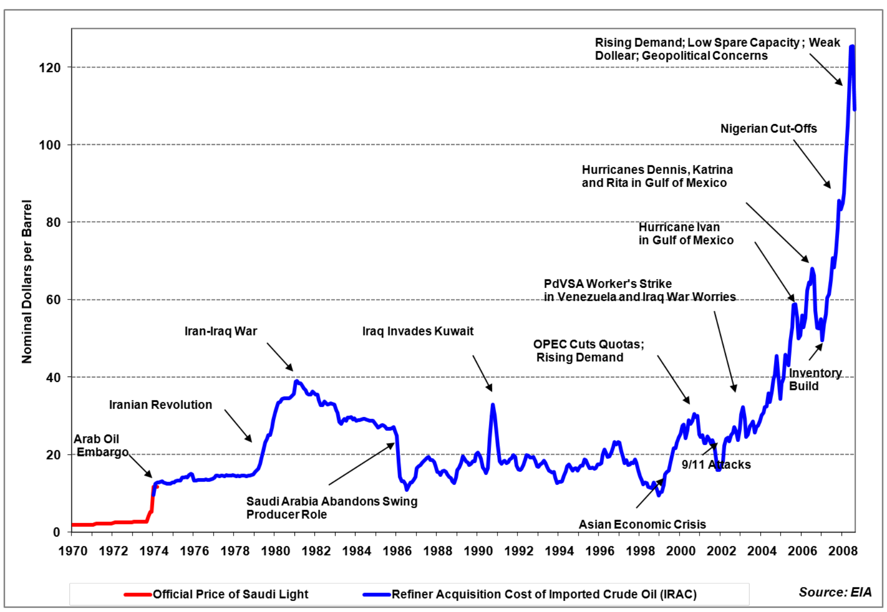
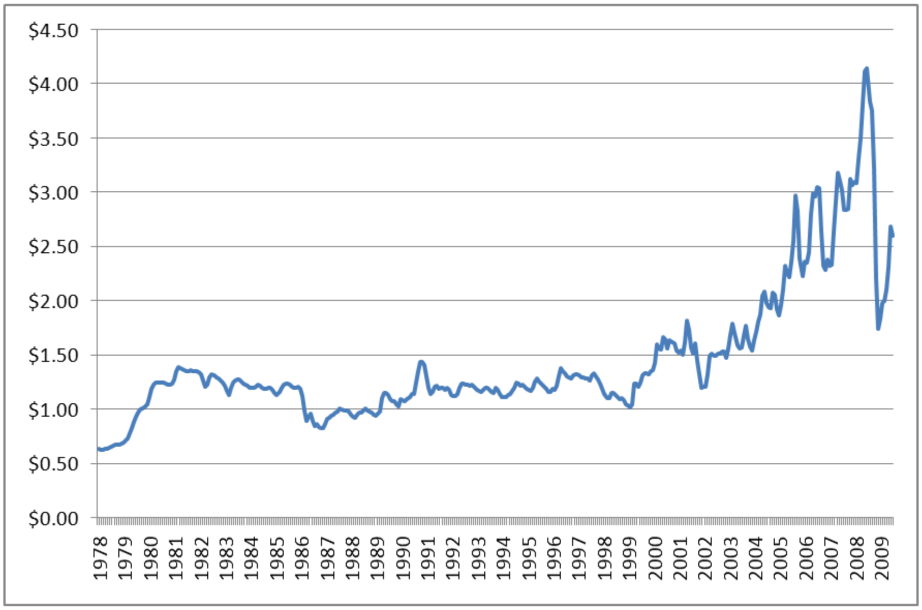
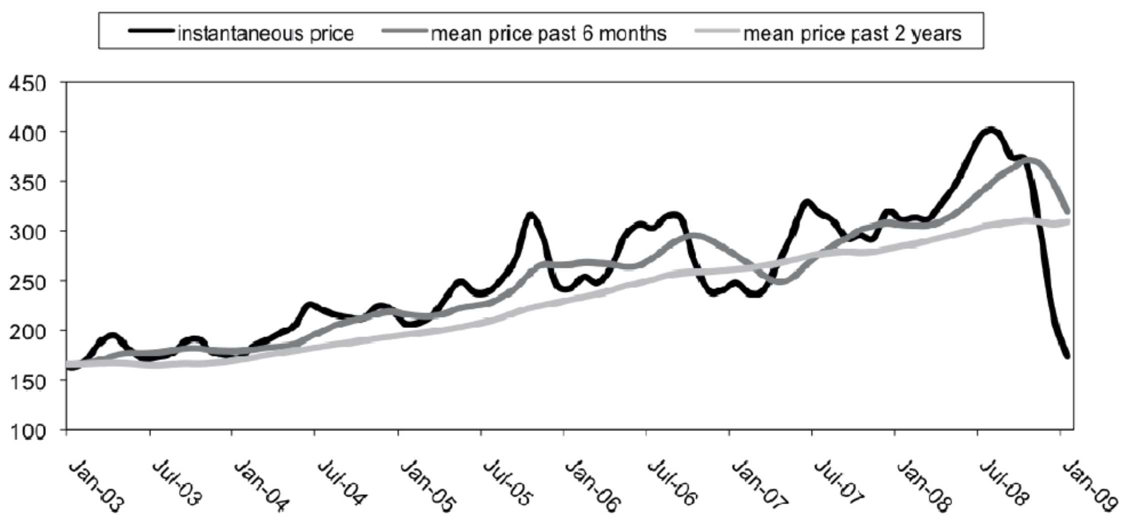


Figure 4: United States Retail Gasoline Prices
(national, all grades, 2008 dollars)



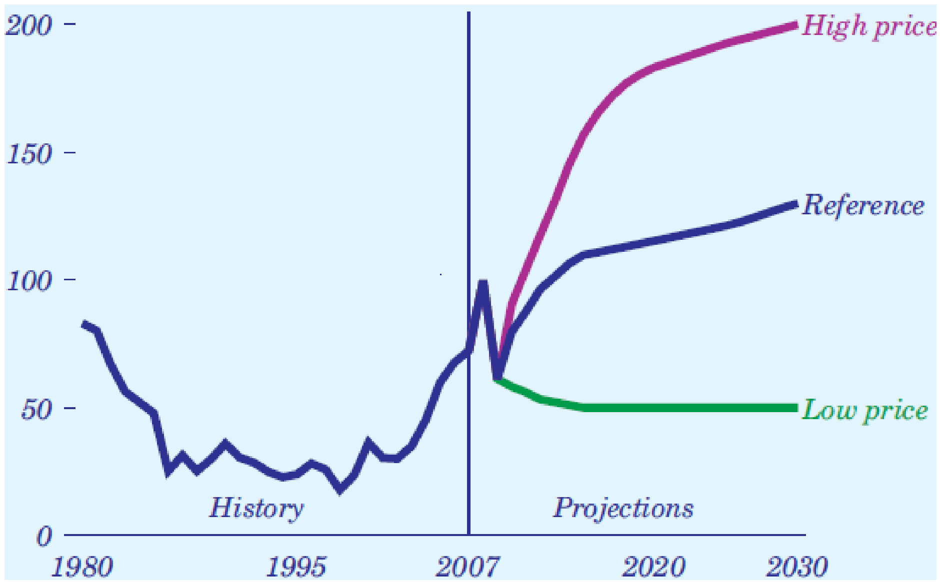
Source: Bureau of Economic Analysis, Series APU00007471A.

Figure 5: United States National Average Retail Gasoline Price Trends
(Constant USD per 100 gallons)



Source: Lin et al: 2010.

Figure 6: Future World oil prices in three cases, 1980-2030
(2007 dollars per barrel)



Source: DOE, 2009

Recent price escalation has also increased expected volatility, as official estimates by the United States Department of Energy make clear. The most recent official U.S. expectations regarding oil prices are depicted in Figure 3 below, comprising Low, Reference, and High scenarios. Not only are all three scenarios well above 10-20 year historical averages, their variation (fourfold difference between low and high) shows that the today's official information is of limited reliability in predicting future prices. In light of history, however (six fold increase between 2002 and 2008), it is also inevitable.

These structural changes in market fundamentals portend a new forward oil price future, with higher mean and variance than the distributions assumed and/or estimated by the CERI study. Although today's prices are within the bounds they predict for long term ranges, it would be desirable if they were re-calibrated to changed fundamentals as IEA's own work as acknowledged was necessary. This of course is no reflection on the author's original effort, but in light of intervening circumstances it would be risky for policy makers to rely too heavily on these projections. Meanwhile, higher average prices only make fuel efficiency policies more valuable, while higher uncertainty reinforces the basic energy security motivation at the heart of SFP.

Vehicle Market Fundamentals

Since the primary driver of rising oil demand is demand for transport services, the same tectonic shifts in demand are at work in the vehicle market, regardless of mode choice, emergent middle classes around the world are seeking increases local and wider mobility. This process is further intensified by demographic transitions in many populous emerging economies that we undergoing large scale demographic transitions from rural to urban majorities. While these aggregate forces expand the envelope of transport services, traditional services (cars) and fuels (gasoline and diesel) represent the leading categories of early growth.

Like the CERI study, Econoler's research was a very competent effort with available information, but it was also based on expectations formed over the decade to 2005 rather than 2010. The difference can be striking, as is apparent from Table 2 below. These figures show updated data (where available) for Econoler's own Table 13, deployment of CNG vehicles and fueling stations around the Asian region, with extra columns showing how these numbers have changed recently. Despite a serious global recession, the region has roughly tripled CNG deployment in less than five years.

These disparities between the initial conditions for the previous studies and more recent trends are difficult to generalize, but they have important implications for forecasting, both in terms of baseline trends and what might be considered reasonable counterfactual scenarios. To better inform this process of scenario development, we are currently updating as many of the CERI and Econoler datasets as possible. It will not, within the scope of the current TOR, be possible to redo all their estimates, but an inventory of data is essential to set appropriate scenario trends.

Table 2: Deployment of Compressed Natural Gas Vehicles and Fueling Stations

	Most Recent			Econoler: 2007, Table 13			Percent Change	
Country	Vehicles	Stations	Updated	Vehicles	Stations	Updated	Vehicles	Stations
Pakistan	2,740,000	3,285	Dec 10	1,000,000	930	May 06	174%	253%
India	1,080,000	571	Dec 10	334,658	321	Apr 06	223%	78%
People's Republic of China	450,000	1,350	Dec 09	97,200	355	Jan 05	363%	280%
Bangladesh	193,521	546	Dec 10	54,715	118	Nov 06	254%	363%
Japan	39,623	342	Sep 10	28,402	311	Jun 06	40%	10%
Malaysia	46,701	159	Jun 10	19,000	46	Dec 06	146%	246%
S. Korea	28,628	165	Dec 10	11,232	226	Dec 06	155%	-27%
Thailand	218,459	426	Nov 10	9,000	44	Dec 05	2327%	868%
Indonesia	2,000	9	Oct 06	6,600	17	Jul 05	-70%	-47%
Australia	2,750	47	Mar 07	895	12	Aug 01	207%	292%
New Zealand	201	14	Feb 07	471	12	Jun 04	-57%	17%
Philippines	36	3	Feb 06	12	1	Jul 04	200%	200%
Singapores	5,348	3	Dec 10	7	1	May 05	76300%	200%
Taiwan	4	1	Apr 05	4	1	Apr 05	0%	0%
North Korea	4	1	Dec 06	4	1	Aug 00	0%	0%
Total/Average	**4,807,275**	**6,922**		**1,562,200**	**2,396**		**208%**	**189%**

Partial Equilibrium Analysis

As indicated above, the CERI study makes capable use of the estimation methodologies chosen for their study. Having said this, the economics profession as a variety of approaches to estimating the impacts of relevance to this study, including price and income responsiveness of demand and supply. In particular, the CERI study is an example of partial equilibrium (PE) analysis. This approach studies responsiveness (i.e. elasticities) one market at a time, under the assumption that other markets remain stable. This approach can be contrasted with general equilibrium (GE) analysis, which takes account of linkages between markets and consequent spillovers of price and quantity effects.

Partial equilibrium approaches are also decomposable between those that estimate direct elasticities with a structural equations for supply and demand that include these parameters, and indirect methods (e.g. macromodels) that estimate elasticities implied by changed demand or supply levels that are outputs of other models. Finally, PE demand and supply estimates can also be distinguished between separable estimates, made each without considering the other, and coupled or iterative estimates, where feedback between price and quantity are considered in elasticity estimates. The latter approach is intended to overcome a fundamental identification or *simultaneity* problem involving endogeneity of price determination between supply and demand behavior.

The simultaneity problem exists when econometricians want to infer the distribution F(D,S,X) of demand (D) and supply (S) functions conditional on some covariate (X).[1] However, they can only observe the variables (pt, qt, xt). If the observations on market price, quantity and the covariate (P,Q,X) were obtained by a random sampling process, then the distribution G(P,Q,X) of the observed variables could be inferred. The simultaneity problem is that, although the econometrician can infer G(P,Q,X), knowledge of G is not sufficient for identifying F(D,S,X). Thus, it is possible that neither supply nor demand is identified.

The CERI study uses a hybrid of PE approaches, confining analysis to the sector at hand (oil), but combining demand and supply models with iterative solution for "stable" adjustment response (elasticity) measures. This approach is better than the simplest, direct PE estimation, but takes only limited account of the identification problem or economywide linkages. For a commodity like oil whose use is so pervasive, infiltrating every economic activity, omitting consideration of economywide feedback or GE effects may seriously undermine such estimates.

[1] For more discussion, see e.g. Goldberger (1999), Manski (1995), and Hausmann et al (1987).

In recognition of this, the TOR for this project calls for an approach that "integrates" PE and GE. This would be second best to a full GE analysis, and its efficacy remains to be determined, but the present study will try both approaches in consultation with ADB counterparts.

Literature review and brief summary of similar studies on fuel price projections

Two literatures are of primary relevance to fuel price projections: the fuel market forecasting literature and the literature on underlying behavioral determinants of fuel demand (e.g. elasticities, modal choice, etc.). Both strands of literature have been reviewed and incorporated in the CERI and Econoler studies, and here we only review the past generally and mention a few more recent works.

Oil Market Forecasting

By revenue, energy is the world's largest industry, and for this reason alone it is hardly surprising that energy market dynamics have long been the subject of research. Thus it is perhaps surprising the so little in the way of definitive findings are available to public and private observers of these huge markets. There have been many learned efforts to predict the course of oil prices[2], and literally hundreds of tools exist for short term, high frequency forecasting. Despite all these efforts, predicting long term oil prices remains a very uncertain science. A good overview recent work in this area can be found in Kirichene (2005).

Perhaps because of the short term orientation of private market forecasts, and the challenges academics have faced in reliably predicting long term trends, the primary source of such projections remains agencies charged with national or international oversight or policy dialogue. Leaders in this area are the International Energy Agency (IEA) a partner in the SFP, the United States Energy Information Agency and Department of Energy (EIA, DOE), and the Institute of Energy Economics of Japan (IEEJ). All these institutions produce regular research products that will form the basis for the current study.

[2] See e.g. Adelman (1962), Berndt and Wood (1975), Gately (1984), Gately and Huntington (2002), Griffin (1985), Hausman (1975), Kennedy (1974), Nordhaus (1980).

Behavioral Parameter Estimates

Much energy market forecasting and industry analysis is grounded in empirical research on the microeconomics of energy production and consumption. This has generated a large literature on models and parameters related to energy behavior, including an extensive "elasticity literature" that addresses price responsiveness of oil producers and income responsiveness of consumers.

The CERI and Econoler reports both appear to be well-informed about this literature and cite appropriate sources up to the time of their publication. We summarize here what is relevant for our work, and add a few sources that have emerged in the interim.

Generally speaking, the elasticity literature lacks a strong consensus of findings. Much of the disparity in results can be attributed to differences in functional form, model assumptions, specification and measurement of variables, and econometric estimation technique. Lin and Prince (2010) is the most recent authoritative work in this area, with intensive analysis of recent price trends.[3] This succeeds a number of meta-studies (Espey 1998, Dahl and Sterner 1991), studying differences in fuel demand price elasticity by regressing others' estimates on different sets of explanatory variables

The Dahl and Sterner (1991) meta-study encompasses 97 prior estimates of price and income elasticities of gasoline demand since 1989. They stratify their analysis into ten distinct models, finding estimates tend to be more uniform when they fall within a specific cluster. They find a range of short- to intermediate-run price elasticities to be -0.22 to -0.31 and long-run elasticities to be -0.8 to -1.01. Short-run and long-run income elasticites are in the range of 0.44 to 0.52 and 1.10 to 1.31, respectively.

The most comprehensive meta-study thus far is Espey (1998), who compared hundreds of alternative estimates from studies over six decades (1929-1993). Short- to intermediate-run price elasticity is estimated to be within the range of 0 to -1.36 with a mean of -0.26 and long-run price elasticity to be within the range of 0 to -2.72 with a mean of -0.58 and a median of -0.43. Short- and long-run income elasticities are estimated to have a mean of 0.47 and 0.88 respectively. In terms of short- versus long-run estimates, Espey argues that models which include some measure of vehicle ownership and fuel efficiency capture the "shortest" short-run elasticities as they control for changes in vehicle ownership and fuel economy over the longer run. Further, because static models produce more elastic short-run estimates and less elastic long-run estimates than

[3] Material in this section draws heavily upon Lin and Prince (2010).

dynamic models, Espey notes that they are likely producing intermediate-run elasticities.

A number of authors have addressed the issue of how elasticities change with time. As intuition would suggest, there is some empirical regularity in price responsiveness, where elasticities over longer time horizons are greater because long term price trends are more credible and agents have more time to adapt.

A more subtle and complex issue is whether or not elasticities for a given time interval are themselves changing over time. This issue has been difficult to study, but it is quite important for initiatives like SFP because it bears upon the efficacy of price based (e.g. subsidy) policies. In response to the suggestion that that short-run elasticities are decreasing over time and in response to the need for updated estimates of elasticity of demand for price-based policies, Hughes et al (2008) analyzed data over two distinct time periods to demonstrate changes in short-run elasticities over time. They find that the majority of literature overestimates gasoline demand elasticities for the past decade. In a comparison study using data from two different time periods, they show that the short-run gasoline price elasticity shifted down considerably from a range of -0.21 to -0.34 in the late 1970s to - 0.034 to -0.077 in the early 2000s. Income elasticities do not vary significantly between the two time periods and are estimated to range from 0.21 to 0.75.

The basic argument of these authors is related to a national policy, but probably has wider implications for other economies contemplating or already implementing similar measures. Hughes et al believe that the change in price elasticity of demand arises from structural and behavioral changes in the U.S. since the 1970s, including implementation of Corporate Average Fuel Economy program (CAFÉ), changing land-use patterns, growth in per capita and household income, and expansion of public transport. Hughes et al (2008) suggest that long-run elasticities have probably decreased over time also, while Espey (1998), argued that short-run elasticities have declined over time, but long-run elasticities have increased. Very recent work by Lin and co-authors suggest that elasticities were either smaller in the past (different estimation methods), or are declining rapidly.

Table 3 summarizes results of the meta-studies and more recent work to estimate fuel demand price elasticities over different time horizons, encompassing data since 1929. In light of the diversity of these findings, it is recommended that uncertainty analysis of forward prices be undertaken across a range of estimates for demand elasticities.

Table 3: Short and Long Run Estimates of Transport Fuel Demand Elasticities

	Short Run			Long Run		
Study	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Dahl and Sterner, 1991	-0.26	-0.22	-0.31	-0.86	-0.8	-1.01
Espey, 1998	-0.26	0	-1.36	-0.58	0	-2.72
Goodwin, 1992						
Time series	-0.27			-0.71		
Cross section	-0.28			-0.84		
Goodwin et al, 2004	-0.25	-0.01	-0.57	-0.64	0	-1.81
Graham and Gleister, 2002		-0.2	-0.5		-0.23	-0.8
Graham and Gleister, 2004	-0.25	0.59	-2.13	-0.77	0.85	-22
Hanley et al, 2002	-0.25	-0.01	-0.57	-0.64	0	-1.81
Hanley et al, 2008						
1975-1980		-0.21	-0.34			
2001-2006		-0.034	-0.077			
Lin and Prince, 2010	-0.06	-0.02	-0.09	-0.20	-0.11	-0.29

Source: Lin and Prince (Forthcoming).

Methodological Approach Proposed for Specific Project Components

Oil price projections

The overall approach to oil price projection for this project will be to use baseline trends developed as consensus estimates, and then evaluate price changes for policy scenarios around this baseline using a dynamic global CGE model. Consensus baseline trends mean a combination of official and authoritative independent estimates, evaluated and agreed among the authors of the report and ADB counterparts. The authors will present alternative sources and series with recommendations for synthesis into a pair of baselines, one reflecting low price expectations and one for higher expected prices.

Summary of the Global GE Model

A global model has already been developed for this work and is extensively documented elsewhere (Roland-Holst: 2011). The complexities of today's global economy make it very unlikely that policy makers relying on intuition or rules-of-thumb will achieve anything approaching optimality in either the international or domestic arenas. Market interactions are so pervasive, and market forces so powerful in determining economic outcomes that more sophisticated empirical research tools are needed to improve visibility for both public and private sector decision makers. The preferred tool for detailed empirical analysis of economic policy is now the Calibrated General Equilibrium (CGE) model. It is ideally suited to trade analysis because it can detail structural adjustments within national economies and elucidate their interactions in international markets. The model is more extensively discussed in an appendix and the underlying methodology is fully documented elsewhere, but a few general comments will facilitate discussion and interpretation of the scenario results that follow.

