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UNLOCKING THE ASSETS: ENERGY AND THE FUTURE OF CENTRAL ASIA AND THE CAUCASUS

CONVERGENT ECONOMIES:

IMPLICATIONS FOR WORLD ENERGY USE

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Introduction

The neoclassical model predicts that countries converge to their own steady states. Assuming identical technologies across countries, this implies that exogenous differences in savings, employment, and education are the causes of all observed differences in levels of income and rates of growth. However, just as countries differ in accumulation rates, they also use different technologies. In fact, hardly any group of countries fits the assumption of identical technologies. The existence of a technology gap may therefore present an additional opportunity for growth through technology flows. However, a nation’s ability to adopt and absorb new knowledge must also be considered. Indeed, if "follower" countries are characterized by both a large technology gap and a low absorption capacity, then the predictions about rate of growth will be ambiguous. Abramovitz (1986) proposes that the abilities of countries to take advantage of the catching-up potential depends on their respective "social capabilities" (i.e., that systematic variations in social institutions and processes make some countries better or worse at catching up). The institutional economics literature also highlights the importance of the security of property rights and the efficiency of government policies as determinants of countries’ growth rates (North, 1990; Olsen, 1982). Empirically the importance of institutions in the growth-accounting framework has been previously established (Barro, 1991; Knack & Keefer, 1995; Scully, 1988). However, these studies only consider cross-country regressions.

Building on the standard neoclassical framework, we formalize the ideas that technology gaps and differing abilities to take advantage of this catch-up potential exist. The inclusion of technology adoption, with and without institutional inefficiency, slightly modifies the standard results for nations’ steady states and rates of convergence; also, more importantly, it allows for quite different convergence paths. For example, the model allows for poor nations to overtake initially richer nations without resorting to random productivity shocks. We also test these ideas empirically using panel data. We include the possibility of adopting technology from more advanced countries by adding a catch-up term. This adoption potential is subjected to compromise by varying political and social rigidities as estimated by a measure of efficiency. The paper’s novelty lies in the introduction of a rate of adoption of technology and the consideration of relative efficiency of nations. We achieve this using panel data methods that are consistent with the dynamic frontier literature. In particular, we use an extension of the least squares dummy variable methodology in which one slope coefficient is allowed to vary across countries and regions. The included fixed effects are meant to capture all the inevitable country heterogeneities that are due to varying social and political institutions.

The estimation is performed on countries for which data is available through the Penn World Tables.

We determine the length of time it would take for particular countries in the sample to converge to the U. S. per capita income level which is the world standard. We then use these catch-up times to predict the increases in energy use that would be necessary if, given exogenous rates of populations growth, rates of development were such that per capita energy consumption converged to the United States. Based on forecasts from the Energy Information Administration, we allocate the energy use among the various categories of "oil," "coal," and "other" to forecast oil consumption by country. World energy demands are then developed and compared to baseline estimates from the Department of Energy. We find remarkable similarity between our forecasts and those from the U. S. Department of Energy through the year 2015, when our forecast ends.

The second section of the essay discusses our theoretical growth model, and section 3 presents the model we estimate. Section 4 highlights the data and the econometric model. Results and energy forecasts are are reported in section 5. Section 6 concludes.

Theoretical Model

The Solow-Swan growth model is modified to allow for the transmission of technological knowledge across national borders. The standard neoclassical model assumes a closed economy and an exogenous constant saving rate to predict that countries converge to their own steady states determined by levels of accumulation and the depreciation rate. However, in addition to having different accumulation rates, economies also differ in levels of technology. This introduces the possibility that flows of technology may present an additional opportunity for growth. Thus, adoption of technology from abroad is one possible mechanism through which the capital stock of a nation increases, as better technology improves the productivity of the existing stock of capital. Figure 5 in Appendix 1 gives a graphical representation of this model; the difference from the standard Solow model can be seen in the fact that adoption of technology from abroad reduces the rate of effective depreciation, which leads to higher growth.

We are thus replacing the closed-economy nature of the traditional Solow-Swan model by a partially open economy. This will potentially affect a nation's steady state and transitional dynamics. Our results are similar to those derived for capital and labor mobility (i.e., that mobility tends to speed up an economy's convergence toward its steady state, and such technology flows might augment the level of that steady state).

A Model with Technology Adoption

Our estimation will build on the standard neoclassical model with a Cobb-Douglas production function

$$Q_{it}=A_{it}K_{it}^{ß1}L_{it}^{ß2}H_{it}^{ß3},$$

where output Q depends on technology A, physical capital stock K, employment L, and human capital H (Mankiw, Romer, & Weil, 1992). All countries are represented by i, i=1,...,N, in each time period t, t=1,...,T. We use the common specification of the evolution of exogenous world technology and number of workers so that

$$A_{it}=A_{iO}e^{\gamma t}$$

$$L_{it}=L_{iO}e^{nt}$$

We include human capital as a factor of production, but other authors have shown how it might affect the growth process through different channels. Several possibilities have been suggested (Benhabib & Spiegel, 1994; Kyriacou, 1992). We consider the human capital growth rate in our derivation, but we also include its level in the estimation.

The only difference from the standard model appears in our equation for the evolution of capital. The capital evolution depends on an exogenous saving rate, the depreciation rate, and a technology catch-up term, $\xi\ (T,T^{w})$, so that

$$K_{it}=sQ_{it}-\delta\ K_{it}+\xi\ (T,T^{w})_{it}K_{it}$$

It is worthwhile to point out the difference to models of purely disembodied technical change. These models specify capital evolution as $\partial\ K_{it} / \partial\ t = sQ_{it} - \delta\ K_{it}$ so that the stock K_t can be interpreted as new-machine equivalents implied by the stream of past investments (and δ is the weight that transforms each vintage investment into new-machine equivalents). We assume, in contradistinction, that new investment might also embody differences in technical design. Thus a new "machine" may be more efficient than an old "machine" even if there is no difference in physical capacity. The standard capital evolution equation will then tend to understate the true productivity of the capital stock. In our setup, technology from abroad may make the existing and new capital stock more productive and therefore increase the capital stock (capital is measured in efficiency units). We specify the catch-up term as a logarithmic function of the inverse ratio of labor productivity, $Y_i = (Q_{it} / L_{it})$, to the "desired" level of labor productivity, Y_i^{*}, which may differ between countries $\xi_{it}\ (T, T^{W})_{it} = \rho_i \ln(Y^{*}_{i,t-1} / Y_{i,t-1})$.

Using a desired level of labor productivity reflects our belief that all countries are not able to obtain the same level of productivity. For example, the Latin American nations may not be able to adopt the entire technology gap between themselves and the U.S. because of institutional inefficiencies.

Log linearizing and differencing the production function and substituting for the growth rate of capital yields that the growth rate of per worker output depends on the growth of factor inputs as well as the productivity gap,

$$y_{it} = \varphi + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 h_{it} + \rho_i [\ln Y^*_{i,t-1} - \ln Y_{i,t-1}],$$

where $\rho_i = \beta_{1\theta i}$ is the country-specific technology adoption rate and $\phi = (\gamma - \beta_1 \delta)$ is net exogenous technology growth.

Next, in an attempt to capture some of Abramovitz's (1986) ideas of "social capabilities," we suggest that in addition to economies' varied abilities to adopt the technology gap, they may also differ in ability to recognize or use the available technology. To incorporate this into the model, we include a term that acts to reduce the available technology gap to economies. The term used is similar to what frontier production literature refers to as "efficiency"; we refer to it in the same way. It is understood that this term captures much more than mere production slack, as it encompasses the institutional framework, adjustment costs, international openness, and so forth. So, to account for varied institutional rigidities, we postulate that the desired or maximum level of labor productivity, controlling for institutional features, is some fraction of the leader's productivity, and that the fraction is determined by the nation's level of inefficiency

$$Y^*_{it} = \frac{Y^L_t}{E_{it}} \Rightarrow \ln Y^*_{it} = \ln Y^L_t - \ln E_{it},$$

where Y_t^L is the leader's labor productivity and E_{it} is the inefficiency parameter. Substituting into equation (1) and rearranging yields the equation that we estimate

$$y_{it} = \varphi + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 h_{it} + \rho_i [\ln Y^*_{i,t-1} - \ln Y_{i,t-1}],$$

That is, the growth rate of GDP per worker for country i depends on the rate of growth of factor inputs, the common rate of exogenous technological change minus capital depreciation, country-specific inefficiency, and the technology gap between the leader and the follower countries lagged one period. Interpretation of the parameters are straightforward: β_1 ,β_2, β_3 show the elasticity of per worker GDP to a change in the growth of factor inputs; ρ_i , is the adoption of available technology from abroad and the (estimated) inefficiency measure; $\rho_i \ln E_{i,t-1}$, shows the reduction in growth of labor productivity due to political and social factors that reduces the available technology gap.