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economy-wide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economy-wide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economy-wide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions, which themselves can have policy implications.

The present global modeling facility has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to Version 7 of the GTAP global economic database.[4] The result is a 22-country/region, 10-sector global CGE model, calibrated over a 40-year time path from 2010 to 2050. The regional aggregation was chosen to identify leading Asian and other economies individually as indicated in the project TOR and in consultation with ADB counterparts.

Fuel payment and subsidy projections by country

Apart from its traditional neoclassical roots, an important features of this model include detailed treatment of energy and transport services (see annex). The TIGER model and database track household and enterprise expenditure on energy fuels and permit detailed accounting for energy price policies. In this

[4] See e.g. Meeraus et al (1992) for GAMS and Hertel et al (2008) for GTAP.

capacity, the model will be used to track the effects of SFP and related policies on national and regional subsidy programs and budgets, including their effects on transport and fuel use incentives and other microeconomic behavior. Although it is outside the present activity, TIGER also has the capacity model policy induced trading systems like FSCs, carbon markets, etc.

Oil price volatility impacts

Using a General Equilibrium Model, assess the dynamic reaction of international oil markets and oil prices for the oil‐savings scenarios against the two baseline projections. The model captures second‐round and other spillover effects (e.g. rebound effects) on supply and demand in Asia and the Pacific and other parts of the world caused by oil price changes. The model will take account of ADB oil demand projections and other independent information to adjust transport fuel demand by mode. Finally, it will compute implied price elasticities of supply and price elasticity of demand as part of the modeling output. These values will assist the team to understand the interactive nature of oil supply and demand when the alternative scenarios of sustainable transport are introduced.

Proposed treatment and representation of analytical uncertainty

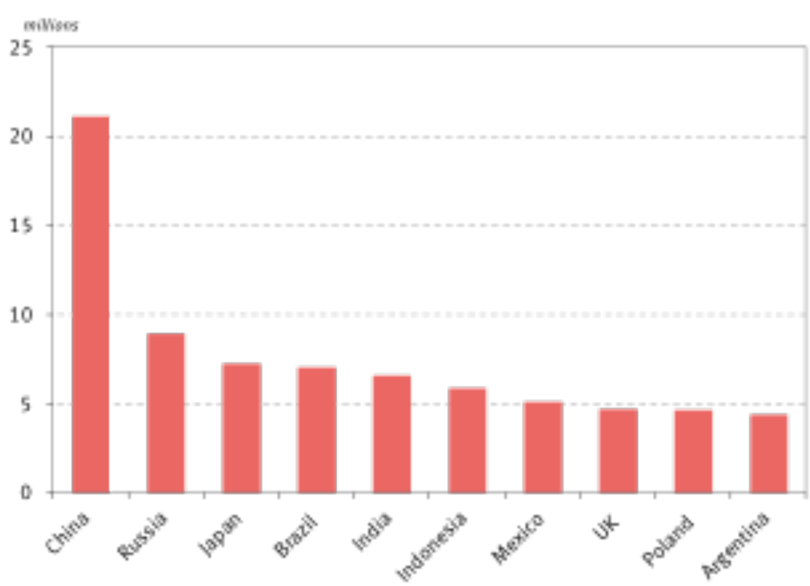
From much of the discussion above, as well as previous work by Econoler, CERI, and many others, it is apparent that uncertainty is endemic to the analysis of energy markets. The most important sources of this uncertainty in practical terms are price expectations and the nature of behavioral responses to changing external conditions. The former can be evaluated as price distributions around low and high expected trajectories, and a dynamic GE model like TIGER is designed to track these and provide corresponding solution bands. This will be done for both consensus Baseline estimates and the approximately 20 scenarios determined in consultation with ADB counterparts.

Current Status and General Trends

The contrast between car ownership in developed countries and developing countries is dramatic. Of a global total of 823 million cars in 2007, less than 22% were in developing countries. Looking at motorization rates in 2007, developing countries had 35 cars per 1,000 inhabitants compared to 490 cars per 1,000 inhabitants in OECD countries. Given this large disparity in ownership levels, it should come as no surprise that there has been and continues to be strong growth in the number of cars in developing countries. For example, five of the fastest six growing car populations over the 2000 – 2007 period were in non-OECD countries (OPEC 2010).

Growth is especially robust in Asia, home to numerous countries with large populations and fast growing economies. Of the six fastest growing car populations over 2000 – 2007, 4 where located in Asia, of which 3 were developing countries (China, India, and Indonesia). China has had far and away the fastest rate of growth, increasing its national stock of automobiles by 21 million over that period (Figure 1.1). More recently car volumes in China have accelerated even faster increasing nearly 50% in 2009 with over 13 million light-duty vehicles purchased, making China the largest auto market in the world (OPEC 2010).

Figure 1.1: Growth in Passenger Cars, 2000 - 2007



Source: OPEC 2010

From 2010 to 2030, global vehicle stocks are expected to rise by 549 million cars. Nearly three-quarters of this increase is expected to come from developing countries, rising by 430 million cars over that period. Developing Asia will be instrumental to this growth, with over half of the global rise in passenger cars expected to occur in the region (OPEC 2010).

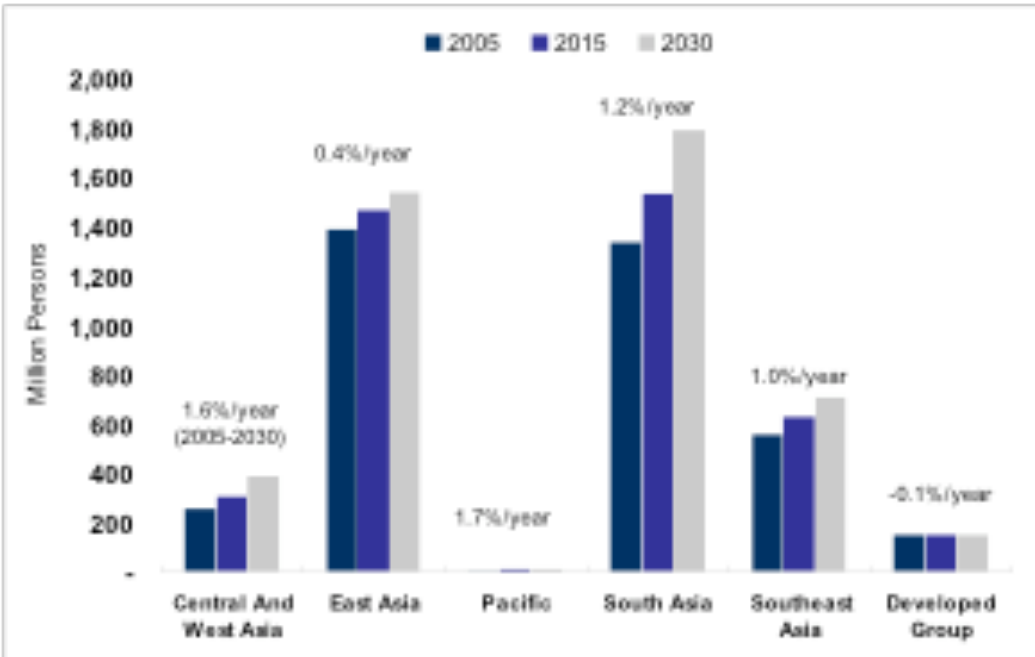
Projecting future vehicle growth is complicated by the fact that relationship between the growth of vehicle ownership and per-capita income is highly non-linear. Vehicle ownership grows relatively slowly at the lowest levels of per-capita income, then increasing rapidly at middle-income levels, and eventually slowing as vehicle ownership reaches a saturation rate. Thus, the relationship between vehicle ownership and per capita income resembles an s-shaped curve, rather than a straight line. In regards to saturation, it is assumed that developing countries will head towards lower saturation levels than OECD countries although countries will low levels of motorization are not expected to reach saturation levels for a long time. For example according to one projection, China is expected to reach 120 million vehicles by 2020, which would only amount to a motorization rate of 80 cars per 1,000 peoples which is well below its presumed saturation rate (IEEJ 2004).

Adding further complications to modeling motorization rates are other constraints on growth such as congestion, available infrastructure, public transportation, taxation, and local pollution. Conversely, stimuli to growth such as tax breaks and subsidies can lead to a rapid expansion of new car purchases. This most recently happened in China as consumers were supported by some $15 billion in government-sponsored incentives, including sales tax rebates for the purchase of small cars and subsidies for buyers in rural areas (Chu and MacLeod 2010).

Given the difficulties in projecting motorization rates, analysts have consistently identified three primary demographic and economic factors that influence the growth of motor vehicles in developing countries – population growth, increased urbanization, and economic development.

Intuitively population growth can have a significant influence on the number of motor vehicles in Asian countries. As the size of a population increase, so too does its scale of consumption of goods and services including motor vehicles. Population growth rates across the region vary. The highest growth rate per annum is expected in the Pacific subregion followed by 1.6% per annum in Central and West Asia. South Asia, Southeast Asia, East Asia, and the Developed Group are assumed to have per annum growth rates of 1.2%, 1.0%, 0.4% and -0.1% respectively. The decreasing population in the Developed Group can be largely attributed to Japan, which is projected to have an annual population decline of 0.4% (UN 2007).

Figure 1.2: Population in Asia and the Pacific by Subregion (2005-2030)



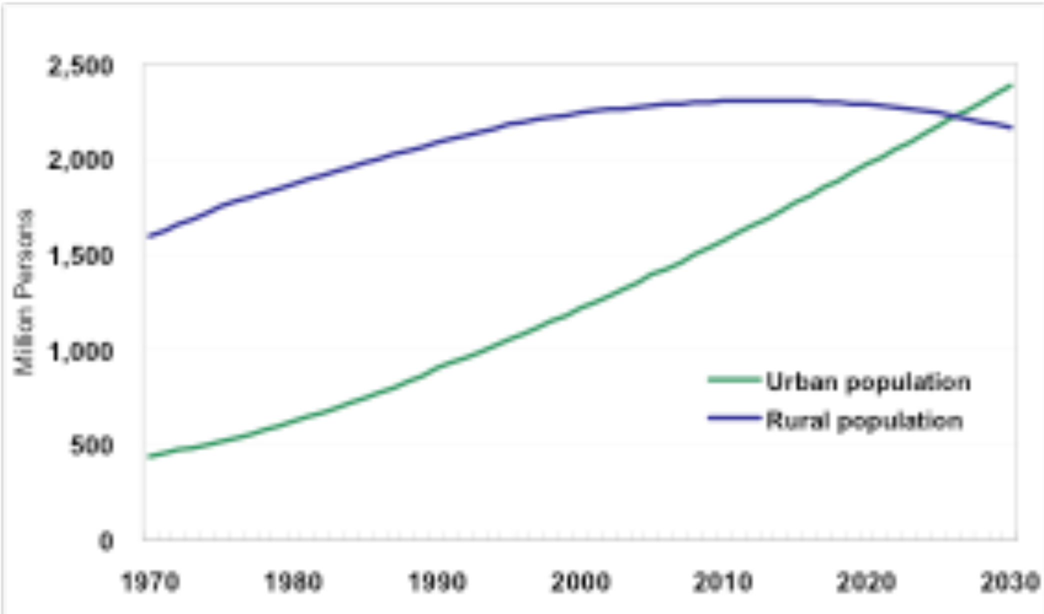
Source: Doi et al. 2010

Urbanization also contributes to increased motor vehicle ownership in two ways. First, car ownership is often seen as one of the first symbols of success and prosperity as residents earn higher income and standards of living in urban areas. Secondly, although growth in dense urban areas may lead to the development of public or alternative transportations systems (thus reducing demand for personal motor vehicles), urbanization can have an effect on motor vehicles ownership in non-urban areas. With the growth of urban centers comes increased economic opportunities, which may lead to greater demand for motor vehicle in non-urban areas as individuals and business rely on motor vehicles to access and participate in these urban activities.

Urban population in the Asia and Pacific Region is projected to increase 2.2% annually (representing a five-fold increase) from 2005 to 2030. This growth will come from both a combination of rural-urban migration and the transformations of rural areas into urban ones. Conversely, rural populations in the region are expected to peak at 2015 and then begin to slowly decrease at an annual rate of

0.2%. Urban population is expected to surpass the rural population by 2027 (UN 2007 and Figure 1.3).

Figure 1.3: Rural and Urban Population in Asia and the Pacific (2005-2030)



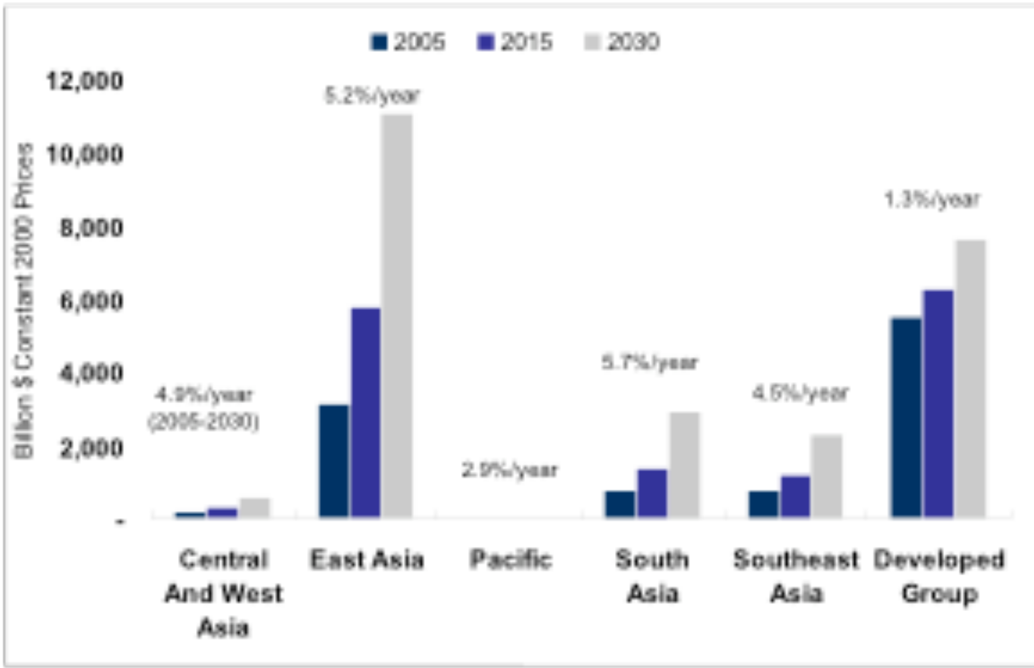
Source: Doi et al. 2010

Finally, industrialization and economic growth can have a tremendous influence on the number and growth of motor vehicles. As personal incomes rise above subsistence levels, demand for consumer goods tends to become income-elastic. The availability of excess income provides individuals and households the economic opportunity to purchase more expensive durable goods such as automobiles. Economic development also has affects on the supply side of motor vehicles. Growth in the business sector can lead to increased production or imports of new vehicles. As economies of scale are achieved the price of vehicles falls within the means of a greater segment of the population. Furthermore, economic growth can contribute to the growth of the public sector leading to the development of an infrastructure of roads, fuel sources, and other services related to vehicles.

Strong economic growth is forecasted for the Asian economies until 2020 with annual growth projected at 5.4 percent (outside Japan) compared to 2.7 percent for the world economy. The enormous markets of China, the Association of Southeast Asian Nations (ASEAN), and India, as well as the reinforcement of mutual interdependence in the region and swift technological advancements will fuel this robust growth (Ito et al. 2005).

Looking at the separate subregions, South Asia is projected to have largest economic growth at 5.7% per year until 2030 closely followed by East Asia at 5.2% per year. Annual economic growth rates in Central and West Asia, Southeast Asia, the Pacific and the Developed Group are projected at 4.9%, 4.5%, 2.9%, and 1.3% respectively (Figure 1.4).

Figure 1.4: GDP in Asia and the Pacific by Subregion (2005-2030)



Source: Doi et al. 2010

Individual Country Outlooks

All projections given are for light duty vehicles only (no two or three wheeled vehicles) unless noted. Motor vehicles refer to cars, buses, and freight vehicles. Passenger vehicles refer to vehicles intended for the carriage of passengers only.

Central and West Asia

Afghanistan

The transportation sector in Afghanistan is expected to grow rapidly at an average annual rate of 11.8% increasing from 0.1 MTOE in 2005 to 1.4 MTOE in 2030. Ravaged by years of conflict, energy demand in the transportation sector has stayed around 0.1 MTOE for the past several decades, although demand is expected to return to the 1990 level of 0.4 MTOE by 2015. Despite being landlocked and thus relying on motor vehicle transportation, Afghanistan has some of the worst road networks and conditions in the region. Because of this, the government and multilateral aid agencies have made the improvement of road infrastructure a priority in the hopes of increasing regional trade and enhancing the country's economic development. Thus, road traffic is expected to increase through 2030 although exact estimates are not available (ADB 2009).

Afghanistan's motorization rate was 27 motor vehicles per 1000 people as of 2008 (WB 2011).

Armenia

The transportation sector in Armenia is expected to grow by 4.0% annually, increasing from 0.2 MTOE in 2005 to 0.7 MTOE in 2030. Motor gasoline demand is projected to grow by only 2.6% annually due to a slight decline in population growth toward 2030 and a relatively low GDP per capita level, estimated to be $4,216 in 2030. Additionally, use of natural gas in passenger vehicles is expected to increase due to increased availability through pipelines from Iran and Russia making natural gas more accessible and price competiveness with petroleum products (ABD 2009).

Armenia's motorization rate was 105 motor vehicles per 1000 people as of 2007 (WB 2011).

Azerbaijan

Given Azerbaijan's important location between Europe, Central Asia, and China, enhanced transportation infrastructure may increase commodity trade in the country leading to increased transportation demand. Transportation energy demand is projected to increase at 4.5% per year tripling the sector's energy demand from 2.3 MTOE in 2005 to 7.0 MTOE in 2030.

Gasoline for passenger transport is expected to grow at an annual rate of 4.8%. Recently the increase in vehicle stocks has been concentrated in the Baku area, accounting for nearly 90% of the incremental growth between 2001 and 2007. However, economic growth in other areas of Azerbaijan are expected to cause vehicle stocks across the country to more than double from 72.9 per 1,000 people in 2005 to 148.7 per 1,000 people in 2030 (ADB 2009).

In 2007, Azerbaijan's motorization rate was 89 motor vehicles per 1,000 people (WB 2011).

Georgia

The transportation sector in Georgia is expected to increase at an annual rate of 2.2% through 2030. By energy type, diesel for freight trucks and buses will increase the fastest, followed by gasoline for passenger vehicles at 2.0% annually (ADB 2009). Georgia's motorization rate was 116 motor vehicles per 1000 people as of 2007 (WB 2011).

Kazakhstan

Transport energy demand is expected to nearly double from 3.6 MTOE in 2005 to 7.0 MTOE in 2030, representing an annual growth rate 2.7%. Rising incomes are expected to increase demand for both passenger and freight vehicles resulting in a 2.1% annual increase gasoline demand (ADB 2009).

Kazakhstan's motorization rate was 197 motor vehicles per 1000 people as of 2008 (WB 2011).

Kyrgyz Republic

The transportation sector in the Kyrgyz Republic is projected to increase at an annual rate of 2.4% through 2030 (ADB 2009). The motorization rate was 59 per 1000 people as of 2007 (WB 2011).

Pakistan

The transportation sector in Pakistan is projected to grow by 3.9% annually through 2030. The sector is the largest consumer of oil products in the country due to the market penetration of compressed natural gas. As of 2008, Pakistan is the largest user of CNG in Asia, and the third largest in the world (ADB 2009).

Motorization rates are low in Pakistan with only 11 motor vehicles per 1000 people as of 2007 (WB 2011). However, moderate growth is expected with motorization rates reaching 29 vehicles per 1000 people in 2030 with the national vehicle stock increasing by 5.6% annually. This corresponds to an estimated 7.8 million vehicles by 2030 (Dargay et al. 2007).

Tajikistan

Transportation energy demand in Tajikistan is projected to increase slowly with an annual growth rate of 1.8% increasing from 1.2 MTOE in 2005 to 1.8 MTOE in 2030. Growth in this sector is limited due to the slow urbanization rate and sustained low level of per capita income (projected $410 in 2030) (ABD 2009).

Tajikistan's motorization rate was 38 motor vehicles per 1000 people as of 2007 (WB 2011).

Turkmenistan

The transport sector in Turkmenistan is projected to increase at an annual rate of 3.3% through 2030. During the outlook period per capita income is projected to grow fourfold, and thus as a result the motorization rate is likely to increase although no estimates are available. Gasoline for passenger vehicles will more than double from 0.8 MTOE in 2005 to 1.8 MTOE in 2030 (ADB 2009).

Turkmenistan's motorization rate was 106 motor vehicles per 1000 people as of 2008 (WB 2011).

Uzbekistan

The transport sector in Uzbekistan is projected to moderately increase from 3.4 MTOE in 2005 to 5.2 MTOE in 2030, with an annual growth rate of 1.7% (ADB 2009). There is no data on current or future levels of motorization.

East Asia

Hong Kong, China

Transport energy demand in Hong Kong is projected to increase slightly from 6.7 MTOE in 2005 to 7.7 MTOE in 2030. Much of this growth is expected to come from increased international air transport (ABD 2009).

Hong Kong's motorization rate was 73 motor vehicles per 1000 people as of 2008. No future projections were located for Hong Kong, but given its small market any increases in vehicle holdings should not have significant regional impacts (WB 2011).