The key to this model is that it allows for countries to either leap ahead or fall behind since countries may differ in both technology adoption rates and inefficiency levels. Figures 1-4 in Appendix 1 show various simulations of this model. Figure 1 is the standard neoclassical model, where the marginal product of capital leads to convergence of output levels. Figures 2 and 3 show the effect of different adoption rates and inefficiency levels. Our technology catch-up term leads to initially higher rates of growth depending on the catch-up parameters, but in the end it is the familiar diminishing marginal product of capital that closes the gap. Figure 4 depicts three possible follower-country convergence paths.

Data and Econometric Model

Data

For the empirical estimation we predominantly use variables from the Summers and Heston data set (Penn World Tables Mark 5.6). Number of workers is the labor variable. The number of workers was found by multiplying each nation’s population by its labor force participation rate. For physical capital growth we use the share of investment in output as a proxy. The rate of growth of depreciated capital stock is missing for several nations and time periods, so its use was not possible. Implicit in the use of this proxy is that the capital-output ratios are constant across time and countries since

$$k_{it} = \frac{K_{i,t-1} - I_{i,t-1}}{K_{i,t-1}} \cong \frac{I_{i,t-1}}{K_{i,t-1}} = \frac{I_{i,t-1}}{Y_{i,t-1}} \cdot \frac{Y_{i,t-1}}{K_{i,t-1}},$$

so that if $Y_{i,t-1}$ /$K_{i,t-1}$ is constant for all i and t, the growth rate of physical capital will be proportional to the investment ratio. If this is true, then we have

where z is a constant. This is an assumption that finds validation in Dowrick and Nguyen (1989) for the OECD sample and Oroczo, Hultberg, and Sickles (1996) for the Latin American countries as well. The risk is that there is a systematic relation between capital intensity and level of output. If poorer nations have a lower capital intensity, a fixed investment share will have greater proportional effect on the capital stock (Dowrick & Nguyen, 1989). This assumption could overstate country heterogeneities because we do not allow countries to move along their isoquants. However, this chapter focuses on the technological change aspect of growth as in Abramovitz (1986) and Baumol (1986), which should not be seriously affected by the constant capital-output assumption since the technological change argument concerns country isoquants’ differentiated rate of contraction toward the origin. Also, we do not allow the factor shares to vary over time and across countries. Thus we assume that countries cannot vary their technology, which may introduce misspecification into the model.

For the human capital variable, we use the percentage share of total population that attained secondary education from Barro and Lee (1993). We use secondary schooling instead of primary education since many countries in the sample are likely to have reached their upper limits for primary education.

Econometric Issues

Before discussing the statistical analysis used in the estimation, we wish to explain why we choose to use panel data. Most of the empirical convergence literature has used cross-country data, but lately the literature has moved towards the use of panel data. Panel data have some very desirable attributes. For example, a panel data formulation supports all the steady state arguments made in the cross-country literature and is in fact more appropriate since it assumes that the accumulation rates are constant over a shorter time period. Also, the fact that we can control for unobservable individual country effects when using panel data should create a cleaner relationship between the included economic variables. Pooled data provide more information, more variability, less multicollinearity among the variables, more degrees of freedom, and more efficiency (see Baltagi, 1995). In addition the panel can identify and measure effects that are not observable in pure cross-sections or pure time-series data. Another issue is whether the individual effects should be considered as fixed or random. In a random effects framework the effects are assumed to be uncorrelated with the exogenous variables included in the model. In our case this is not an appropriate assumption. The fact that such correlation exists is a further argument for the use of panel data.