Republic of Korea

The transport sector in the Republic of Korea is projected to grow modestly by 1.7% annually. Car ownership levels are also expected to grow slowly due in part to population growth projecting to peak in 2019. Passenger car ownership will rise from 9.7 million in 2002 to an estimated 15 million in 2020, representing an annual growth rate of 2.4%. From 2020 to 2030, growth rates will slow to 0.3% reaching 15.4 million in 2030 (ADB 2009).

Other estimates project higher vehicle numbers with 26 million motor vehicles in 2020, and 30.5 million motor vehicles by 2030 (Table 1 in Annex).

Mongolia

Transport energy demand is projected to increase substantially in Mongolia, growing by 3.5% annually. As a natural transit country for trade between China and Russia, the Mongolian government has proposed a total investment in transport infrastructure of $2.9 billion between 2008 and 2015 to facilitate economic growth. Growth in passenger vehicles has recently been brisk, increasing at an annual rate of 14% from 2001 to 2007. With urban progress around the capital, Ulaanbaatar, and improving road conditions, the strong increase in motor vehicles is expected to continue in the future. As a result, gasoline for passenger vehicles is projected to grow at an annual rate of 3.2% through 2030 (ADB 2009).

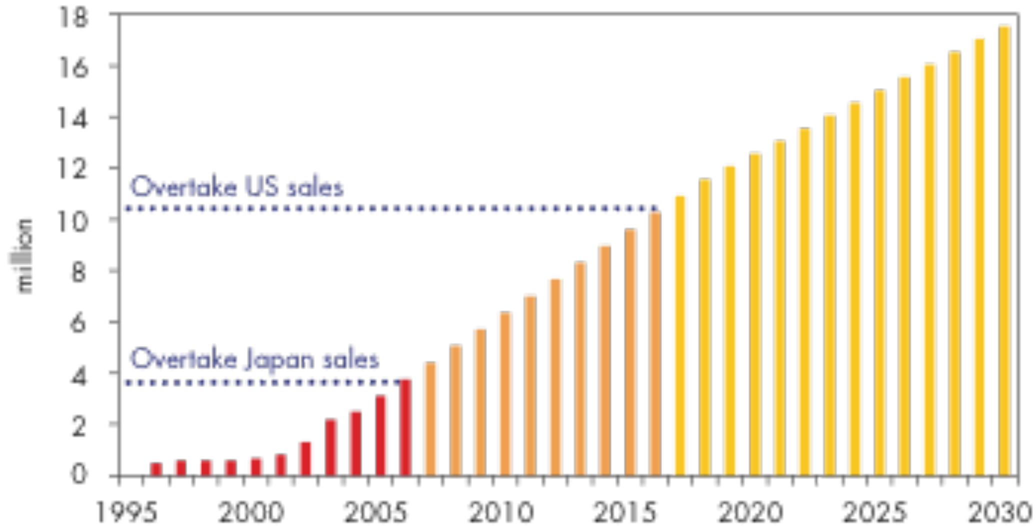
As of 2008, there were 72 motor vehicles per 1000 people in Mongolia (World Bank).

People's Republic of China

Much has been written about China's future motorization rates. With its surging economy and large population, growth in motor vehicles is expected to increase rapidly, which will have significant impacts on global vehicle markets, fuel consumption, and the environment.

China is already the world's largest car market, surpassing the United States in 2009 when light-duty vehicle sales reached 13.6 million ("China Car Sales Top U.S."). Furthermore, many analysts believe that vehicles sales are just beginning to start in China and are expected to grow fivefold between 1997 and 2020 (EIA 2000). This corresponds to some 120 million light duty vehicles by 2020, an increase of 100 million from 2000 (IEEJ 2004). Further estimates for China project an increase to 233 to 270 million vehicles by 2030 depending on the source (Table 1 in Annex 1)

Figure 1.5: New Car Sales in China



Source: IEA 2007

Despite this large potential increase, China's vehicle ownership rate at the 2030 projection would still only by 14%, which is well below the OECD levels of approximately 50% (Komiyama). Thus, China is projected to have enormous motorization growth potential even after 2030.

Undoubtedly vehicle holdings will increase significantly in China, although what role different factors play is uncertain. Although population growth is cited as an indicator for increased motorization rates, there is some evidence that population growth has not contributed substantially to motor vehicle growth. For example, population grew at an annual rate of 2.61 percent from 1965 – 1970, but has substantially declined in recent years to 1.10 percent annually (UN 1998). Meanwhile growth in motor vehicles in recent years has far outpaced that of the population, suggestion that population growth has played a very minor role in China's motor vehicle growth.

In regards to urbanization, there is also some indication that urbanization has not contributed substantially to the number and growth of motor vehicles in China. Despite the enormous absolute size and number of China's cities it still remains a largely rural country. For example, in 2007, 42 percent of China's population was considered urban compared to 81 percent in South Korea. Although the urban share of total population is expected to increase in China over time, rates will still remain relatively low with 57 percent expected to live in urban areas by 2025 (UN 2007). Furthermore, although urban growth rates have been larger than total population growth rates, they still remain relatively moderate when compared to the growth of motor vehicles. Additionally one must consider the factors contributing to urban growth in China, specifically the role of rural-to-urban migration. Much of the growth in urban areas comes from low-wage rural laborers seeking jobs in cities that cannot afford motor vehicles.

Of the three primary factors indentified as affecting motor vehicles in China, economic growth has likely had the most substantial influence (Riley 2002). Economic reform and subsequent increases in income have long been associated with changing patterns of spending on goods, services, and the emergence of consumerism in China (Wu 1999). Furthermore, strong economic growth and greater economic liberalization has led to an emerging domestic private market of automobiles, helping automobile growth expand in recent years.

Taipei, China

In Taipei, transport energy demand is expected to grow by 1.3% per year until 2030. The population is expected to peak sometime in 2020 and mass transit rail systems are expected to gradually replace demand for busses and passenger vehicles for city travel. Thus, gasoline demand is expected to grow modestly by 0.6% annually from 2005 – 2030 (ADB 2009).

Taiwan's national motor vehicle stock is expected to increase to 11 million vehicles in 2020 and 13.6 million vehicles in 2030 (Table 1 in Annex).

The Pacific

Fiji Islands

The transport sector is expected to grow by 0.7% annually from 2005 – 2030 (ADB 2009). Fiji's motorization rate was 175 motor vehicles per 1000 people as of 2008 (WB 2011).

Papua New Guinea

Transport energy demand in Papua New Guinea is expected to increase at an annual average rate of 1.6% until 2030 (ADB 2009). The motorization rate was only 9 vehicles per 1000 people as of 2007 (WB 2011).

Timor-Leste

Oil use in the transport sector is expected to increase at annual rate of 7.8% from 2005 to 2030 (ADB 2009).

Other Pacific Islands

The transport sector is projected to grow at 1.6% per annum (ADB 2009).

South Asia

Bangladesh

Transport energy demand is projected to increase from 1.9 MTOE in 2005 to 5.8 MTOE in 2030, growing annually by 4.7%. Road transport dominates in Bangladesh, accounting for 88% of passenger transport and 80% of freight transport as of 2005. Despite this, personal vehicle ownership rates remain among the lowest in the world and are expected to remain minimal given the high incidence of poverty. By 2030 per capita income is estimated to be only $908, and thus car ownership will likely be limited for the small wealthy population (ADB 2009).

Bangladesh's motorization rate was only 2 motor vehicles per 1000 people as of 2008 (WB 2011).

Bhutan

With a landlocked and mostly mountainous region, vehicle transport is essential to both passenger and freight transport. Thus the demand for petroleum products and vehicles is likely to increase although given the country's small size, vehicle stock increases are unlikely to have significant impacts on global vehicle markets. Overall, the transport sector's energy demand is expected to grow at 6.6% per year, eventually reaching 0.2 MTOE by 2030 (ADB 2009).

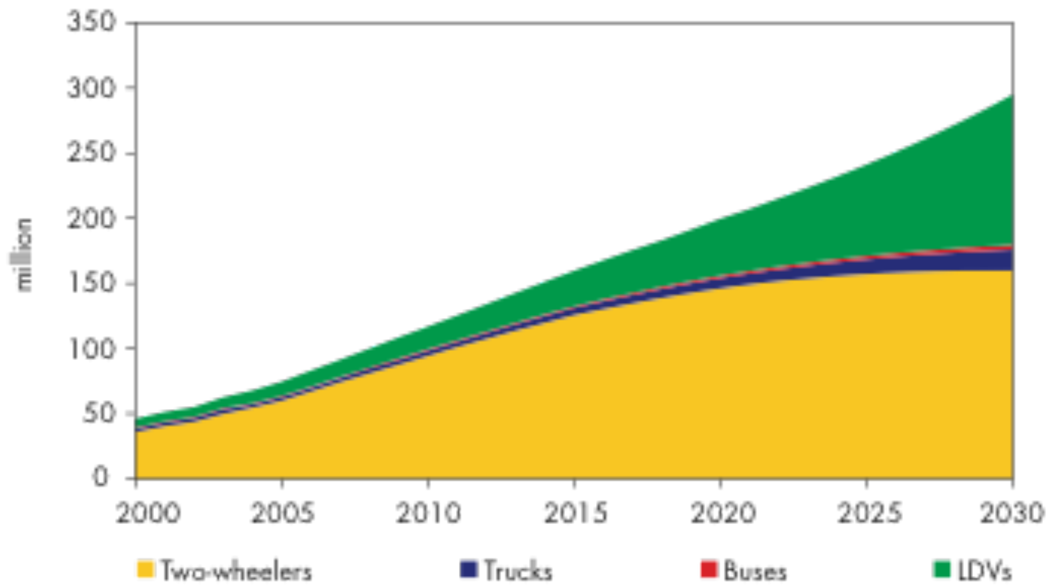
Bhutan's motorization rate was 47 motor vehicles per 1000 people as of 2008 (WB 2011).

India

India's total transportation energy use is expected to increase by 3.4 percent per year from 2007 to 2035, giving the country the second fastest growing transportation sector after China (EIA 2010). Much of this growth will come from increases in the stock of small automobiles and vehicles with two or three wheels. Government stimulus in the face of the 2008 – 2009 recession helped increase motor vehicle sales in 2009 with sales increasing by more than 1.4 million units representing an annual increase in sales of nearly 19 percent (Nair 2010). By 2030, India is projected to have between 73 to 115 million passenger vehicles depending on estimates, representing nearly a fivefold increase from the 15.4 million in 2005 (Table 1 in Annex). Based on upper bound estimates, motorization rates will increase from 13 vehicles per 1,000 people in 2007 to 93 vehicles per 1,000 people in 2030 (IEA 2007).

In 2007, two wheelers made up over 80% of the vehicle stock, although they only consumed 15% of road-transport fuels due to increased efficiency. By 2030, ownership of two wheelers is expected to plateau, as more people purchase passenger cars. However, two-wheelers are still projected to account for 50% of the total 295 million motor vehicle stock in 2030 (IEA 2007 and Figure 1.6).

Figure 1.6: India's Vehicle Stock (2000 – 2030)



Source: IEA 2007

Republic of Maldives

As a small island nation, motor vehicles do not play a large role in the transportation sector in the Republic of Maldives. Although the number of passenger vehicles has grown rapidly in recent years, there were still only 39,334 registered vehicles as of 2008. Thus even with sustained growth in motor vehicles, the overall number will remain minimal compared to other countries in the region (ADB 2009).

The Maldives' motorization rate was 23 motor vehicles per 1000 people as of 2008 (WB 2011).

Nepal

Transport energy demand is projected to increase at an annual rate of 2.8% through 2030, with the largest share of growth coming from gasoline for passenger vehicles (ADB 2009).

Nepal has low motorization rate with only 5 motor vehicles per 1000 people as of 2007 (WB 2011).

Sri Lanka

Transport energy demand is projected to increase by 4.1% annually through 2030. Road transport accounts for 92% of all passenger and freight transport, and the road sector has been highlighted by the government as an area of focus for poverty reduction. As a result, gasoline for passenger vehicles is expected to grow by 4.4% per year through 2030. The fastest vehicle growth is expected in the urban areas, among high-income individuals (ADB 2009).

Sri Lanka's motorization rate was 61 motor vehicles per 1000 people as of 2008 (WB 2011)

Southeast Asia

Brunei Darussalam

Brunei Darussalam's transport energy sector is projected to increase at an average annual rate of 2.2% increasing from 0.4 MTOE in 2005 to 0.7 MTOE in 2030 (ABD 2007).

Brunei Darussalam has an extremely high motorization rate of 696 motor vehicles per 1000 people as of 2007 (WB 2011).

Cambodia

Transport energy demand in Cambodia is projected to increase at an annual rate of 6.2%. This relatively large increase is due in part to an increase in the number of road vehicles as the economy develops although estimates are unknown (ADB 2009).

Cambodia's motorization rate was 20 vehicles per 1000 people as of 2005 (WB 2011).

Indonesia

Indonesia's transport energy sector is projected to increase at an average annual rate of 3.4% increasing from 25.7 MTOE in 2005 to 59.8 MTOE 59.8. Included in this forecast is the assumption that 60% of gasoline used in 2030 will be gasoline-bioethanol blend (E10) and that 80% of automotive diesel will be biodiesel (B10). Although CNG was introduced as a gasoline substitute in Jakarta and other large cities in the mid 1980s, the CNG-based vehicle stock had declined to only 600 vehicles as of 2005 and is not projected as a future source of growth (ADB 2009).

Indonesia's motor vehicle stock is projected to grow 3.6% annually ultimately reaching 12 million motor vehicles in 2020. Other estimates project much larger growth and suggest Indonesia could have 46.1 million motor vehicles by 2030 (Table 1 and 3 in Annex).

Lao People's Democratic Republic (Lao PDR)

The transport sector in Lao PDR is projected to grow at 6.8% annually through 2030 (ADB 2009). Lao PDR's motorization rate was 21 motor vehicles per 1000 people as of 2007 (WB 2011)

Malaysia

As of 2006 there were about 15.8 million registered vehicles, increasing at an average annual growth rate of 6.6% (ADB 2009). This amount of vehicles is above previously projected rates, which estimated only 13 million vehicles by 2020. However, another estimate projects 23.8 million vehicles by 2030, which is still of use (Table 1 in Annex).

Malaysia's motorization rate was 334 motor vehicles per 1000 people as of 2008 (WB 2011).

Myanmar

The transport energy sector in Myanmar is projected to increase by 6.8% annually through 2030 (ADB 2009). Given the countries development prospects and low level of per capita income, significant increases in the national vehicle stock are not expected.

Myanmar’s motorization rate was only 7 motor vehicles per 1000 people as of 2008 (WB 2011).

The Philippines

Transport energy demand in the Philippines is projected to grow at an annual rate through 2030. Demand in the sector is characterized by a heavy reliance on the road transport subsector (ADB 2009). Current motorization rates in the Philippines are 33 motor vehicles per 1000 people (WB 2011).

Strong growth is expected in the Philippine automobile market, with projections of 5.7% annual growth from 2010 – 2020. This corresponds to some 8 million vehicles in the country by 2020 (Table 1 and 3 in Annex).

Singapore

The transport sector in Singapore is projected to grow at an annual rate of 1.1% through 2030. Oil is expected to remain the dominate fueled in the sector and is projected to grow by 0.9% annually (ADB 2009). Singapore’s motorization rate is 180 motor vehicles per 1000 people as of 2008 (WB 2011).

Significant growth is not expected in Singapore’s automobile market, as the market is largely saturated. Vehicle holdings are only projected to increase to 0.7 million by 2020, up from 0.6 million in 2000 (Table 1 in Annex).

Thailand

Between 1990 and 2005, Thailand has seen its transport energy demand double, largely due in part to an increase in road transportation. Transport energy demand will continue to grow by 2.8% annually through 2030. The government also aims to replace 10% of gasoline and diesel demand by 2015 through introducing gasohol and biodiesel (ADB 2009).

According to one estimate, Thailand’s vehicle stock is projected to increase to 18 million by 2020. However, another estimate projects Thailand’s vehicle growth to be much more robust, reaching 44.6 million motor vehicles by 2030 (Table 1 in Annex).

Viet Nam

The transport energy sector in Viet Nam is projected to increase by 5.8% annually through 2030. Road transport is the dominant source of demand, accounting for approximately 80% (ADB 2009).

Viet Nam is projected to have significant automobile growth, growing by 6% annual from 2010 to 2020. However, Viet Nam's automobile stocks are limited and are only projected to reach 0.8 million vehicles by 2020 (Table 1 and 3 in Annex).

Developed Group

Australia

The transport sector in Australia is characterized by a high dependence of oil as a source of energy due to large volumes of road an air transport. Oil demand is projected to increase by 0.8% annually, reaching 35.6 MTOE by 2030 (ADB 2009).

Australia's motorization rate was 687 motor vehicles per 1000 people as of 2008 (WB 2011).

Japan

Japan was among the hardest hit economies of OECD Asia by the 2008-2009 recession and as a result transportation fuel use in the country declined from 4.0 quadrillion Btu in 2007 to 3.7 quadrillion Btu in 2009. In the long term, Japan's demand for transportation fuels is not expected to recover substantially form current levels. By 2035, the country's consumption of transportation fuels is expected to total only 3.4 quadrillion Btu. This can partially be explained by demographic reasons as the Japanese population is aging and expected to decline by 9.0 percent (11 million people) from 2007 to 2035 (EIA 2010).

Other estimates show transport energy demand in Japan decreasing by 1.0% annually through 2030. Currently, automobiles consume nearly 90% of the total energy consumed by the transport sector. Thus the reduction in transport energy demand is due mostly to the reduction of energy consumed by automobiles through increased fuel efficiency and a saturated vehicle market. Alternative fuel sources such as fuel cells, natural gas, and LPG, are not expected to significantly alter vehicle markets due to the lack of supporting infrastructure (ADB 2009).

Japanese automobile growth is expected to be minimal growing by 0.3% annually from 2010 – 2020 before reaching a projected 81 million vehicles in 2020. Further estimates show the slight growth trend continuing eventually reaching a projected 86.6 million motor vehicles in 2030 (Table 1 in Annex).

New Zealand

Transport energy demand in New Zealand is projected to grow at an annual rate of 2.1%, largely fueled by continued growth in suburban automobile growth (ADB 2009).

New Zealand's motorization rate was 733 motor vehicles per 1000 people as of 2008 (WB 2011).

Conclusion

Despite the significant importance of increased vehicle holdings in the Asia and Pacific region, data on future projections is often limited. This is especially true of smaller countries and economies in the region, as essentially no information on future vehicle projections could be located. Although significant vehicle increases in individual small developing countries are unlikely, taken as a whole these markets will have an important global impact and should not be over looked.

On the other hand, much has been written about China and India's future vehicle demands. Vehicle growth in these two countries will account for the lion's share of vehicle growth in the region accounting for an estimated 46.8% of the total regional stock by 2020. Thus, projections for these two countries alone are the most important because they will be home to nearly 50% of all vehicles in the region by 2020. Furthermore, as previously discussed motorization rates in China and India are expected to be far below saturation levels signaling the further potential for growth in motor vehicle stocks.

2 Estimation of Long Term Oil Price Trends

The ultimate course of global oil prices is determined by three primary forces, supply conditions, demand, and policies. Because oil and other liquid fuels are relatively homogeneous commodities, supply conditions can be seen from a global perspective. To the extent that these commodities are relatively freely traded, demand factors are also inherently global in the sense that countries are drawing net imports from a global pool of energy resources. Finally, domestic energy policies can differ, but at the margin most countries remain responsive to global energy prices. In an attempt to understand how these complexities will affect oil and other transport fuel prices over the coming decades, we take two empirical approaches. The first of these is purely econometric, projecting future prices from information about past prices. The second is to use a so-called structural simulation model, which is designed to explicitly model supply, demand, and policy interaction over the long term. Each approach has different strengths, and we attempt to combine them below to elucidate energy price futures and the potential for fuel policies to influence these trends.

Econometric Estimation

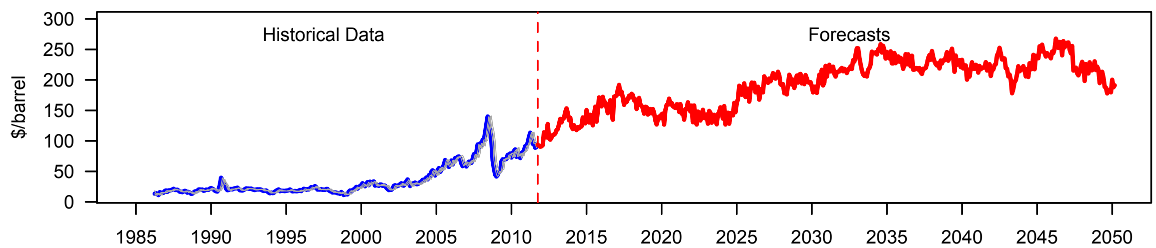
Although oil prices respond to specific and generally understood market forces, there are elements of uncertainty in these market outcomes that defy deterministic modeling. For that reason, projections with deterministic models will underestimate or even be blind to price volatility that presents serious financial risks to both buyers and sellers. For this reason, we begin by examining historical oil price volatility to see what it can tell us about the future.