A problem with ordinary least squares (OLS) estimation is that we have a lagged dependent variable on the right-hand side of the estimable equation, a problem common to economic relationships that are dynamic in nature. The problem is that since y_{it} is a function of the disturbance, $y_{i,t-1}$ must also be a function of the disturbance; that is, a right-hand side regressor is correlated with the error term. This implies in general that OLS is biased and inconsistent. So for the typical panel where N is large and T is fixed, the within (least squares dummy variables [LSDV]) estimator will be biased and inconsistent. It will be consistent if T goes to infinity, but this is not likely in a panel data.

Several solutions for this problem have been suggested in the econometric literature (see Baltagi, 1995, for an overview). The obvious way to remove the problem is to use an instrumental variable technique. For example, Arellano and Bond (1991) argue that to get a consistent estimate of lagged dependent variable for large N and finiteT, one needs to (a) first difference to eliminate the individual effects and (b) use lagged differences or levels as instruments. This is straightforward: the problem, in our estimation, is that we want to leave the individual effects. Further, Ahn and Schmidt (1993) point out that there are additional moment conditions that are ignored by the IV estimators suggested by

Arellano and Bond. Ahn and Schmidt therefore suggest a GMM estimator. Their GMM estimation is asymptotically equivalent to Chamberlain's (1982, 1984) optimal minimum distance (MD) estimator. This is something that is important for our results because Islam (1995) compares the MD estimator with LSDV in a Monte Carlo study using the same data set that we are using. Islam's result is that the LSDV, although it is consistent in the direction of T only, actually performs very well. We thus use Islam's simulation results as the motivation for our LSDV estimation.

Results

Extended Least Squares Dummy Variable

We estimate our new model as described above using a fixed effect panel data estimator in order to capture the inevitable country heterogeneity due to political and social institutions. The results of these estimations are given in Table 1 and contrasted to the estimation using initial income as an explanatory variable. Including fixed effects lead to highly significant results for almost all countries (with the exception of the Netherlands and Mexico). When considering the three regions separately, a different regional heterogeneity ranking is obtained. However, the change in estimated fixed effects is accompanied by technology adoption rates of different magnitudes across the three regions. This indicates that fixed effects may pick up the countries' different abilities to incorporate new technology as well.

Table 1

Least Squares Dummy Variable, 5-Year Pooled Data

	Using Initial Income				Using Technology Gap			
	All	EU	EA	LA	All	EU	EA	LA
Const.	2.821	2.693	2.727	3.903	-0.264	0.009	-0.325	-0.139
	(0.268)	(0.289)	(0.509)	(0.619)	(0.094)	(0.075)	(0.147)	(0.184)
Inv/gdp	0.015	0.007	0.019	(0.017	0.015	0.005	0.018	0.018
	(0.002)	(0.002)	(0.004)	(0.004)	(0.002)	(0.002)	(0.003)	(0.004)
Empl.	-0.506	-0582	-0.291	-0.621	-0.311	-0.366	-0.268	0.102
	(0.250)	(0.265)	(0.492)	(0.488)	(0.259)	(0.280)	(0.468)	(0.530)
H.C.	0.002	0.001	0.003	0.001	0.001	-0.001	0.001	-0.007
	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)	(0.001)	(0.004)	(0.005)
Lngdp0	-0.301	-0.269	-0.304	-0.408				
	(0.029)	(0.030)	(0.058)	(0.064)				
Gap0					0.409	0.380	0.371	0.583
					(0.038)	(0.043)	(0.064)	(0.087)
EU	-0.154	-0.126			-0.232	-0.211		
EA	-0.297		-0/309		-0.512		-0.463	
LA	-0.235			-0.381	-0.412			-0.828
R2	0.65	0.81	0.68	0.53	0.66	0.80	0.71	0.57
F	6.93	13.57	5.31	3.79	7.15	13.28	6.15	4.27
P	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000

To explore whether the fixed effects in fact contain the ability of nations to adopt new technology, we estimate the model using an extension of the LSDV methodology. In particular, we allow one slope coefficient (the technology adoption parameter) to vary across countries and regions (Cornwell, Schmidt, & Sickles, 1990). We thus estimate both adoption speeds and "inherent" inefficiency levels as country-specific parameters. The added fixed effect (whether 5-year or annual pooling is used) yields highly significant negative coefficients for all countries, confirming our hypothesis that the U.S. is the productivity leader in our sample(s).