For this exercise, we implemented the most advanced econometric techniques available, vector autoregressive trend estimation with prior information. This approach was initiated by Christopher Sims (1996) and has achieved its most sophisticated statement thus far in the work of Sims, Wagonner, and Zha (2008).[5] This approach, summarized technically in an annex to this report, uses Baum-Hamilton-Lindgren-Kim state-space filter for a multivariate Markov-switching model, calibrated to one series of historical spot oil prices, complemented with contemporaneous (rebased) prices for 30, 60, and 90 day futures contracts. The latter three series are used to represent prior information, assuming markets can efficiently anticipate future values.

[5] Indeed, as a recipient of this year's Nobel Prize for Economics, Sims was cited for this work in particular.

This approach uses the first series (spot prices) as the central tendency, with the other three representing alternative prior distributions with known variance (uncertainty). Figure 2.1 displays estimates under a mid-range variance scenario, where mid-term contracts are thought to embody median price expectations and volatility.

Figure 2.1: Average Monthly Oil Price Forecasts with Median Variance Prior



Note: Prices below are normalized to 100 in the last base year (2011).

These estimates capture historical processes of price trends and volatility and project these forward. These will then be incorporated into a deterministic model to evaluate the impacts of structural changes, including fuel efficiency scenarios.

The Dynamic Forecasting Model

The complexities of today's global economy make it very unlikely that policy makers relying on intuition or rules-of-thumb will achieve anything approaching optimality in either the international or domestic arenas. Market interactions are so pervasive, and market forces so powerful in determining economic outcomes that more sophisticated empirical research tools are needed to improve visibility for both public and private sector decision makers. The preferred tool for detailed empirical analysis of economic policy is now the Calibrated General Equilibrium (CGE) model. It is ideally suited to trade analysis because it can detail structural adjustments within national economies and elucidate their interactions in international markets. The model is more extensively discussed in an appendix and the underlying methodology is fully documented elsewhere, but a few general comments will facilitate discussion and interpretation of the scenario results that follow.[6]

[6] The model used here is typical of modern global models and is based on the LINKAGE model developed at the World Bank (van der Mensbrugghe: 2008).

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economy-wide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economy-wide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economy-wide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions, which themselves can have policy implications.

Apart from its traditional neoclassical roots, an important feature of this model is product differentiation, where we specify that imports are differentiated by country of origin and exports are differentiated by country of. This feature allows the model to capture the pervasive phenomenon of intra-industry trade, where a country is both an importer and exporter of similar commodities, and avoids tendencies toward extreme specialization.

This paper uses a global, multiregion, multisector, dynamic applied version general equilibrium model.[7] This model is implemented in the GAMS programming language, and calibrated to Version 7 of the GTAP global economic database.[8] The result is a 19-country/region, 10-sector global CGE model, calibrated over a 40-year time path from 2010 to 2050. As the concordance in Table 2.1, indicates, the countries and regions individually identified for this database comprise more than 90% of Asian GDP, population, and oil consumption.

Scenarios

Using the model and aggregation, the dynamic CGE model is calibrated to a baseline time series reflecting a business-as-usual (BAU) or Baseline scenario over 2006–2050. This baseline comprises consensus forecasts for real GDP obtained from independent sources (e.g. International Monetary Fund, Data Resources International, and the World Bank). The model is then run forward to meet these targets, making average capital productivity growth for each country and/or region endogenous. This calibration yields productivity growth that would be needed to attain the macro trajectories, and these are then held fixed in the model under other policy scenarios. Other exogenous macro forecasts could have been used and compared, but this is the standard way to calibrate these models.[9]

As outlined in the introduction, the main objective of the present forecasting exercise is to assess the implications for Asian regional energy markets of sustained upward or downward trends in transport fuel prices. To elucidate this issue, we developed two baseline projections for different trends in oil prices – a low oil price trajectory and a high oil price trajectory – based on economic growth and energy supply/demand assumptions. In particular, we assumed baseline factor productivity growth, that which would be needed to achieve BAU targets for annual GDP growth by country and region over the period 2010-2050.

[7] The model is more fully described in Annex 1 below and complete technical documentation is available from the author.
[8] See e.g. Hertel et al (2008) for GTAP.
[9] A more detailed description of model calibration is given in Annex 2 below.

Table 2.1: Developing Member Countries of ADB

Country	Population in millions (2010)	GDP in billions USD with PPP (2010)	GDP in billions USD (2010)	GDP per capita with PPP (2010)	Oil consumption in 2009 (bbl/day)	Oil consumption per capita (bbl/day per 1000 people)
Afghanistan	30	30	17	1000	5,000	0.168
Armenia	3	17	9	5800	49,000	16.498
Azerbaijan	8	90	52	11000	136,000	16.249
Bangladesh	159	259	100	1700	82,340	0.519
Bhutan	7	4	1	5000	1,000	0.141
Cambodia	15	30	11	2000	4,000	0.272
China, People's Republic of	1,337	9,872	5,745	7400	8,200,000	6.134
Hong Kong, China	7	327	224	45600	418,200	58.736
India	1,189	4,046	1,430	3400	2,980,000	2.506
Indonesia	246	1,033	695	4300	1,115,000	4.540
Kazakhstan	16	198	131	12800	241,000	15.528
Korea, Republic of	49	1,467	986	30200	2,185,000	44.821
Kyrgyz Republic	6	12	4	2200	15,000	2.683
Lao PDR	6	16	6	2400	1,918	0.296
Malaysia	29	417	219	14700	536,000	18.656
Maldives	0	2	1	4600	6,000	15.385
Mongolia	3	10	6	3300	16,000	5.112
Myanmar	54	60	36	1100	42,000	0.778
Nepal	29	35	15	1200	18,000	0.612
Pakistan	187	451	175	2400	373,000	1.991
Philippines	102	353	189	3500	307,200	3.017
Singapore	5	292	234	57200	927,000	195.570
Sri Lanka	21	105	48	4900	90,000	4.229
Taipei,China	23	824	427	35800	834,000	36.151
Tajikistan	8	15	6	2000	38,000	4.980
Thailand	67	580	313	8700	356,000	5.336
Timor-Leste	1	3	616	2600	2,500	2.119
Turkmenistan	5	37	28	7400	120,000	24.000
Uzbekistan	28	86	38	3100	145,000	5.155
Viet Nam	91	278	102	3100	311,400	3.439
Total Asia	3,730	20,918	11,848		19,555,558	
GTAP Countries	3,524	19,724	10,069		18,128,058	
Percent Asian Coverage	94	94	90		93	

Because we are using a global forecasting model, which computes market prices, it is necessary to take an indirect approach to trending energy prices. To project lower long term oil prices for oil, we assume in the Low Price scenario that global supply capacity grows 20% more rapidly than forecast in the Baseline scenario.[10] Conversely, to generate a scenario of High Prices, we assume that global oil supply capacity grows 20% more slowly. Table 2.2 below provides a summary description of the three core scenarios. In all three scenarios, price volatility (variation around the deterministic trend) is assumed to follow the econometric projections above.

Table 2.2: General Scenarios

Scenario	Name	Description
1	Baseline	The global economy grows at consensus Business as Usual rates.
2	Low: Oil Prices Below Baseline	Assume global oil supply capacity grows up to 20% faster than the Baseline by 2050.
3	High: Oil Prices Above Baseline	Assume global oil supply capacity grows up to 20% more slowly than the Baseline by 2050.

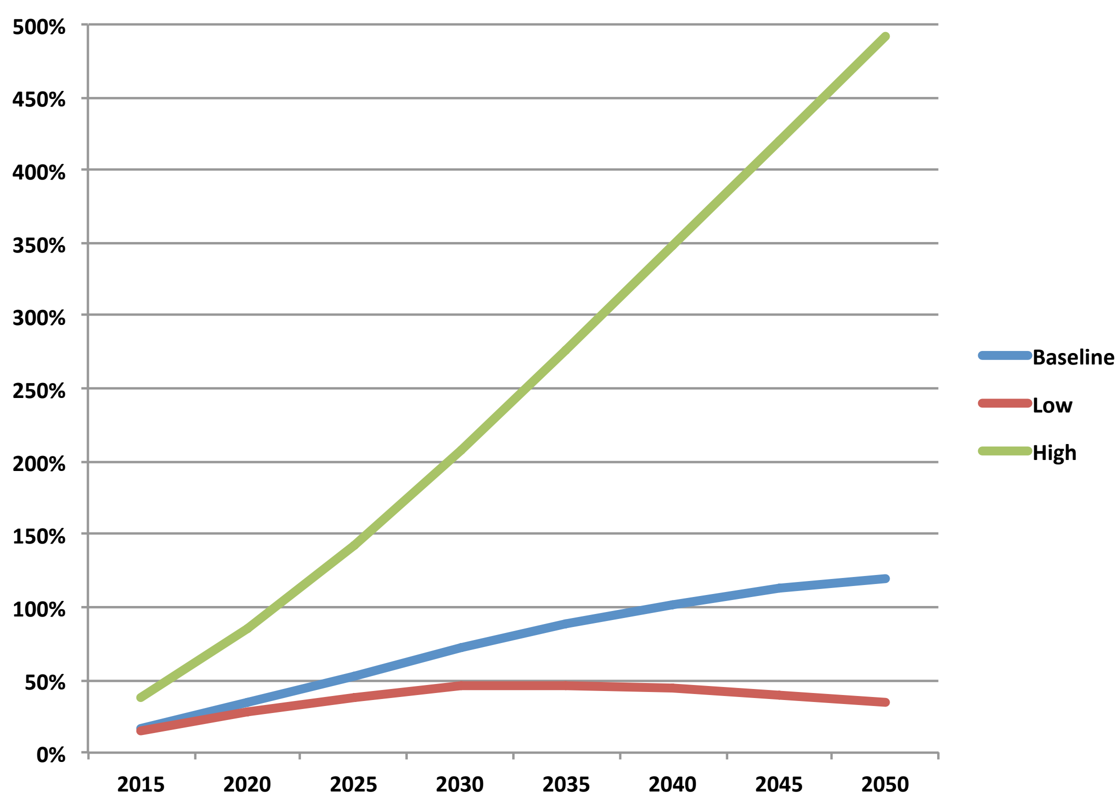
[10] This was achieved by reducing resource productivity in the Oil sector (uniformly across countries), stepping it down linearly until it is 20% below projected Baseline capacity by 2050.

3 Simulation Results

Price trends

Real world experience reminds us that markets are far from homogeneous, and prices vary with a myriad of diverse conditions that characterize and influence both supply and demand. To see the implications of our oil capacity scenarios in this context, Figure 3.1 shows estimated price trends for Oil in the Low and High price scenarios, respectively.

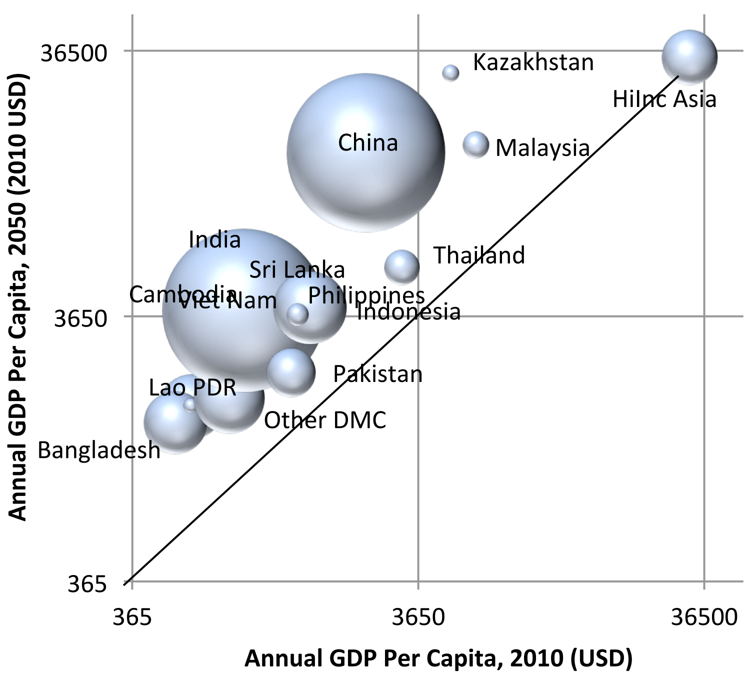
Figure 3.1: Global Oil Price Trends under Alternative Supply Scenarios



Recalling that these are deterministic estimates from the dynamic structural model, we see smooth trends in response to continuous and monotone variation in oil availability. This contrasts with econometric estimates, which explicitly incorporate uncertainty, but these results come from detailed interaction between supply and demand factors globally. Indeed, it is surprising that the baseline trend in prices, with about 100% increase over forty years, is so congruent with the underlying trend in the median variance econometric estimates (Figure 2.1)

A a few observations on the price results are instructive. Firstly, note that although the energy supply constraints are symmetric in the two counterfactual scenarios, average price responses are not. This is because our baseline calls for productivity and real GDP growth, which means price responses to constraints will have an upside bias, responding more strongly (in percentage terms) when the energy constraint is tightened than when it is loosened. This fact explains, for example, why upside price volatility for energy has been steeper than its downside counterpart during the last two decades of rapid emerging market growth and globalization.

Figure 3.2: Baseline Growth of Per Capita Real GDP (bubble diameter proportional to population)



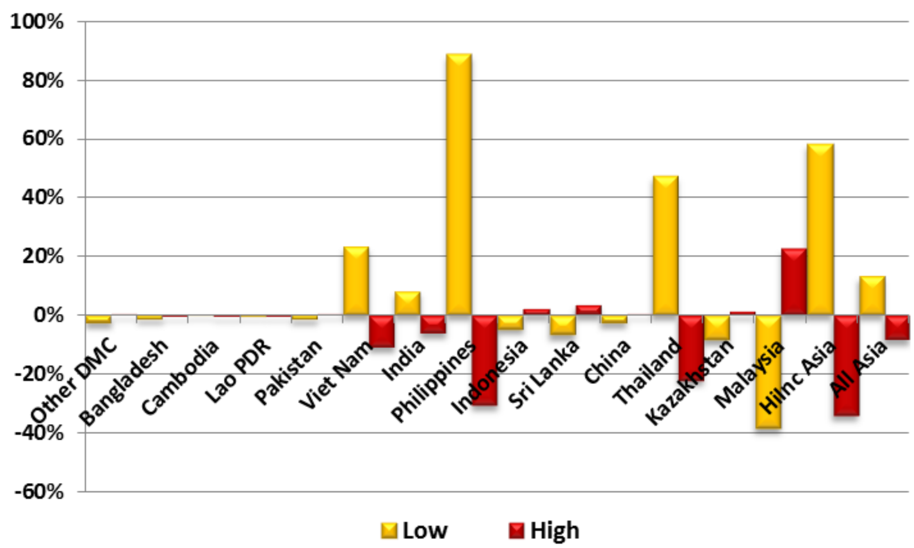
Source: Authors' estimates.

Macroeconomic impacts

Now we examine the macroeconomic implications of such structural changes in oil markets. Figure 3.2 shows the baseline growth assumptions, with all Asian economies better off in per capita terms by 2050, but advancing at different rates.

The macroeconomic results for the two archetype oil price scenarios are summarized in the following tables and figures. Figure 3.3 illustrates the real GDP impacts that would result in the terminal year, expressed as a percentage change from the Baseline value in the same year (2050).

Figure 3.3: Real GDP Impacts of Alternative Oil Price Trends (percentage change from Baseline in 2050)



Source: Authors' estimates.

The same results are summarized numerically in Table 3.1. Generally speaking Higher oil prices are more likely to be adverse than beneficial. While this is of course intuitive to oil consumers, benefits of higher prices do accrue to two kinds of economies: oil producers (Malaysia, Kazakhstan, Indonesia), and countries that obtain competitive advantage from relatively lower energy intensity (Sri Lanka). Lower energy prices, as would be expected, have generally opposing effects, but they are larger in average magnitude and particularly so in light of the price trend asymmetry (Figure 3.1). Particularly countries with high energy-driven growth potential, such as Viet Nam, Thailand, and High Income Asia, experience strong growth dividends from lower oil prices. An outlying case is the Philippines, which is acutely constrained by high energy intensity of GDP, high import shares, high domestic expenditure shares, and high poverty rates.

Table 3.1: Real GDP Impacts of Difference Oil Price Trends

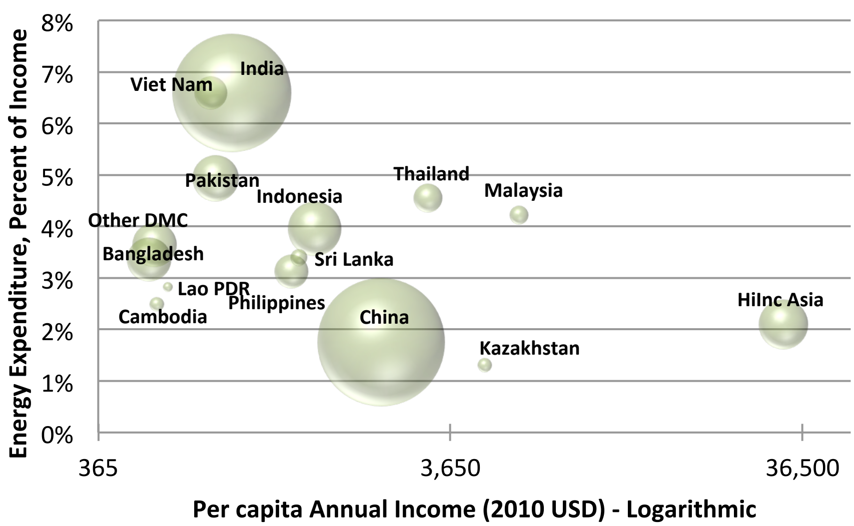
(percentage change from Baseline in 2050)

	Low	High
Other DMC	-2.8%	0.1%
Bangladesh	-1.3%	0.0%
Cambodia	0.2%	-0.6%
Lao PDR	-0.5%	-0.5%
Pakistan	-1.6%	0.2%
Viet Nam	23.2%	-11.0%
India	8.2%	-6.3%
Philippines	88.5%	-30.7%
Indonesia	-4.8%	2.1%
Sri Lanka	-6.8%	3.5%
China	-2.7%	0.1%
Thailand	47.2%	-22.2%
Kazakhstan	-8.5%	1.0%
Malaysia	-38.5%	22.5%
Hilnc Asia	58.3%	-34.2%
All Asia	13.3%	-8.6%

Source: Authors' estimates.

To some readers, it may be surprising that many of these results comprise only single digit changes in GDP. The main reason for this is that, despite the pervasive nature of energy services in today's economies, household energy expenditure remains a small percentage of GDP (see Figure 3.4). This means price changes of less than one hundred percent are unlikely to affect real incomes by more than 10% and therefore to have a lasting effect on the business cycle. At the same time, however, many countries in the region use subsidies to modulate these effects, and we have assumed these policies remain in place for the current scenarios.

Figure 3.4: Household Energy Expenditure as a Percent of GDP (bubble diameter proportional to population)

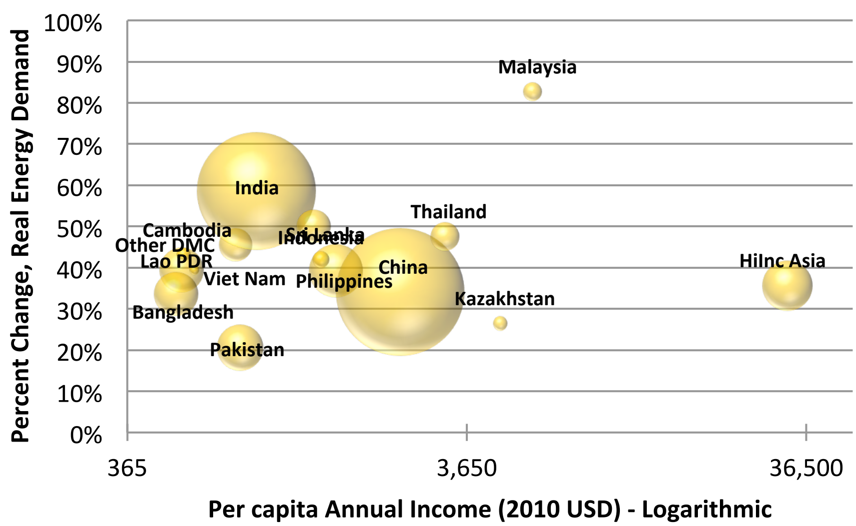


Source: Authors' estimates.

Although aggregate economic output responds in diverse ways to oil price shocks, energy demand, even at the economywide level, is more predictable. The following figures show the percentage changes in cumulative real energy demand (Oil, Gas, Coal, Electric Power) for the entire 2010-2050 period, but scenario and Asian country/region.