We test whether adoption rates differ across countries by including an interactive dummy variable for each country’s technology gap. This produces two general results for the 5-year pooled data: approximately half of the fixed effects become insignificant at 5%, and only two of the 38 different slope coefficients are statistically significant. For the annual data the results are even less significant. Furthermore, several adoption rate parameters are nonsensical, being either negative or greater than one. We attribute the weakness of these results to the reduced degree of freedom stemming from insufficient data points. We can, however, reject the hypothesis that all technology adoption rates are the same at the 5% significance level.

Our previous results suggest that the Latin American adoption rate might be greater than the other two major regions (see gap 0 in Table 1). If we include an interactive regional dummy, we can indeed reject the equality of Latin America’s adoption rate with that of Europe and East Asia at the 99% significance level. However, we are unable to reject the equality of Europe’s and East Asia’s adoption rates. When considering the regions separately, we also reject the equality of adoption rates of all Latin American countries but cannot reject the equality for both European and East Asian countries at any standard level of significance. Thus there is some evidence of heterogeneity of adoption rates for Latin American countries. However, considering individual countries once again produces nonsensical results. We choose to consider only a separate technology adoption rate for the three regions, our main goal being to contrast the three regions and not individual countries.

Technology Adoption Rates

The results for 5-year adoption rates are Europe, 0.367; East Asia, 0.322; and Latin America, 0.597. That is, before considering institutional inefficiencies, Europe closes 36.7% of the initial technology gap every 5 years. The numbers indicate that Latin America has been more successful at adopting foreign technology than Europe and East Asia—a perhaps surprising result. However, recall that we have separated out the technology adoption that presumably is included in the growth of physical and human capital. Also, we can speculate that Latin America has adopted technology faster than Europe because it might be further behind, and that "older" technologies might be easier to adopt than new production techniques. This does not, however, explain why Latin America has a greater adoption rate than East Asia. Perhaps, again we are speculating, East Asia’s technology adoption is to a larger degree embodied in new capital, and the large amount of foreign direct investment to Latin America might have contributed significantly to the region’s technology adoption. The amount of foreign direct investment is less for the East Asian countries.

To test the robustness of these measures we estimate the model using annual data as well. The annual results are also significant, except for East Asia. It is also for East Asia that the annual results differ from the 5-year panel results