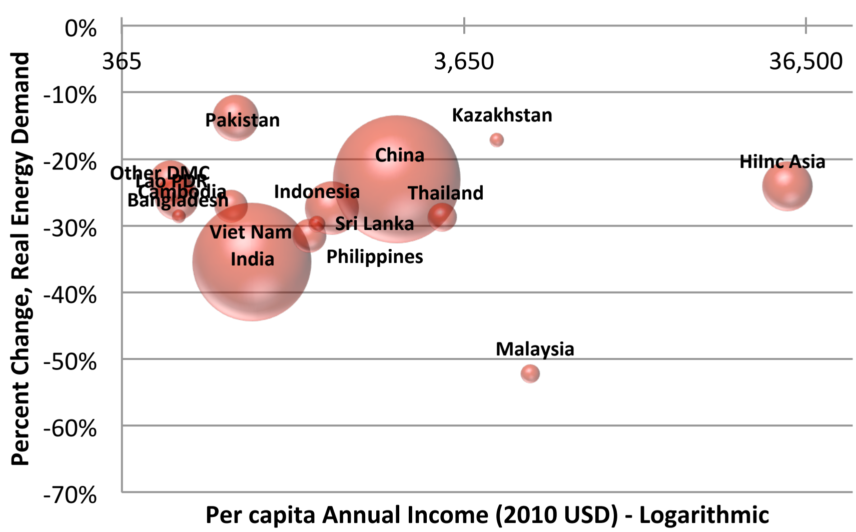
These results, by focusing on the energy products category begin to suggest national demand elasticities. For the same reason, they are much more homogenous, agreeing in sign across countries for each scenario and more consistent in magnitudes (with a few exceptions for extremely energy and subsidy intensive Malaysia). Figures 3.5 and 3.6 break these results down by scenario and give an idea of the national magnitude of adjustments. Here we see, again, comparability greater than in the GDP results, suggesting that economic structure is more individualized, while commodity specific price responsiveness is more universal. When comparing these results across countries, it is important to bear in mind that we have maintained today's energy (subsidy and tax) policies across the entire scenario period. Later experiments will assess the sensitivity of these results to such policies.

Figure 3.5: Change in Real Cumulative Domestic Energy Demand – Low Oil Prices (Percentage change from Baseline, 2010-2050)



Source: Authors' estimates.

Figure 3.6: Change in Real Cumulative Domestic Energy Demand – High Oil Prices (percentage change from Baseline, 2010-2050)



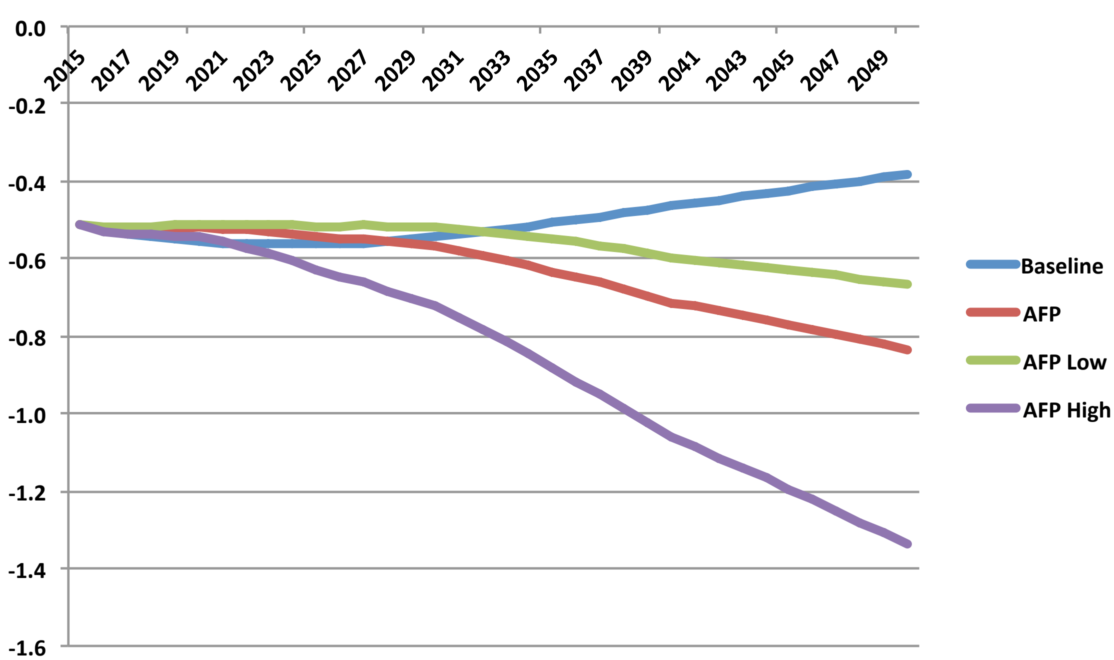
Source: Authors' estimates.

Price Responsiveness – Implied Demand Elasticities

Moving from macroeconomic aggregates to composite energy sector demand, we see more consistent adjustments across economies, and thereby greater opportunity to generalize policy lessons. To further sharpen our insight, we focus on the energy commodity featured in these scenarios, Oil. Although domestic price trajectories in the economies studied differ across countries, the underlying trends of Oil price escalation or moderation are consistent across countries/regions in each scenario. Likewise, regardless of the relative magnitude of Oil price adjustments, elasticities are unit free and easy to compare across time and space.

Before presenting such results, a few caveats are in order. Firstly, we remind the reader that an elasticity estimate here is not a microeconomic demand metric, but the ratio of global market averages of world prices and aggregate demand changes for oil in a relatively generic (ISIC-2 digit) commodity group. Secondly, these are not partial (single market) but general equilibrium comparisons, evaluating demand and price levels that include income changes and a myriad of other effects that vary from one model equilibrium to another. For these reasons, the results should be interpreted with care.

Figure 3.8: Elasticities of Asian Regional Oil Demand



Source: Authors' estimates.

Having allowed for these distinctive features of the analysis, we present forecast global Oil price elasticities for four scenarios in Figures 3.7, the Baseline and AFP's 21 fuel policy interventions in the Baseline and two price trend scenarios. These results reward closer inspection, but a few salient characteristics are worthy of emphasis.

1. In the Baseline elasticities increase (in absolute value, all are negative throughout this discussion) for about half the interval considered, in response to rising Baseline oil prices (fuel substitution and multi-modality) measures. Later, as sustained growth further tightens net energy supplies (without AFP technology options), average demand elasticity declines.

2. In the AFP scenarios, elasticities increase with relative fuel savings. The reason for this is simple – Fuel economy creates slack in the market and greater price sensitivity.

3. The higher the price trajectory, the more attractive fuel efficiency becomes in the autonomous component of fuel demand, and thus the larger the "AFP" effect on demand elasticity.

4. These results are in strong agreement with the econometric literature (Table 3.2), especially since general equilibrium estimates are likely to underestimate partial elasticities because aggregate growth allows for a broader range of non-fuel substitution. Rising income reduces the impact of price variation.

5. Above all, the results have an important policy message for those considering AFP. The regional economy can adapt to rising energy prices, and a wider array of alternative transportation technology choices reduces energy price vulnerability, with the indirect benefit of more sustainable energy use. Of course, prices in themselves offer an incentive for transition to low carbon growth paths, but policies that promote technology diffusion can reduce private adjustment costs and facilitate adaptation.

Table 3.2: Long Term Oil Demand Elasticity Estimates

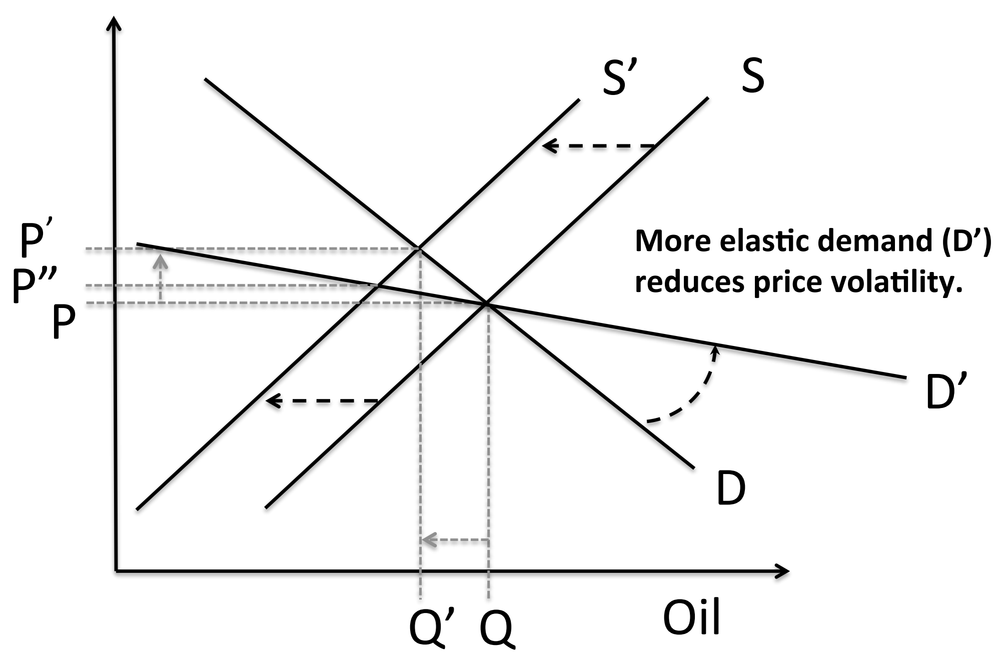
Study	Mean	Min	Max
Dahl and Sterner, 1991	-0.9	-0.8	-1.0
Espey, 1998	-0.6		-2.7
Goodwin, 1992			
* Time series	-0.7		
* Cross section	-0.8		

Goodwin et al, 2004	-0.6		-1.8
Graham and Gleister, 2002		-0.2	-0.8
Graham and Gleister, 2004	-0.8	0.9	-22.0
Hanley et al, 2002	-0.6	0.0	-1.8
Lin and Prince, 2010	-0.2	-0.1	-0.3

Oil Price Volatility

As explained earlier, the standard GE forecasting model and Baseline do not account for uncertainty, yet this is endemic to actual markets, imposing costs on all participants. To capture this systemic risk factor, and assess its significance for the AFP, we incorporated estimated oil price variance from the econometric exercise in our baseline, essentially creating a Monte Carlo experiment with respect to oil prices.

Figure 3.9: Price Adjustments with Difference Demand Elasticities



Our basic finding from this empirical analysis is that AFP policies reduce the volatility of oil prices. The mechanism for this is straightforward. As we have seen already, fuel efficiency measures increase oil demand elasticities. As the following diagram shows, when supply shifts against more elastic demand, price effects are moderated.

To test this more rigorously, we introduced two sources of stochastic variation to the deterministic projections. Under each of the three basic scenarios, we incorporated the intertemporal price variation estimated with the Bayesian forecasts of oil prices. Secondly, for each scenario, we sampled baseline oil demand elasticities from a lognormal distribution (100 times) and ran the scenarios with these alternative values. The results for all 600 experiments are shown in Figures 3.10-3.12 and show dramatic effects of lowering oil price volatility, regardless of the underlying average prices (Baseline, Low, or High). These results strongly support the argument that higher demand elasticity can significantly attenuate price risk in oil markets.

Figure 3.10: Baseline Oil Price Volatility, with and without AFP

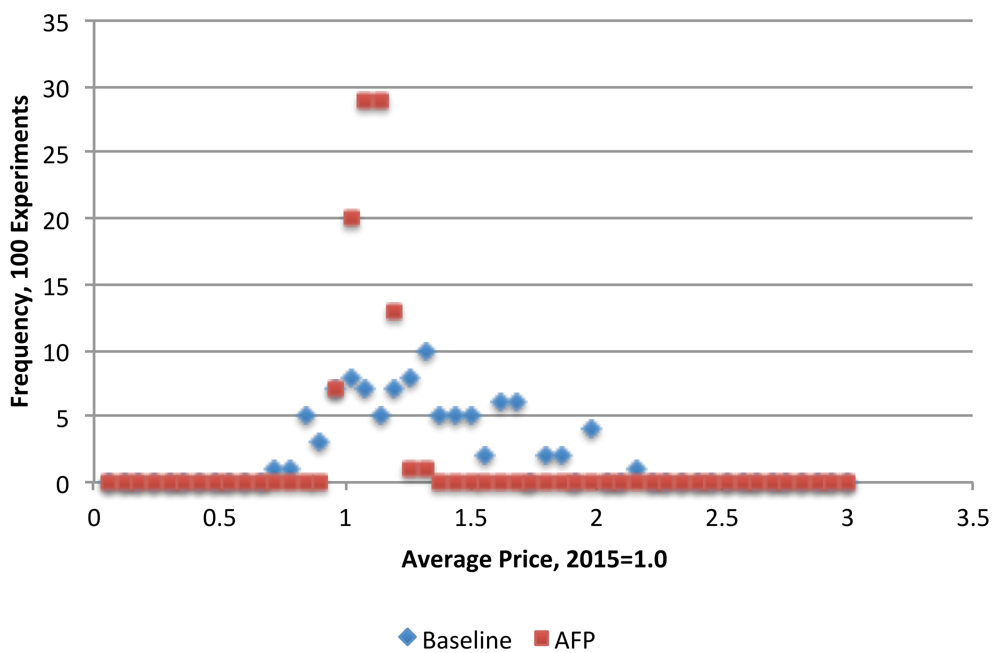


Figure 3.11: Low Oil Price Volatility, with and without AFP

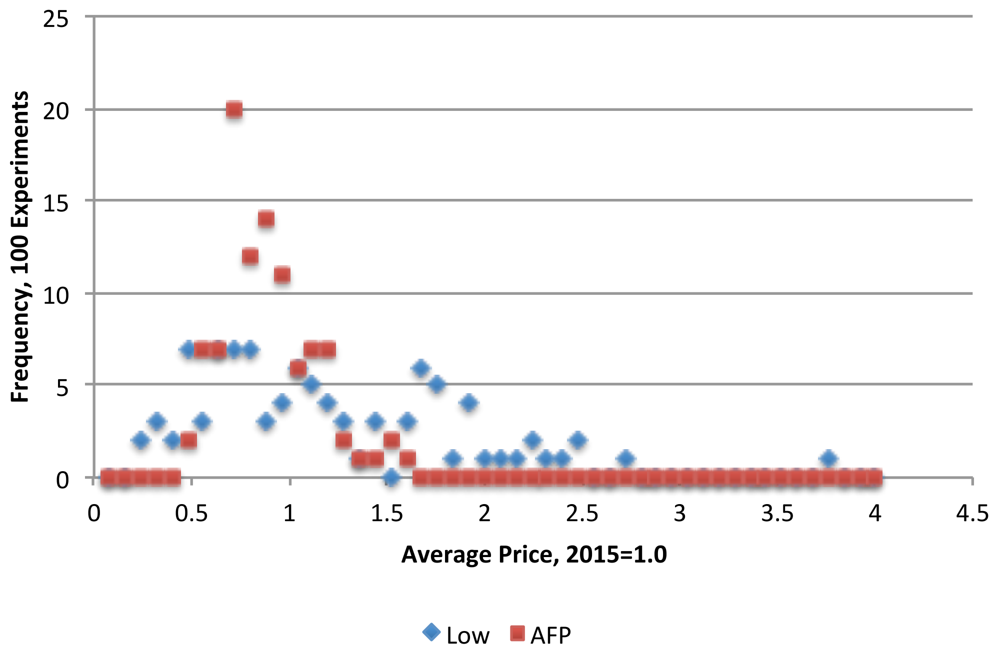
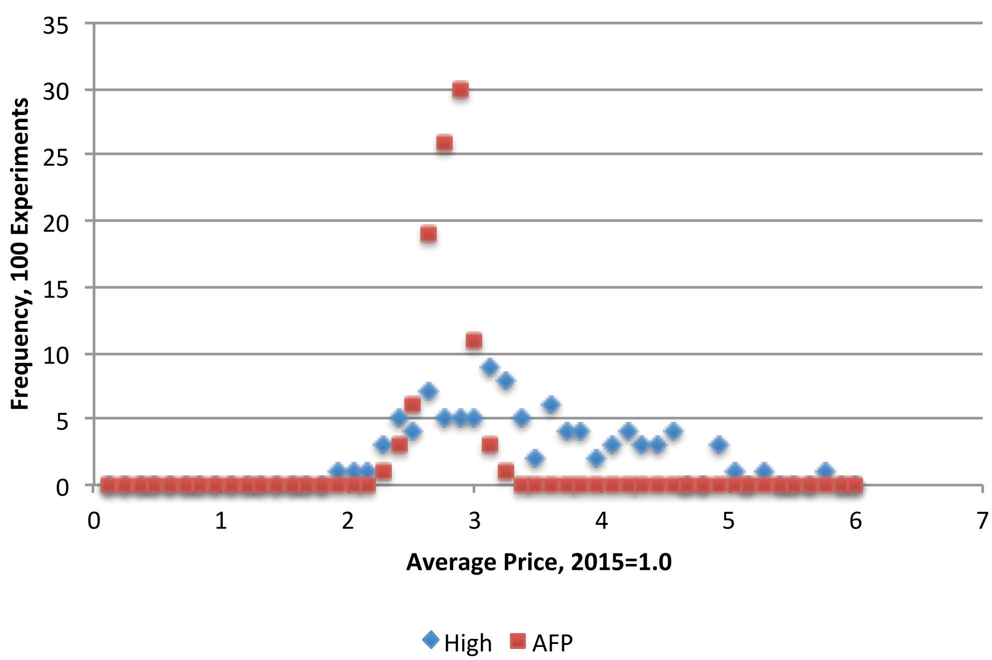


Figure 3.12: High Oil Price Volatility, with and without AFP

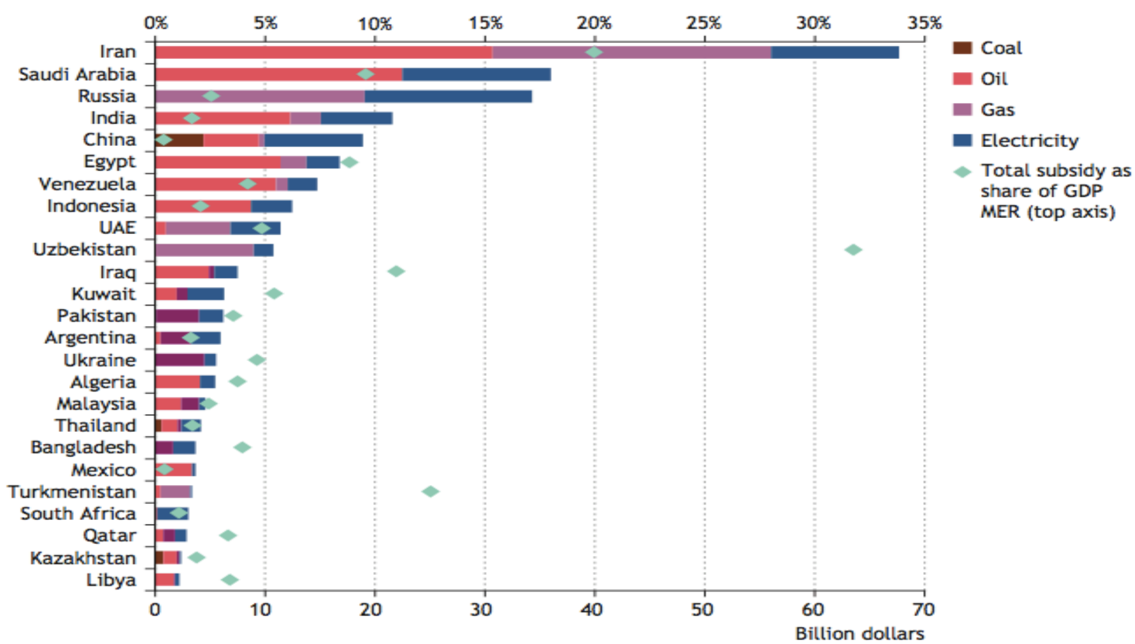


Fuel Subsidies

Subsidies to energy fuels, as well as energy carriers (electricity), are popular in many countries as a means of livelihood protection and economic growth promotion. Like most subsidies, however, they present challenges to efficient resource allocation and fiscal sustainability. By distorting prices of an important resource commodity, energy subsidies promote excessive use and may hinder innovation, adoption and diffusion of more efficient technologies. In low income countries, livelihood based energy subsidies can become captive of bargaining processes and adverse economic cycles, escalating support budgets to fiscally dangerous levels and crowding out more productive used of public funds.

In Asia, transport fuel subsidies remain widespread, although they have been shrinking in both coverage and as a percent of energy cost in most countries for the two reasons just stated. Figure 3.13 give recent evidence, however, suggesting that these price distortions remain substantial in the region.

Figure 3.13: Energy Subsidy Burden by Country

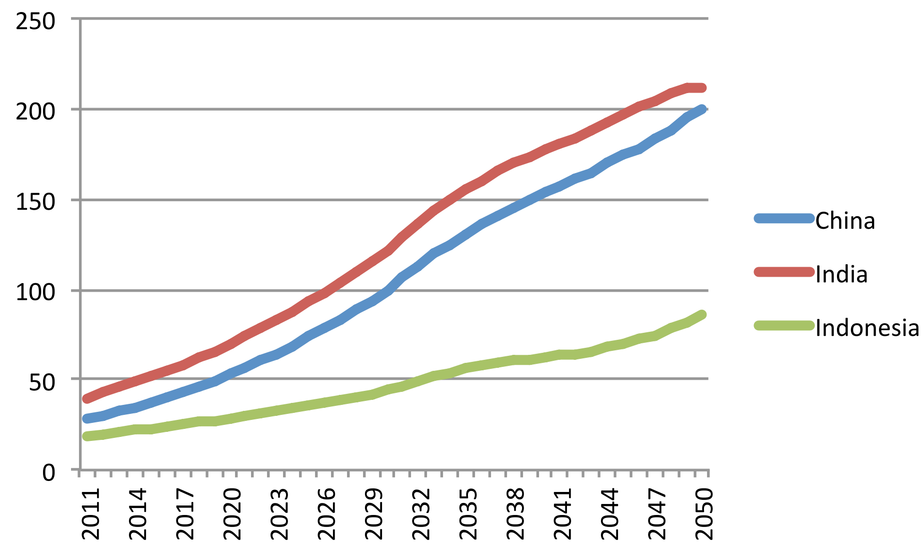


Source: IEA:2010.

How would these policies affect the Asian region going forward? To assess this question, we can use the GE model to estimate the cost of subsidies, assuming oil prices proceed on the course we have charted for the Baseline scenario. We do this for three of the larger regional economies, China, India, and Indonesia, for which energy subsidy rate data are readily available (WEO: 2010). Figure 3.14

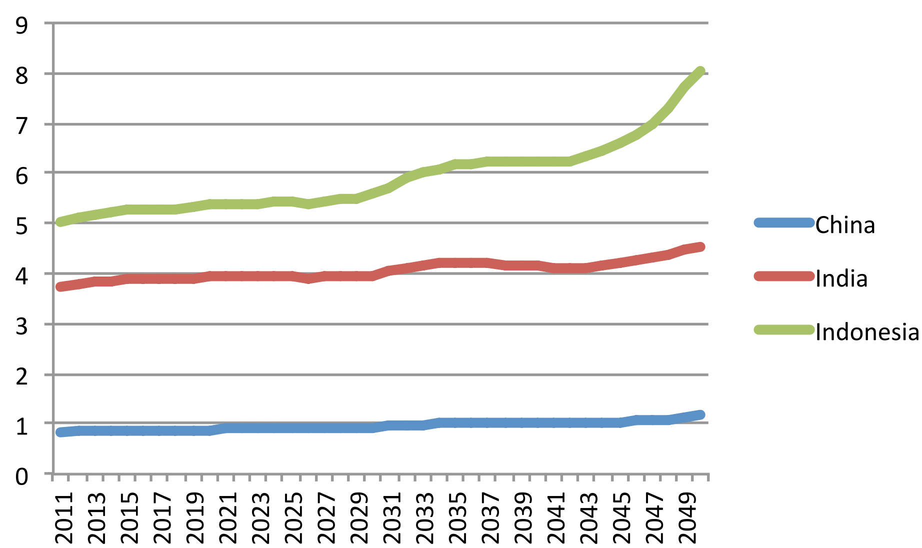
shows total fuel, electricity, and natural gas subsidy expenses for these three countries across the baseline.

Figure 3.14: Baseline Subsidy Burden, in Billions of 2010 USD



Clearly there will be a substantial rise in energy expenses for the public sector if current support levels remain in place. Of course these economies are also growth across the Baseline, however, so perhaps this will be sustainable. Figure 3.15 shows the subsidy burden as a percent of domestic GDP.

Figure 3.15: Baseline Subsidy Burden as a Percent of GDP



Here we see that some economies, particularly those on higher growth trajectories, might be able to redistribute the cost of energy across the economy with subsidy instruments. In addition to the equity issues this raises, macroeconomic sustainability cannot not address the efficiency or environmental challenges posed by energy price distortions.

Fuel Security

National policies in all countries are strongly influenced by the most fundamental forms of economic security, i.e. personal health, safety, nutrition, and other basic needs. In lower income countries, the risks associated with these basic needs are higher because a larger proportion of the population is vulnerable, not meeting basic needs, or worse. In countries with large poor urban populations, energy vulnerability relates mainly to consumption goods, while for rural poor it affects income as well as consumption. We have seen in above that the Asian region faces many uncertainties regarding energy prices and availability, and that there are many ways to measure the attendant risks. In this section we examine the long term forecasts from this perspective.

We saw that global energy prices have the potential to substantially influence Asian livelihoods. What they mean for fuel security is suggested first by the results of Table 3.2, which re-state national changes in total energy use for each scenario and country/region analysed above. We focus attention on the two price scenarios.

Table 3.2: Real Energy Demand by DMC

Cumulative Percent Change from Baseline, 2010-2050

	Low	High
Other DMC	39.4%	-25.8%
Bangladesh	33.6%	-23.4%
Cambodia	43.1%	-28.6%
Lao PDR	39.5%	-24.6%
Pakistan	20.6%	-13.9%
Viet Nam	45.6%	-27.1%
India	58.6%	-35.5%
Philippines	50.1%	-31.5%
Indonesia	39.3%	-27.4%
Sri Lanka	42.0%	-29.7%
China	34.1%	-23.1%
Thailand	47.5%	-28.8%
Kazakhstan	26.5%	-17.1%
Malaysia	82.8%	-52.2%
HiInc Asia	35.7%	-24.1%
All Asia	47.8%	-30.4%

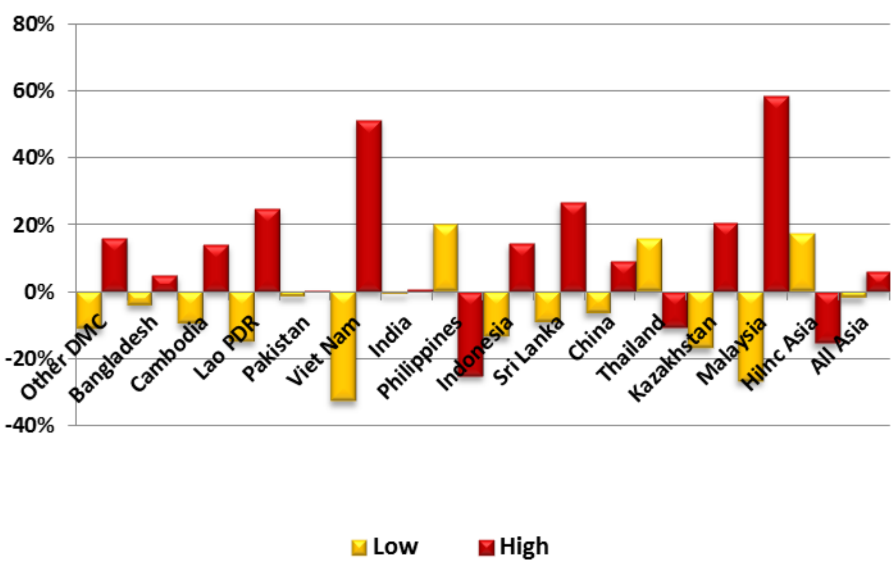
Source: Authors' estimates.

If we examine the concept of fuel security more closely, different insights can be expected to emerge.[11] Figure 3.10, for example shows the percentage change in the Production Security indicator (equation 3.1 in Annex 3) in each of the two oil price scenarios. According to this definition of fuel security, all countries and regions considered will be better off if they promote energy productivity growth and FDI.

If, on the other hand, one adopts the more restrictive energy Demand Security metric (Figure 3.11), outcomes are much more mixed. The reason is simple, Demand Security ignores the potential for regional trade to improve regional fuel security. There is a basic trilemma between domestic energy self-sufficiency, economic diversification, and growth. Countries that insist on only domestic sourcing of energy will find these objectives undermined by policies that promote regional integration, higher incomes, and more sustained growth. These internal inconsistencies need to be recognized for the sake of nationally coherent growth strategy.

Figure 3.10: National Fuel Production Security (PS)

(percent change from Baseline in 2030)

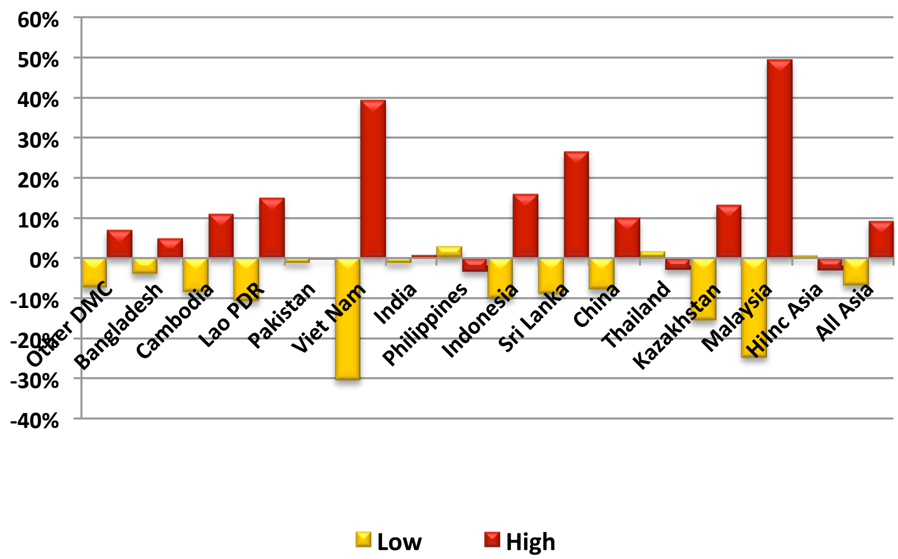


[11] Measurement of fuel security is discussed in Annex 3 below.

Source: Authors' estimates.

Figure 3.11: National Domestic Fuel Security (DS)

(percent change from Baseline in 2030)



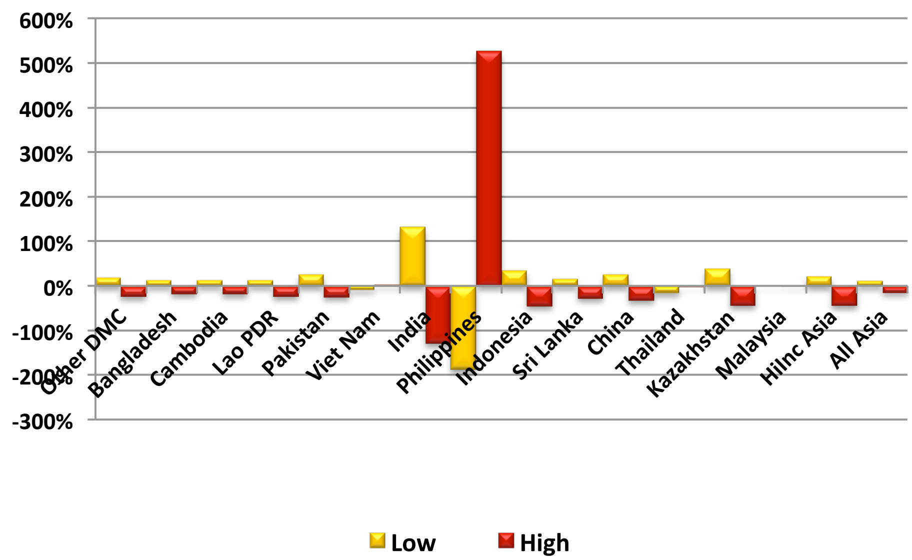
Source: Authors' estimates.

Figure 3.12 displays the energy Consumption Security metric, which measures the degree to which energy is affordable for average domestic households (i.e. household income as a multiple of energy expenditure, equation 3.4 in Annex 3). There results suggest a very important perspective on economy fuel security. The policies considered in these scenarios are far reaching and induce many structural adjustments, both within and between regional economies. Nevertheless, for all but to economies considered, incomes growth more than energy cost for the average household, and substantially so. As an economic definition, this metric may to a better job of capturing the microeconomic reality of fuel security.[12]

[12] The results for Cambodia and Malaysia come from the same source – food prices rise faster than other prices. In both cases, however, real incomes are substantially higher for households and they can afford significantly more food at the same budget shares.

Figure 3.12: National Fuel Consumption Security (CS)

(percent change from Baseline in 2030)

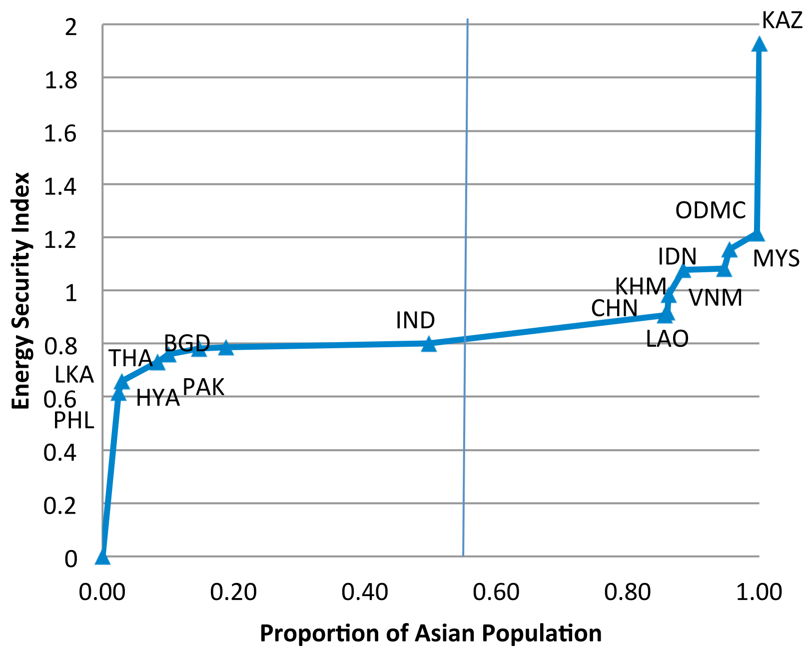


Source: Authors' estimates.

We close this section with two examples of fuel security metrics at the regional level, using the incidence framework set forth in Annex 3 below. Figure 3.13 depicts the incidence of energy Production Security in the Baseline case in 2030. Using self-sufficiency (PS=1), countries comprising about 55% of Asian population are experiencing energy risk.

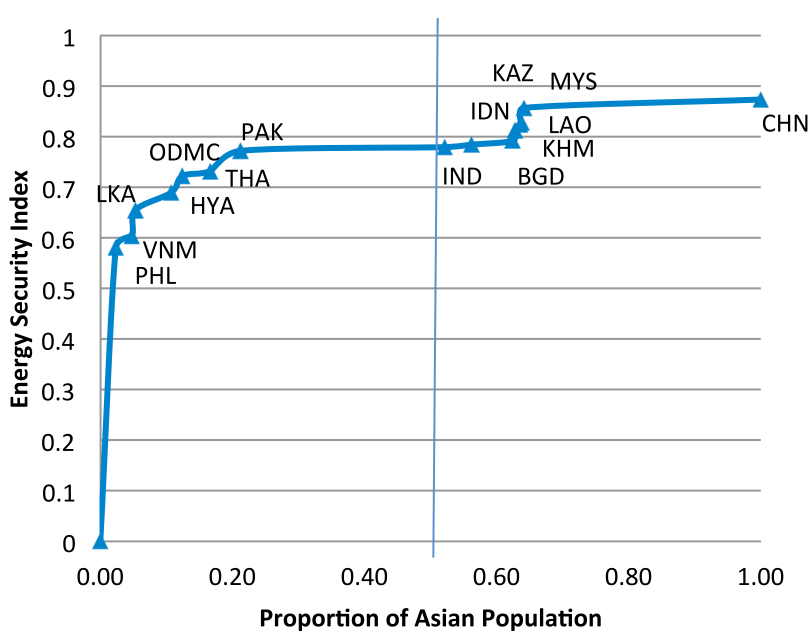
From the perspective of domestic energy Demand Security (DS), countries comprising about half of Asian population have sufficiency levels of 80% or below, indicating that they would require substantial changes in trade patterns to address emergent energy risk. Depending on the case, this might require attenuation of exports (Thailand) or stepping up of imports (High Income Asia).

Figure 3.13: Energy Production Security (PS) Index by Country, Baseline 2050



Source: Authors' estimates.

Table 3.14: Energy Demand Security (DS) Index by Country, Baseline 2050



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5 Annex 1: Detailed Regional Data

Table 1: Millions of Light Duty Vehicles

	Actual		Projected		
	1990	2000	2010	2020	2030
China[1]	5.5	16	52	119	
					233[2]
					270[3]
					390[4]
Japan[1]	58	73	79	81	
					86.6[5]
South Korea[1]	3.4	12	20	26	
					30.5[5]
India[1]	4.3	9.4	20	38	
					73[2]
					115[3]
					77.6[4]
					156[5]
Pakistan[5]					7.8
Indonesia[1]	2.8	5.5	7.9	12	
					46.1[5]
Taiwan[1]	2.8	5.5	8	11	
					13.6[5]
Singapore[1]	0.4	0.6	0.7	0.7	
Malaysia[1]	2.4	5.2	8.1	13	
					23.8[5]

Philippines[1]	1.2	2.5	4.6	8	
Thailand[1]	2.8	6.1	10.4	18	
					44.6[5]
Vietnam[1]	0.2	0.2	0.4	0.8	
Hong Kong[1]	0.4	0.5	0.7	0.8	
Other Asian Countries[1]	2	3.4	4.6	6.4	
Developing Asia[1]	28	67	137	254	
Asian Total[1]	86	140	216	336	

Source: 1=IEEJ 2004, 2=Komiyama, 3=IEA 2007, 4=ADB2009, 5=Dargay et al. 2007

Table 2: Share of Regional Vehicle Stock (%)

	Projected		Actual	
	1990	**2000**	**2010**	**2020**
China	6.4	11.5	24.1	35.4
Japan	67.2	52	36.4	24.2
South Korea	4	8.6	9.1	7.7
India	5	6.7	9.4	11.4
Indonesia	3.2	3.9	3.6	3.5
Taiwan	3.2	4	3.7	3.3
Singapore	0.5	0.4	0.3	0.2
Malaysia	2.8	3.8	3.8	4
Philippines	1.4	1.8	2.1	2.4
Thailand	3.3	4.4	4.8	5.5
Vietnam	0.2	0.2	0.2	0.2
Hong Kong	0.4	0.4	0.3	0.3
Other Asian Countries	2.3	2.4	2.1	1.9
Developing Asia	32.8	48	63.6	75.8
Asian Total	100	100	100	100

Source: IEEJ 2004

Table 3: Average Annual Growth Rates (%)

	1990 - 2000	2000 - 2010	2010 - 2020	2000 - 2020
China	11.3	12.5	8.6	10.5
Japan	2.3	0.8	0.3	0.6
South Korea	13.5	5	2.8	3.9
India	8.1	7.9	6.6	7.3
Indonesia	7.1	3.6	4.1	3.9
Taiwan	7.2	3.7	3.3	3.5
Singapore	2.7	1.7	0.7	1.2
Malaysia	8	4.5	5.2	4.8
Philippines	7.4	6.3	5.7	6
Thailand	8.1	5.4	5.8	5.6
Vietnam	2.2	6.7	6	6.3
Hong Kong	2.7	3.3	2.3	2.8
Other Asian Countries	5.5	3.2	3.4	3.3
Developing Asia	9.1	7.4	6.4	6.9
Asian Total	5	4.4	4.5	4.5

Source: IEEJ 2004

7 Annex 2 – Bayesian Econometric Estimation

8.1. Overview of the Model:

8.1.1 The reduced-form SVAR model:

The standard expression for reduced-form estimation,

$$\sum_{l=1}^{p} y_{t-l} A_l = d + \varepsilon_t , t = 1,2,...,T \tag{1}$$

is an *m*-dimensional (in our case m=4: spot, 30-day future, 60-day future, 90-day future) VAR for a sample of size *T* (*T*=306 for oil, or 25.5 years of monthly data) where y_t is a vector of observed oil prices at time *t*. A_l is the coefficient matrix for the l^{th} lag, *p* is the maximum number of lags, *d* is a vector of constants, and ε_t a vector of *IID* normal structural shocks such that:

$$E[\varepsilon_t | y_{t-s}, s > 0] = 0 \text{ and } E[\varepsilon'_t \varepsilon_t | y_{t-s}, s > 0] = I \tag{2}$$

By dividing *A* into two parts (A_0 is the matrix of correlations at time *t* and A_+ is a matrix of the coefficients on the lagged variables), we can re-write the equation as a multivariate regression where the columns of the coefficients correspond to the equations.

$$YA_0 + X A_+ = E \tag{3}$$

Next, we define compact forms of the VAR coefficients for convenience:

$$a_0 = vec(A_0), a_+ = vec\begin{pmatrix} -A_1 \\ \vdots \\ -A_p \\ d \end{pmatrix}, A = \begin{pmatrix} A_0 \\ A_+ \end{pmatrix}, a = vec(A) \tag{4}$$

where *A* is a stacked representation of the system matrices and *vec* is a vectorization operator that stacks the system parameters in columns, one for each equation (so, for example, *a* is a stacking of all of the parameters in *A*).

Now, letting *Z*=[*Y X*] and *A*=[A_0|A_+], we can rewrite equation(3) as:

$$ZA = E \tag{5}$$

Next, in order to examine the Bayesian estimator for this model, we can examine the conditional likelihood function for normally distributed residuals:

$$L(Y|A) \propto |A_0|^T \, exp[-0.5 \, tr(ZA)'(ZA)] \quad (6)$$

$$\propto |A_0|^T \, exp[-0.5 \, a'(I \otimes Z'Z)a] \quad (7)$$

8.2. The Prior

8.2.1 Finally, we can look at the prior for A_0, the present time coefficient matrix (stacked). The prior in this model is on the structural parameters. The prior over all structural parameters has the form:

$$\pi(a) = \pi(a_+|a_0)\pi(a_0) \quad (8)$$

$$\pi(a) = \pi(a_0)\phi(a^*_{+,} \Psi) \quad (9)$$

where * represents the mean parameters in the prior for a_+, Ψ is the prior covariance for a^*_+ and $\phi()$ is a multivariate normal density. We assume $a_+|a_0$ has a normal distribution and we specify $\pi(a_0)$ later.