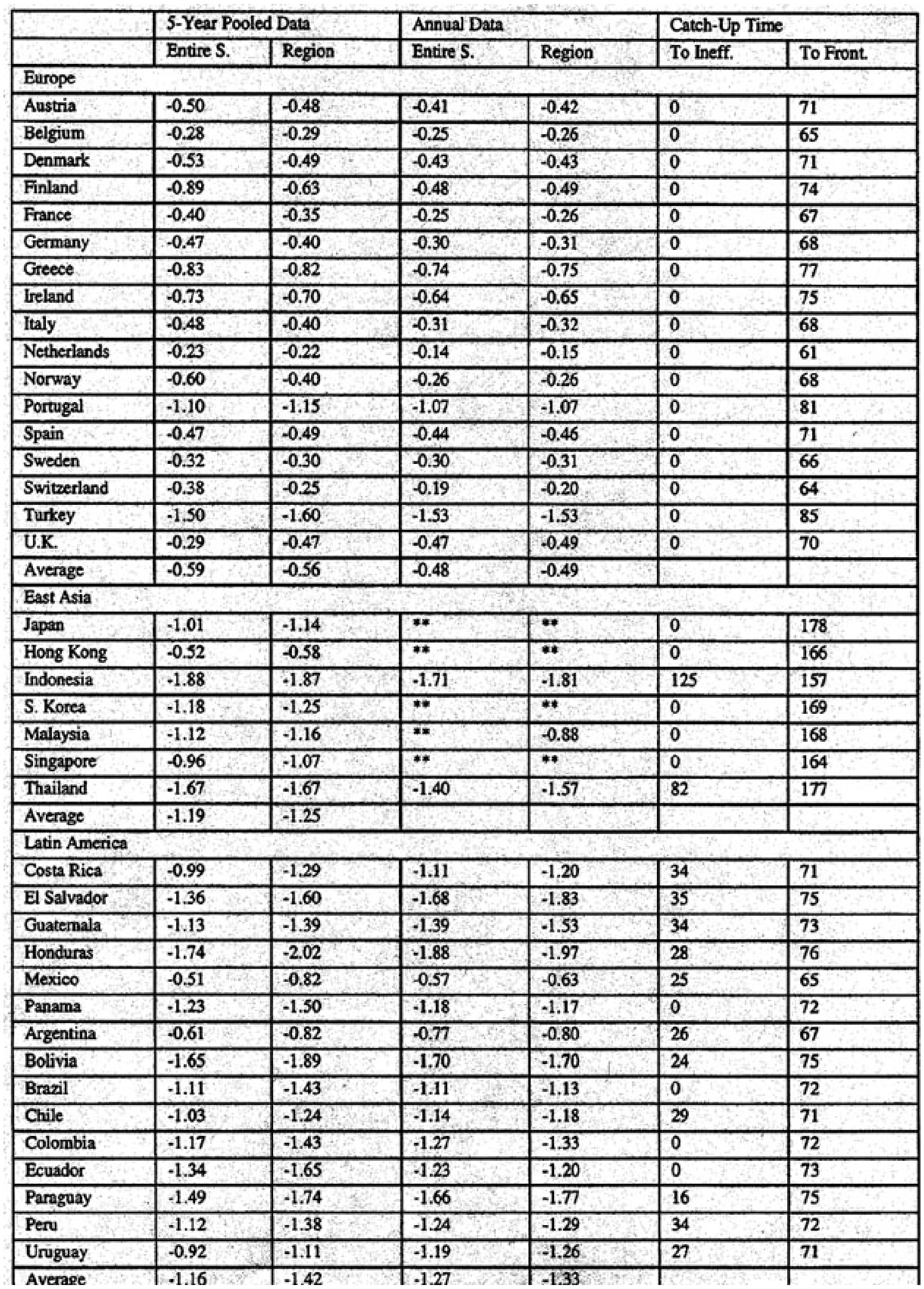
Efficiency

Next we explore the inefficiency of the follower nations; i.e., the negative effect on the potential technology gap stenuning frorn inefficient social and institutional factors. Efficiency is found by dividing nation's estimated fixed effect by the regional adoption rate.

The first two columns of Table 2 show the efficiency measures for all the countries and by regions, using 5-year pooled data, the last two columns use annual data. The efficiency measures are similar across different sample estimations with a minimum correlation of 0.94. Efficiency, as we define it, is quite robust to different estimations and samples. Furthermore, the relative efficiencies of the nations within regions appear to conform to common beliefs. For example, in Europe, the Netherlands, Belgium and Switzerland are the most efficient while Turkey, Portugal and Greece are the least efficient. In East Asia, Hong Kong is the most efficient while Indonesia and Thailand are the least efficient. Finally, in Latin America, Mexico and Argentina are at the top and Honduras and Bolivia at the bottom. 22

Another way to discuss our findings is to consider the time required to catch-up. We calculate the required time period until the nations reach their frontier when only the catch-up term and inefficiency are allowed to vary across regions and countries. We consider two possible frontiers, first the nations' inefficiency frontier which is reached when its inefficiency reduced productivity gap is closed, and secondly, the leader nation's frontier which is obtained once the productivity of the leader is reached. The latter requires that the inefficiency levels fade away in time which we assume occurs at the rate of p. The results are given in Table 2. The European countries, with the exception of Turkey, 0 seem to have reached their inefficiency reduced frontier. The same is true for most of the East Asian countries. Thus, these nations will not catch-up with the U.S. without higher accumulation rates or improved efficiency. For Latin America, most countries are still catching up with their inefficiency frontier, so that if accumulation rates were the same, catch-up would still take place through diffusion of technology. Of course, if inefficiency levels remain, then a follower could never completely catch-up with the leader by taking advantage of the technology gap alone. The last column in Table 3 shows the required time to catch-up with the leader if inefficiency levels were improving at the rate p. Europe and Latin America would then approach the frontier faster than East Asia on account of East Asia's lower rate of technology adoption. This begs the question of what determines these inefficiencies. Hultberg, Nadiri and Sickles(1997) consider whether the estimated inefficiencies are determined by the nations' social and political institutions. They use an econometric approach in which inefficiencies are regressed against variables that relate to government policies [social and political rights, political stability and bureaucratic efficiency], openness to trade and levels of education. The findings are that inefficient nations do in fact have "bad" institutions; that is, these nations have restricted social and political rights, are politically unstable and lack in bureaucratic efficiency. The results for openness and education are less clear, but they do affect inefficiency in the predicted direction.