The posterior for the coefficients is then

$$q(A) \propto L(Y|A)\pi(a_0)\phi(a^*_{+,} \Psi) \quad (10)$$

$$\propto \pi(a_0) \, |A_0|^T |\Psi|^{-0.5} \text{ x } exp[-0.5(a_0'(I \otimes Y'Y)a_0$$

$$-2a'_+(I \otimes X'Y)a_0 + a_+(I \otimes X'X) \, a_+ + a^{*'}_+ \Psi a^{*'}_+] \quad (11)$$

Now, in order to make the prior tractable, we assume the special case for the prior density in (8) where it has a structure that makes the posterior conditionally multivariate normal. The conditional distribution we use (recommended by Sims and Zha) is the distribution of $\pi(a_+|a_0)$.

Since the residuals of the structural models are standardized and have unit variance, we are working with priors on standardized data. This simplifies everything since it removes issues of relative scale.

8.2.2 We can specify a prior on $a_+|a_0$. The unconditional prior has the form $E[a_+]=(I|0)$ so the conditional prior has the form $a_+|a_0 \sim N((A_0|0), \Psi)$. We can then write the normal conditional prior for the mean of the structure parameters as :

$$E(A_+ \mid A_0) = \begin{bmatrix} A_0 \\ 0 \end{bmatrix} \qquad (12)$$

The conditional covariance of the parameters is $V(A_+|A_0) = \Psi$. Each diagonal element of Ψ therefore corresponds to the variance of the VAR parameters. The variance of each of these coefficients is assumed to have the form

$$\bar{\psi}_{l,j,i} = \left(\frac{\lambda_0 \lambda_1}{\sigma_j l^{\lambda_3}} \right)^2 \qquad (13)$$

for the element corresponding to the l^{th} lag of the variable *j* in equation *i*. The prior parameter λ_0 sets an overall tightness across the elements of the prior on Σ

$= A_0^{-1\prime} A_0^{-1}$. As λ_0 approaches 1, the conditional prior variance of the parameters is the same in the sample residual covariance matrix.

8.2.3 Model Beliefs that Relate to Specifying a Prior

Using the MSBVAR model implies that we believe:

1. The standard deviations around the first lag coefficients are proportionate to all the other lags

2. The weight of each variable's own lag is the same as those of other variables lag

3. The standard deviation of the coefficients of longer lags is proportionately smaller than those on the earlier lags. (Lag coefficients shrink to zero over time and have smaller variance at higher lags.)

4. The standard deviation of the intercept is proportionate to the standard deviation of the residuals for the equation.

5. The standard deviation of the sums of the autoregressive coefficients should be proportionate to the standard deviation of the residuals for the respective equation(consistent with the possibility of cointegration).

6. The variance of the initial conditions should be proportionate to the mean of the series. These are ‘‘dummy initial observations’’ that capture trends or beliefs about stationarity and are correlated across the equations.

8.2.4 Choosing a Prior Specification

Most papers devote a significant amount of effort justifying their prior selections based on a combination of looking at the data and theory. For example, some may choose to discount the overall scale of the error covariance and the standard deviation of the intercept if they believe that the sample error will overstate the true error covariance. For example, the observed covariance may put too much emphasis on rare extreme events.

People also consider the dynamics and the lag structure. In particular, they consider how fast the effect of prices in period *t-l* will diffuse. For example, if they expect that the effects of previous periods will decay quickly then they could choose λ_3=2 which implies that the variance of the parameters around lag *j* are approximately proportionate to j^{-2}. They may also choose to place a tighter prior on the first lag coefficient if they believe the more proximate events are highly predictive of the outcome today.

One way to check the prior specification is to conduct a search of the hyperparameter space using the marginal log-likelihood and log-posterior of the data as measures of fit. The reason most people do not use a measure such as the value of the log-posterior pdf of the data or the marginal log-likelihood to select the prior is that this puts too much weight on the prior and only reproduces the density of the sample data. This would limit the ability to make out of sample predictions.

8.3. Forecasting different scenarios with MVBAR

Most papers do not forecast different scenarios by changing the prior specification but instead by introducing soft (range of values) or hard (exact value) constraints for endogenous variables of interest and then use the Gibbs sampler to sample from the posterior distribution conditional on these constraints.

Table 8.1: *Overview of Prior Paramters for BVAR Model*

Par	Range	Technical Description	Intuition
λ_0	[0,1]	Scale of the error covariance matrix	Influences the relationship between the observed variance and the conditional prior variance. Larger values imply greater emphasis on observed covariance.
λ_1	>0	Deviation around A_1.	Controls the tightness of the beliefs about the standard deviation of the first lags.
λ_3	>0	Lag decay (with 1=harmonic). The $l^{\lambda 3}$ term allows the variance of the coefficients on higher order lags to shrink as the lag increases.	Expresses beliefs about quickly the variance on coefficients increases as lags increase.
λ_4	≥0	Scale of sd of intercept. The constant in the model receives a prior variance of $(\lambda_0\lambda_4)^2$.	Expresses beliefs about the relationship between the observed variance and the prior variance of the constant in the model. Larger values imply greater emphasis on observed variance.
λ_5	>0	Scale of sd of exogenous coefficients. The prior variance on all exogenous variables is $(\lambda_0\lambda_5)^2$.	Expresses beliefs about the relationship between the observed variance and the variance of the exogenous variables in the model. Larger values imply greater emphasis on observed variance.
μ_5	≥0	Sum of coefficients/Cointegration. Sets the prior weights on dummy observations for a sum of coefficinet priors. Implies beliefs about the presence of unit roots.	Expresses beliefs about long term trends (larger values stationarity)
μ_6	≥0	The prior weight for dummy observations for trends.	Effectively the weight on initial observations so μ_6 influences the impacts of the initial conditions.

8 Annex 3 – Technical Overview of The TIGER Model

This paper uses a dynamic general equilibrium forecasting tool, the Trade Integrated Global Energy and Resource (TIGER), a global, multi-region, multi-sector, dynamic applied general equilibrium model.[13] The base data set—GTAP[14] Version 7.0—is defined across 118 country/region groupings, and 57 economic sectors. For this paper, the model has been defined for an aggregation of 13 country/regions and 10 sectors including sectors of importance to the poorer developing countries—grains, textiles, and apparel. The remainder of this section outlines briefly the main characteristics of supply, demand, and the policy instruments of the model.

Production

All sectors are assumed to operate under constant returns to scale and perfect competition. Production in each sector is modeled by a series of nested CES production functions which are intended to represent the different substitution and complementarity relations across the various inputs in each sector. There are material inputs which generate the input/output table, as well as factor inputs representing value added.

Three different production archetypes are defined in the model—crops, livestock, and all other goods and services. The CES nests of the three archetypes are graphically depicted in Figures A-1 through A-3. Within each production archetype, sectors will be differentiated by different input combinations (share parameters) and different substitution elasticities. The former are largely determined by base year data, and the latter are given values by the modeler.

The key feature of the crop production structure is the substitution between intensive cropping versus extensive cropping, i.e. between fertilizer and land (see Figure A-1).[15] Livestock production captures the important role played by feed versus land, i.e. between ranch- versus range-fed production (see Figure A-2).[16]

[13] TIGER is based on the LINKAGE model, developed and maintained by the World Bank, which assumes no responsibility for this analysis or its results.

[14] GTAP refers to the Global Trade Analysis Project based at Purdue University. For more information see Hertel, 2008.

[15] In the original GTAP data set, the fertilizer sector is identified with the crop sector, i.e. chemicals, rubber, and plastics.

[16] Feed is represented by three agricultural commodities in the base data set: wheat, other grains, and oil seeds.

Production in the other sectors more closely matches the traditional role of capital/labor substitution, with energy introduced as an additional factor of production (see Figure A-3).

In each period, the supply of **primary** factors—capital, labor, and land—is usually predetermined. However, the supply of land is assumed to be sensitive to the contemporaneous price of land. Land is assumed to be partially mobile across agricultural sectors. Given the comparative static nature of the simulations which assumes a longer term horizon, both labor and capital are assumed to be perfectly mobile across sectors (though not internationally).[17]

Model current specification has an innovation in the treatment of labor resources.[18] The GTAP data set identifies two types of labor skills—skilled and unskilled. Under the standard specification, both types of labor are combined together in a CES bundle to form aggregate sectoral labor demand, i.e. the two types of labor skills are directly substitutable. In the new specification, a new factor of production has been inserted which we call *human* capital. It is combined with capital to form a physical *cum* human capital bundle, with an assumption that they are complements. On input, the user can specify what percentage of the skilled labor factor to allocate to the human capital factor.

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets.

Consumption and closure rules

All income generated by economic activity is assumed to be distributed to a single representative household. The single consumer allocates optimally his/her disposable income among the consumer goods and saving. The consumption/saving decision is completely static: saving is treated as a “good” and

[17] This can be contrasted with, e.g. Fullerton (1983).

[18] This feature is not invoked in results reported here. Because of increased interest in labor markets and human capital in the Latin American context (see e.g. World Bank (2001)), we have developed this modeling capacity and are using it experimentally. For indications about modeling in this context, see Collado et al (1995), Maechler and Roland-Holst (1997), and van der Mensbrugghe (1998).

its amount is determined simultaneously with the demands for the other goods, the price of saving being set arbitrarily equal to the average price of consumer goods.[19]

Government collects income taxes, indirect taxes on intermediate and final consumption, taxes on production, tariffs, and export taxes/subsidies. Aggregate government expenditures are linked to changes in real GDP. The real government deficit is exogenous. Closure therefore implies that some fiscal instrument is endogenous in order to achieve a given government deficit. The standard fiscal closure rule is that the marginal income tax rate adjusts to maintain a given government fiscal stance. For example, a reduction or elimination of tariff rates is compensated by an increase in household direct taxation, *ceteris paribus*.

Each region runs a current-account surplus (deficit) that is fixed (in terms of the model numéraire). The counterpart of these imbalances is a net outflow (inflow) of capital, subtracted from (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving. The fixed trade balance implies an endogenous real exchange rate. For example, removal of tariffs which induces increased demand for imports is compensated by increasing exports which is achieved through a real depreciation.

Foreign Trade

The world trade block is based on a set of regional bilateral flows. The basic assumption in TIGER is that imports originating in different regions are imperfect substitutes (see Figure A-4). Therefore in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports—commonly referred to as the Armington[20] specification—implies that each region faces a downward-sloping demand curve for its exports. The Armington specification is implemented using two CES nests. At the top nest, domestic agents choose the optimal combination of the domestic good and an aggregate import good consistent with the agent's

[19] The demand system used in TIGER is a version of the Extended Linear Expenditure System (ELES) which was first developed by Lluch (1973). The formulation of the ELES used in TIGER is based on atemporal maximization—see Howe (1975). In this formulation, the marginal propensity to save out of supernumerary income is constant and independent of the rate of reproduction of capital.

[20] See Armington, 1969 and compare, e.g. de Melo and Robinson (1989) and Rutherford and Tarr (2001).

preference function. At the second nest, agents optimally allocate demand for the aggregate import good across the range of trading partners.[21]

The bilateral supply of exports is specified in parallel fashion using a nesting of constant-elasticity-of-transformation (CET) functions. At the top level, domestic suppliers optimally allocate aggregate supply across the domestic market and the aggregate export market. At the second level, aggregate export supply is optimally allocated across each trading region as a function of relative prices.[22]

Trade variables are fully bilateral and include both export and import taxes/subsidies. Trade and transport margins are also included; therefore world prices reflect the difference between FOB and CIF pricing.

Prices

The TIGER model is fully homogeneous in prices, i.e. only relative prices are identified in the equilibrium solution. The price of a single good, or of a basket of goods, is arbitrarily chosen as the anchor to the price system. The price (index) of OECD manufacturing exports has been chosen as the numéraire, and is set to 1.

Elasticities

Production elasticities are relatively standard and are available from the authors. Aggregate labor and capital supplies are fixed, and within each economy they are perfectly mobile across sectors.

Equivalent Variation Aggregate National Income

Aggregate income gains and/or losses summarize the extent trade distortions are hindering growth prospects and the ability of economies to use the gains to help those whose income could potentially decline.

[21] The GTAP data set allows each agent of the economy to be an Armington agent, i.e. each column of demand in the input/output matrix is disaggregated by domestic and import demand. (The allocation of imports across regions can only be done at the national level). For the sake of space and computing time, the standard model specification adds up Armington demand across domestic agents and the Armington decomposition between domestic and aggregate import demand is done at the national level, not at the individual agent level.

[22] A theoretical analysis of this trade specification can be found in de Melo and Robinson, 1989.

Real income is summarized by Hicksian equivalent variation (EV). This represents the income consumers would be willing to forego to achieve post-reform well-being (u^p) compared to baseline well-being (u^b) at baseline prices (p^b):

$$EV = E\left(p^b, u^p\right) - E\left(p^b, u^b\right)$$

where *E* represents the expenditure function to achieve utility level *u* given a vector of prices *p* (the *b* superscript represents baseline levels, and *p* the post-reform levels). The model uses the extended linear expenditure system (ELES), which incorporates savings in the consumer's utility function. See Lluch (1973) and Howe (1975). The ELES expenditure function is easy to evaluate at each point in time. (Unlike the OECD treatment of *EV*, we use baseline prices in each year rather than base year prices. See Burniaux et al. (1993)). The discounted real income uses the following formula:

$$CEV = \sum_{t=2005}^{2015} \beta^{(t-2004)} EV_t^a \Big/ \sum_{t=2005}^{2015} \beta^{(t-2004)} Y_t^d$$

where *CEV* is the cumulative measure of real income (as a percent of baseline income), b is the discount factor (equal to 1/(1+*r*) where *r* is the subjective discount rate), Y^d is real disposable income, and EV^a is adjusted equivalent variation. The adjustment to *EV* extracts the component measuring the contribution of household saving, since this represents future consumption. Without the adjustment, the *EV* measure would be double counting. The saving component is included in the *EV* evaluation for the terminal year. Similar to the OECD, a subjective discount rate of 1.5 percent is assumed in the cumulative expressions.

Specification of Endogenous Productivity Growth

Productivity in manufacturing and services is the sum of three components:

- a uniform factor used as an instrument to target GDP growth in the baseline simulation
- a sector-specific fixed shifter which allows for relative differentials across sectors (for example, manufacturing productivity two percentage points higher than productivity in the services sectors)

- a component linked to sectoral openness as measured by the export-to-output ratio

The latter takes the following functional form:

$$(1) \qquad \gamma_i^e = \chi_i^0 \left(\frac{E_i}{X_i} \right)^{\eta}$$

where g^e is the growth in sectoral productivity due to the change in openness, c^0 is a calibrated parameter, *E* and *X* represent respectively sectoral export and output, and h is the elasticity. The parameter c^0 has been calibrated so that (on average) openness determines roughly 40 percent of productivity growth in the baseline simulation, and the elasticity has been set to 1.

In agriculture, productivity is fixed in the baseline, set to 2.5 percent per annum in most developing countries (based on estimates found in Martin and Mitra, 19xx). However, a share of the fixed productivity is attributed to openness, using equation (1).

In the baseline, GDP growth is given. Agricultural productivity is similarly given, and equation (1) is simply used to calibrate the shift parameter, c^0, so that a share of agricultural productivity is determined by sectoral openness. Average productivity in the manufacturing and services sectors is endogenous and is calibrated in the baseline to achieve the given GDP growth target. The economy-wide (excluding agriculture) productivity parameter is endogenous. Equation (1) is used to calibrate the same c^0 parameter, under the assumption that some share of sectoral productivity is determined by openness, for example 40 percent.

In policy simulations, the economy-wide productivity factor, along with other exogenous productivity factors (sector-specific shifters) are held fixed, but the openness-related part of productivity is endogenous and responds to changes in the sectoral export-to-output ratio. In the manufacturing and services sectors, the elasticity is set at 1. In the agricultural sectors it is set to 0.5.

Say sectoral productivity is 2.5 percent, and that 40 percent of it can be explained by openness, i.e. 1.0 percent, with the residual 1.5 percent explained by other factors. Assume sectoral openness increases by 10 percent. If the elasticity is 1, this implies that the openness-related productivity component will increase to 1.1 percent and total sectoral productivity will increase to 2.6 percent (implying that the total sectoral productivity increases by 4 percent with respect to the 10 percent increase in sectoral openness).

Figure A2.1: Production Function for Crops

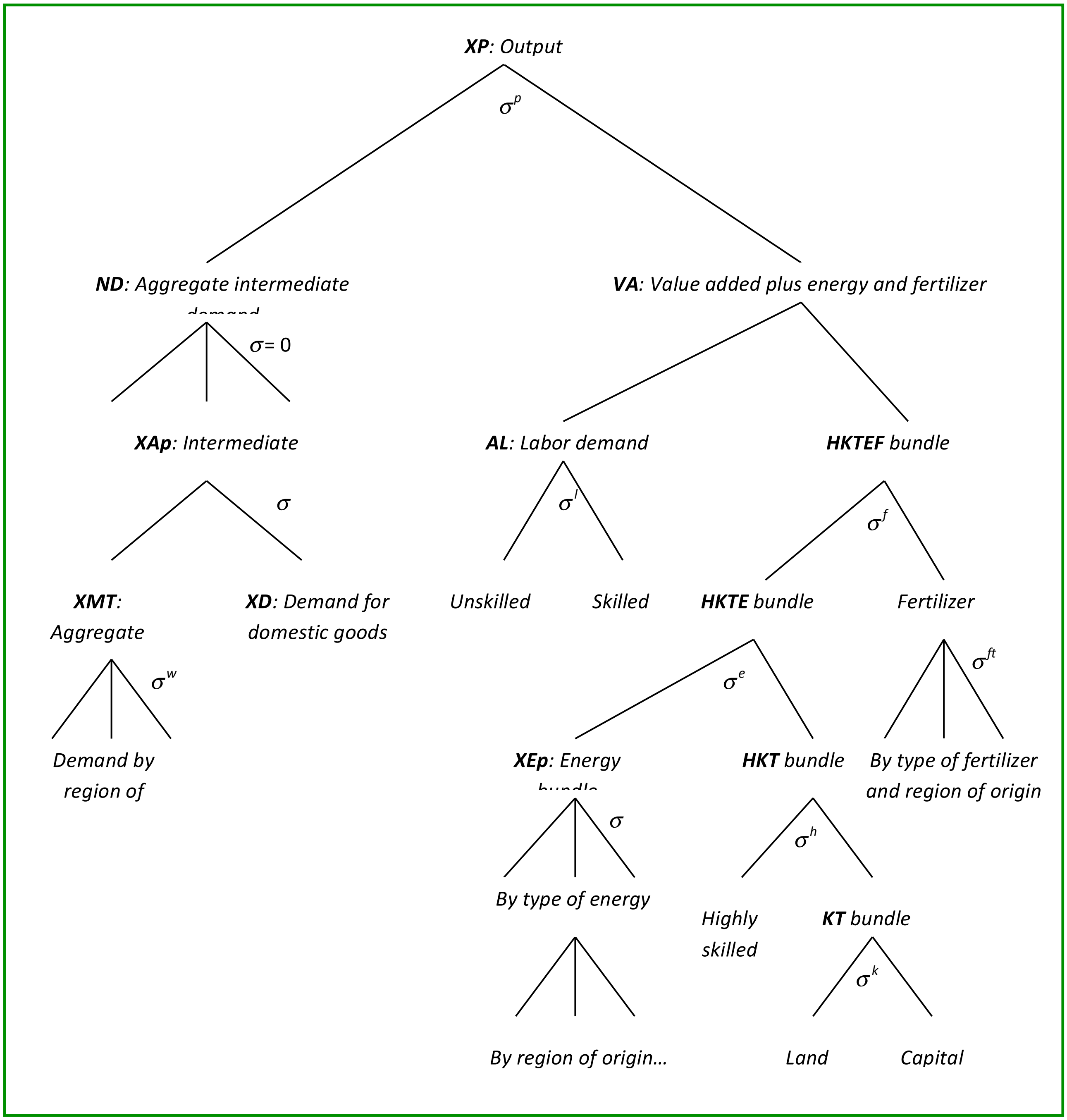


Figure A2.2: Production Function for Livestock

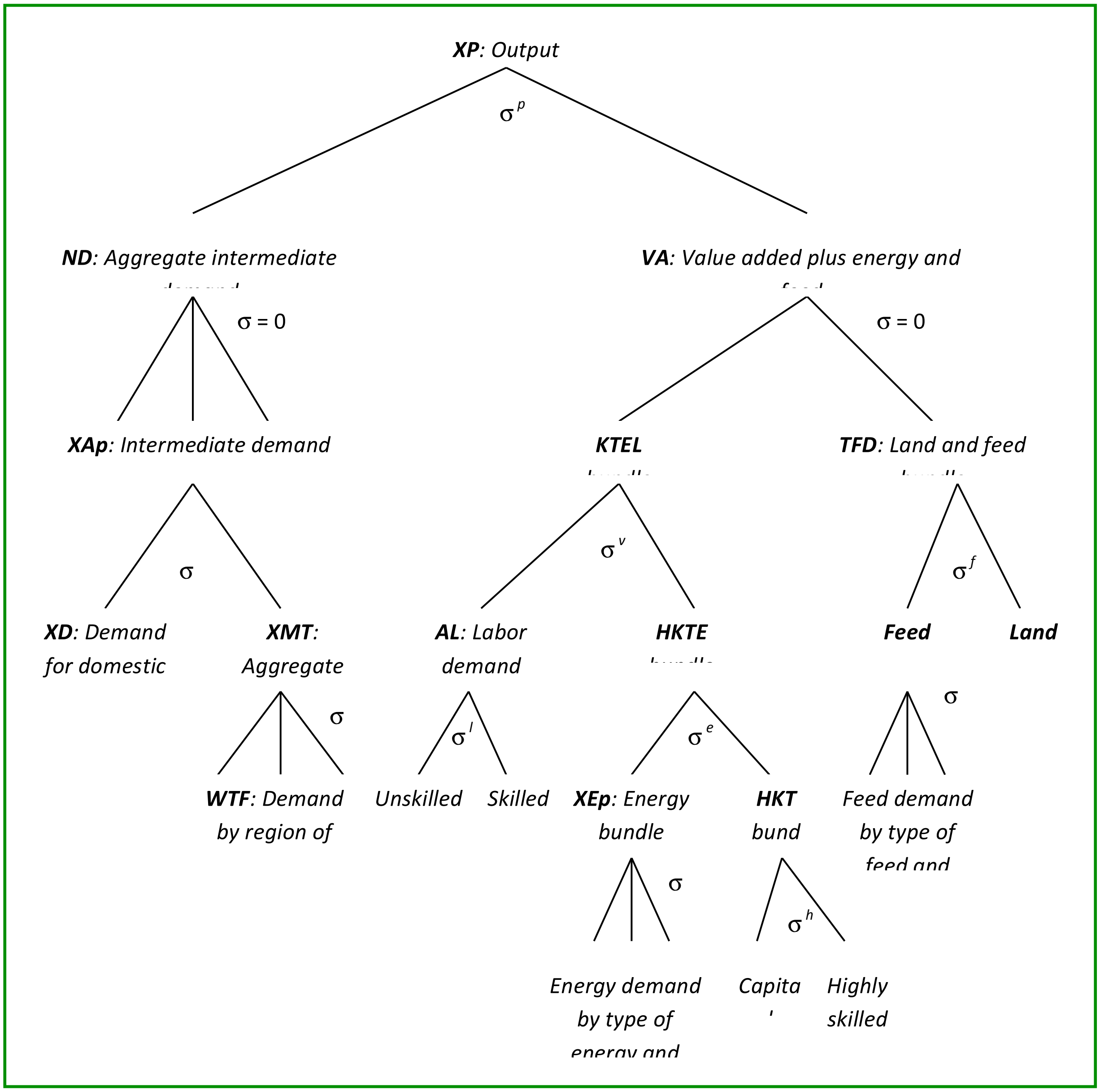


Figure A2.3: Production Function for Non-agriculture

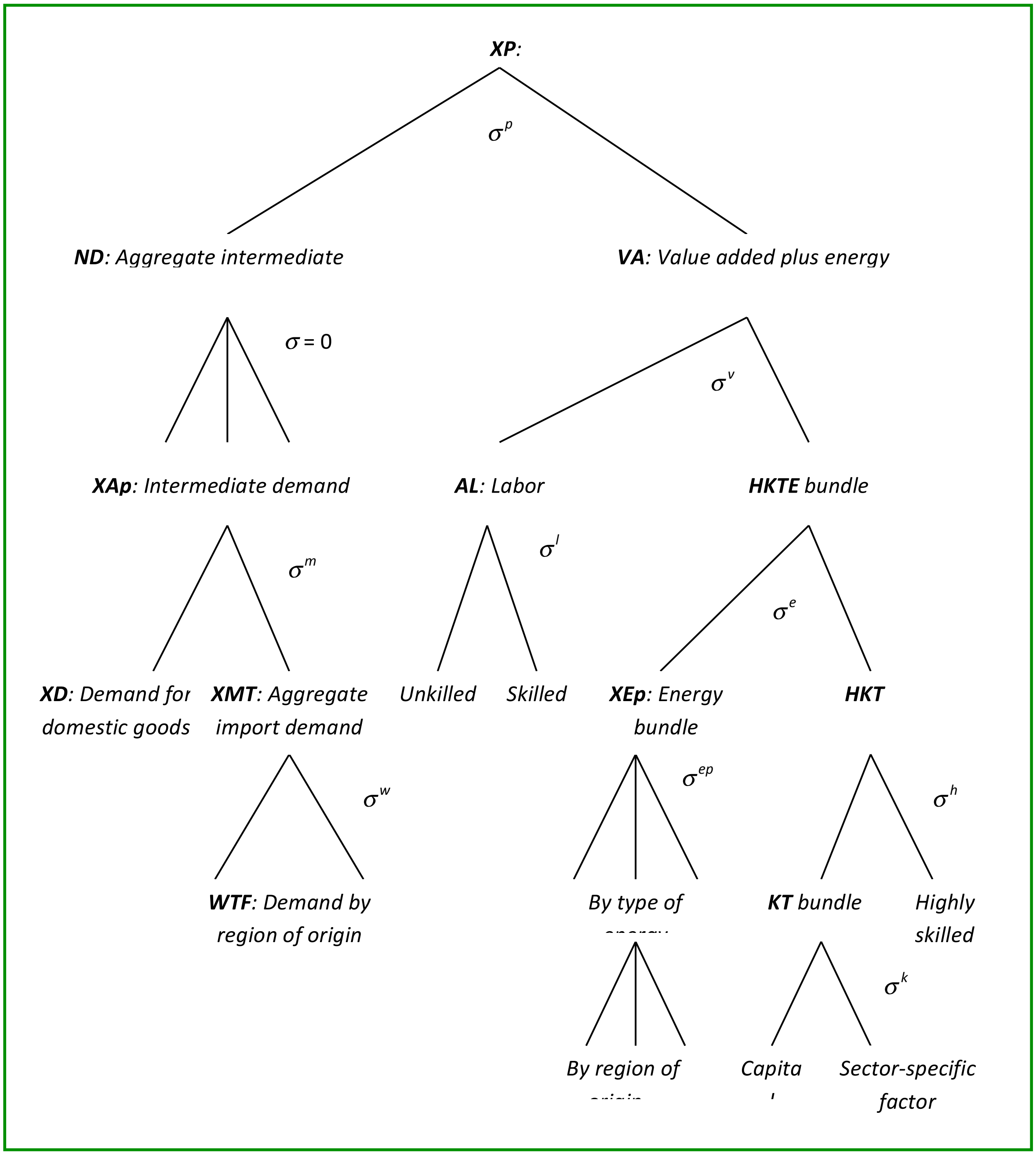
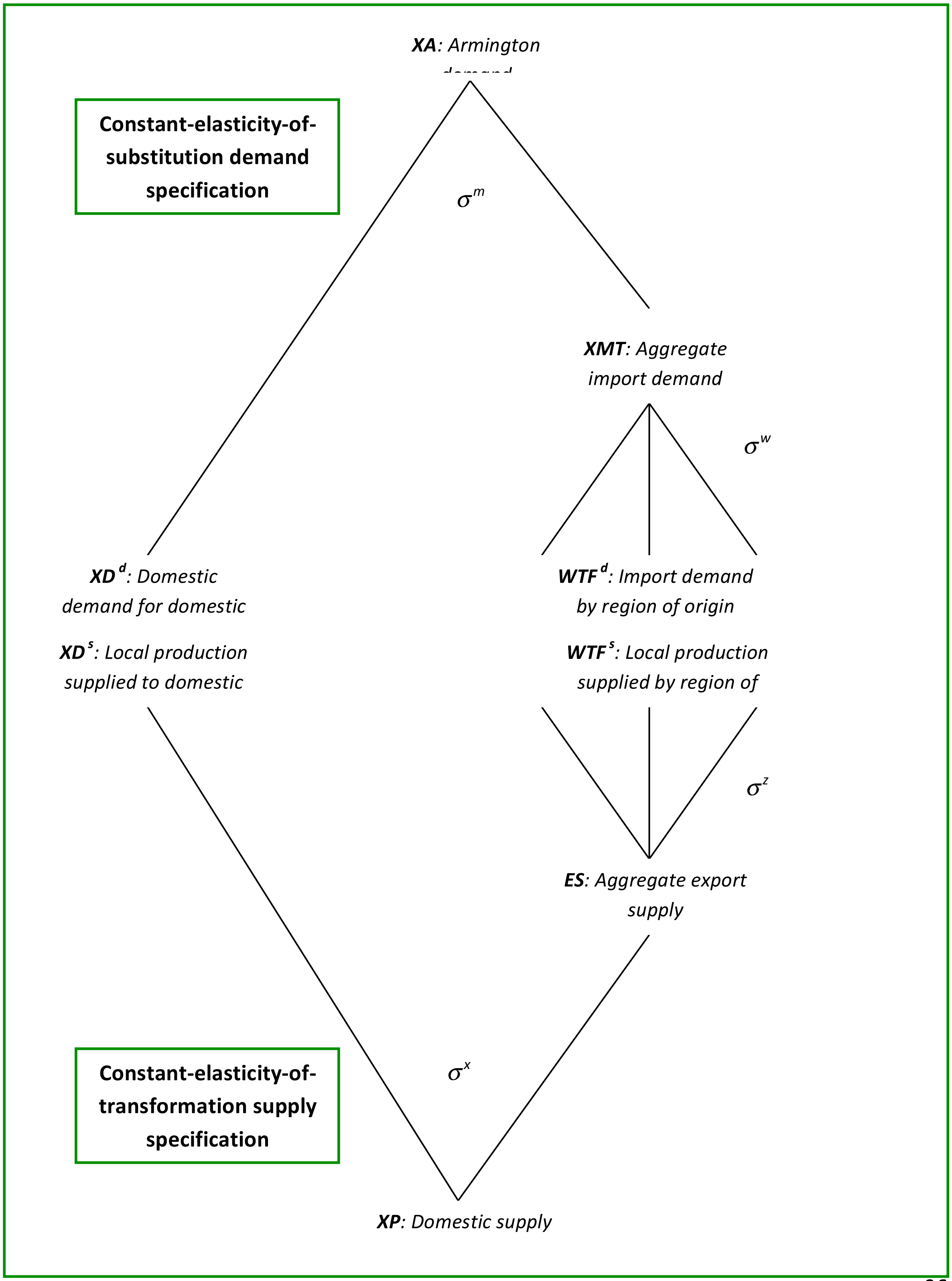


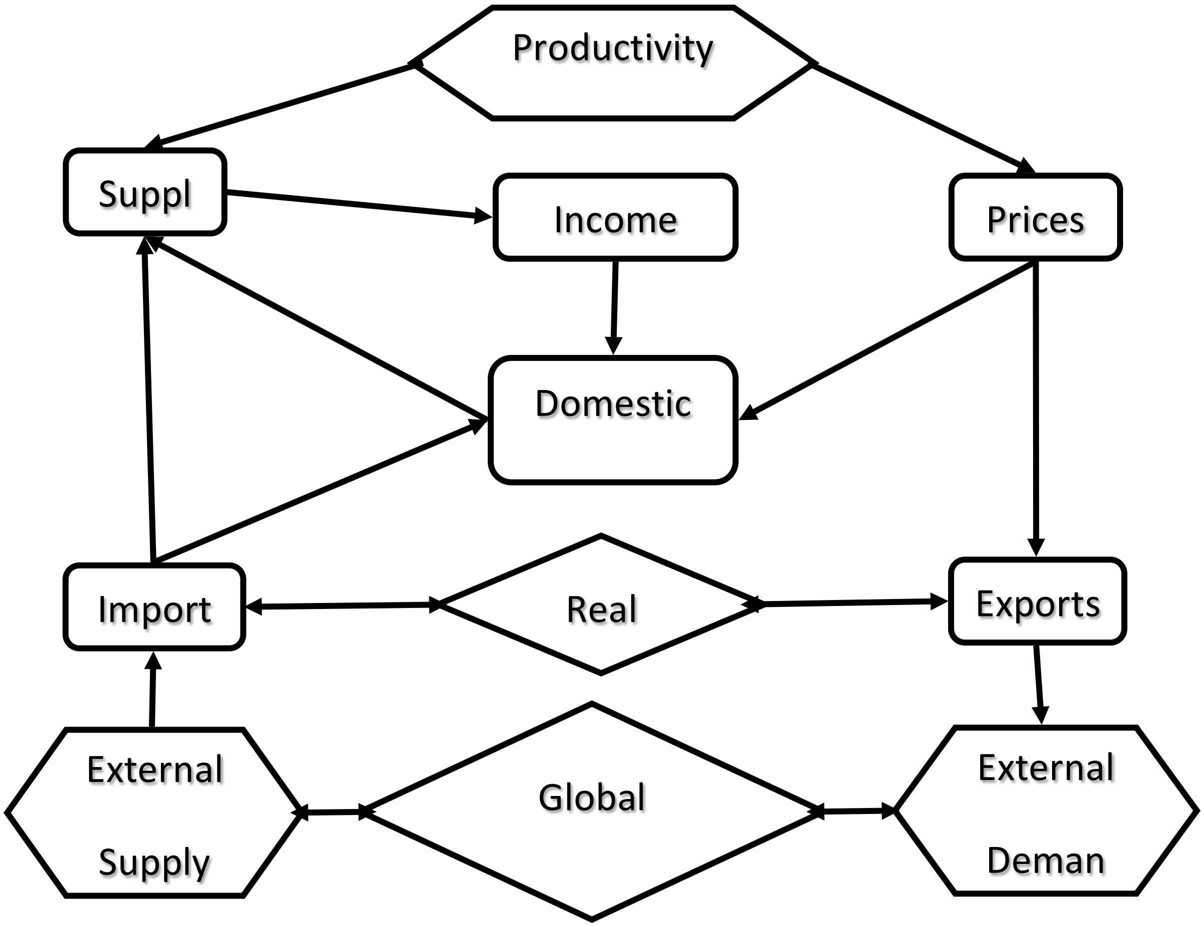
Figure A2.4: Trade Aggregation



Model Calibration

The model is calibrated to country and regional real GDP growth rates, obtained as consensus estimates from independent sources (DRI, IMF, Cambridge Econometrics). Using exogenous rates of implied TFP growth, the model computes supply, demand, and trade patterns compatible with domestic and global equilibrium conditions. Equilibrium is achieved by adjustments in the relative prices of domestic resources and commodities, while international equilibrium is achieved by adjusting trade patterns and real exchange rates to satisfy fixed real balance of payments constraints. The general process is schematically represented in the figure below.

Figure A2.5: General Equilibrium Calibration Mechanism



Notes on the Adjustment Process

The calibration procedure highlights the two salient adjustment mechanisms in the model (as well as the real economies), domestic and international prices. General equilibrium price adjustments are generally well understood by professional economists but, in the multilateral context, the role of exchange rates can be a source of confusion. Generally, in a neoclassical model like this one, there are no nominal or financial variables and the function of the exchange rate is only to equalized real purchasing power between different economies.

Because models like this to not capture the aggregate price level or other nominal quantities, there is no nominal exchange rate in the sense of traditional macroeconomics or finance. Since there is no money metric in the model, all prices are relative prices, and the exchange rate (the composite relative price of foreign goods) is no exception. If there were financial assets in the model, one could define a nominal exchange rate as the relative price of two international financial assets (money, bonds, etc.). Without them, the exchange rate is defined in terms of real international purchasing power, i.e. the relative price of tradeable to nontradeable goods. In a multi-sector setting, the real exchange rate is defined as the ratio of an index of the value of all tradeables (on world markets) to an index of the value of all nontradeables.

Since any tax (or other price elevating distortion) on an import is an implicit tax on all tradeable goods, trade liberalization causes tradeable goods prices to fall and the real exchange rate depreciates. Real exchange rate depreciation also makes exports more competitive, one of the principal motives for unilateral liberalization. The general implication of this is that trade will expand rapidly for a country removing significant import protection, and more rapidly for countries removing more protection. The pattern of trade expansion, and the domestic demand and supply shifts that accompany it, depend upon initial conditions and adjustments among trading partners.

It should also be noted that, even in a second-best world, removing price distortions also confers efficiency gains, increasing output potential and real incomes.

9 Annex 3 - Measuring Fuel Security

Fuel security is an easy concept to motivate, and thus plays a prominent role in policy dialog. Unfortunately, it can be very difficult to measure, depending not only on definitions of energy need but myriad of ways in which such needs can be met. Assuming we agree on a definition of basic needs, even in terms of energy services composition (a big step), these needs can be met by countries from a combination of domestic capacity and international trade. This opens the concept of fuel security to many interpretations.

Consider for example the stricter definition of national energy Production Security, according with the classical notion of national energy self-sufficiency, which can be defined for country *r* as

$$PS_r = \frac{X}{D} = \frac{\sum_e P_{re} X_{re}}{\sum_e P_{re} D_{re}} \tag{3.1}$$

This is essentially the ratio of domestic output to demand, measuring the degree to which a country can be self-sufficient or meet its own energy needs with own supply. Summing over more than one energy commodity (e), here *X* denotes domestic energy sector (*e*) output, domestic demand *D=DD+DM* for the same commodities is comprised of domestic and imported energy products, and P variables are corresponding prices. Note that *PS=1* does not require zero energy imports, but simply that total imports equal exports. In this case, a country could revert to self-sufficiency by suspending trade.

For a narrower definition of fuel security that excludes trade, we define Domestic Security

$$DS_r = \frac{DD}{D} = \frac{\sum_e P_{re} D_{re} - \sum_e PM_{re} M_{re}}{\sum_e P_{re} D_{re}} = \frac{\sum_e P_{re} D_{re} - \sum_e PE_{re} E_{re}}{\sum_e P_{re} D_{re}} \tag{3.2}$$

which measures the proportion of domestic demand that is currently met by domestic production sold domestically. This measure, demand net of imports or supply net of exports, shows the extent to which a country currently meets its own needs, beyond current trade commitments in energy commodities. The perspective given by this indicator (left-hand side) encompasses both the import dependent (middle term) and the export dependent (right-hand side). Both types of countries may have to adjust trade relationships in response to domestic shortfalls of energy output, although this is easier for exporters than importers, it is still disruptive.

Perhaps the broadest notion of fuel security allows for countries to rely partially or even completely on global markets, assuming they can barter net exports to meet domestic energy import needs, i.e.

$$TS_r = \frac{E-M}{M_e} = \frac{\sum_i [PE_{ri}XP_{ri} - PM_{ri}XM_{ri}]}{\sum_e PM_{re}M_{re}} \tag{3.3}$$

where the subscript (i) denotes all tradable sectors/commodities. Of course a country might need to reduce imports of other kinds to cover energy import needs, but in any case this index measures the country r's domestic and international purchasing power relative to domestic energy demand.

A final measure relates not to total energy output and use across the economy, but to final household consumption, defined as energy Consumption Security

$$CS_r = \frac{\sum_i P_{ri}C_{ri}}{\sum_e P_{re}C_{re}} \tag{3.4}$$

which measures the total consumption expenditure as a multiple of the cost of energy consumption. This measure represents a traditional household energy affordability metric that is most likely to inform domestic energy price policy.

Each of these fuel security metrics represents a slightly different perspective on the larger issue of fuel security, and comparing them reveals different challenges and opportunities for energy policy, particularly as it relates to other trade and development strategy.

Before implementing these measures in our Asian regional energy scenarios, consider these indicators in a regional context. For example, assume any one of these four security metrics (call it S) has a policy target level T. Then for a group of countries r=1,2,…,R, with total population P and individual populations P_r, we can define an index of regional fuel security as follows:

(3.5) $$\Sigma_\alpha(T) = \sum_{r=1} \frac{P_r}{P}\left(\frac{S_r - T}{T}\right)^\alpha = \sum_{r=1} \pi_r \left(\frac{S_r - T}{T}\right)^\alpha$$

For α=1, this index measures average regional per capita fuel security with respect to the given metric and target.[23] If the index is greater than zero, then the region as a whole can meet its energy needs through trade, if negative it will have to import from the rest of the world. While for α=2 it measures the variance or regional inequality of fuel security.

To assess energy risk for individual or groups of nations within the Asian region, we can order countries by the fuel security index under consideration (Figure A3.1), and evaluate all countries below the target security level T with the index

(3.6) $$\sigma_\alpha(T) = \sum_{r=1}^{q} \frac{P_r}{P}\left(\frac{S_r - T}{T}\right)^\alpha$$

Where q identifies the last of the set of countries below the fuel security target T. From this formulation, we see that

1) If *a* = 0, $\Sigma_0 = \sum_{r=1}^{q} \pi_r$. This is the *share of Asia's population with national energy risk,* the simplest measure of region energy vulnerability.

2) If *a* = 1, then

(3.7) $$\Sigma_1 = \sum_{r=1}^{q} \pi_r \left(\frac{S_r - T}{T}\right).$$

This is the *energy risk gap index* or the *depth of energy risk*, where: $\sum_{1}^{q}(S_r - T)$ measures the energy vulnerability deficit of an individual country, or its fuel security gap. It measures the cost of eliminating energy insecurity with perfect, nz is the cost of eliminating energy insecurity without targeting (i.e., if we had no information on the expenditure level of anyone in the population). Hence, $\sum_1$ is the ratio of the targeted to the untargeted production needed to eliminate energy insecurity. Alternatively, 100*$(1-\Sigma_1)$ is the percentage saving in the aggregate national energy budget due to ability to target countries specifically.

[23] This index is based on the Foster-Greer-Thorbecke (1984) concept of decomposable poverty indicator.

3) If *a* = 2, $\Sigma_2 = \frac{1}{n}\sum_1^q \left(\frac{S_r - T}{T}\right)^2$. This is the *severity of energy risk* index. It weights the energy risk gap as a square, giving greater weight to energy sufficiency deficits further away from the security line. In that sense, $\sum_2$ is sensitive to the distribution of expenditure among the energy insecure. The greater the share of energy-insecure countries, the higher $\sum_2$, even if it has the same $\sum_0$ and $\sum_1$ as another population.

Figure A3.1: Fuel/Energy Risk Assessment