Table 2. Efficiency and Catch-Up



	5-Year Pooled Data		Annual Data		Catch-Up Time	
	Entire S.	Region	Entire S.	Region	To Ineff.	To Front.
Europe						
Austria	-0.50	-0.48	-0.41	-0.42	0	71
Belgium	-0.28	-0.29	-0.25	-0.26	0	65
Denmark	-0.53	-0.49	-0.43	-0.43	0	71
Finland	-0.89	-0.63	-0.48	-0.49	0	74
France	-0.40	-0.35	-0.25	-0.26	0	67
Germany	-0.47	-0.40	-0.30	-0.31	0	68
Greece	-0.83	-0.82	-0.74	-0.75	0	77
Ireland	-0.73	-0.70	-0.64	-0.65	0	75
Italy	-0.48	-0.40	-0.31	-0.32	0	68
Netherlands	-0.23	-0.22	-0.14	-0.15	0	61
Norway	-0.60	-0.40	-0.26	-0.26	0	68
Portugal	-1.10	-1.15	-1.07	-1.07	0	81
Spain	-0.47	-0.49	-0.44	-0.46	0	71
Sweden	-0.32	-0.30	-0.30	-0.31	0	66
Switzerland	-0.38	-0.25	-0.19	-0.20	0	64
Turkey	-1.50	-1.60	-1.53	-1.53	0	85
U.K.	-0.29	-0.47	-0.47	-0.49	0	70
Average	-0.59	-0.56	-0.48	-0.49		
East Asia						
Japan	-1.01	-1.14	**	**	0	178
Hong Kong	-0.52	-0.58	**	**	0	166
Indonesia	-1.88	-1.87	-1.71	-1.81	125	157
S. Korea	-1.18	-1.25	**	**	0	169
Malaysia	-1.12	-1.16	**	-0.88	0	168
Singapore	-0.96	-1.07	**	**	0	164
Thailand	-1.67	-1.67	-1.40	-1.57	82	177
Average	-1.19	-1.25				
Latin America						
Costa Rica	-0.99	-1.29	-1.11	-1.20	34	71
El Salvador	-1.36	-1.60	-1.68	-1.83	35	75
Guatemala	-1.13	-1.39	-1.39	-1.53	34	73
Honduras	-1.74	-2.02	-1.88	-1.97	28	76
Mexico	-0.51	-0.82	-0.57	-0.63	25	65
Panama	-1.23	-1.50	-1.18	-1.17	0	72
Argentina	-0.61	-0.82	-0.77	-0.80	26	67
Bolivia	-1.65	-1.89	-1.70	-1.70	24	75
Brazil	-1.11	-1.43	-1.11	-1.13	0	72
Chile	-1.03	-1.24	-1.14	-1.18	29	71
Colombia	-1.17	-1.43	-1.27	-1.33	0	72
Ecuador	-1.34	-1.65	-1.23	-1.20	0	73
Paraguay	-1.49	-1.74	-1.66	-1.77	16	75
Peru	-1.12	-1.38	-1.24	-1.29	34	72
Uruguay	-0.92	-1.11	-1.19	-1.26	27	71
Average	-1.16	-1.42	-1.27	-1.33		

Forecasting World Energy Demand

We utilize the estimates above to forecast energy consumption by assuming that the rest of the world's per capita energy consumption levels are catching up with the United States. Forecasts are prepared with the following method. Using the U.S. per capita energy consumption data as the frontier, growth rate of per capita consumption of each of the countries is computed with previously determined catch-up time. Population growth rates are based on World Bank estimates and enable us to construct a projection of future populations. The forecast of total energy is carried out for every 5-year period using 1994 as the base year. We assume that U.S. energy consumption is growing at its population growth rate in order to maintain constancy in its per capita energy consumption. World energy consumption is the sum of the consumption of all of the countries in the above table and that of the United States. Comparisons of per capita consumption and total consumption of the U.S. versus the world indicates that per consumption of the world is upward sloping and is converging to the frontier country, the United States. The temporal pattern of total energy consumption is consistent with the implications of convergence in that the world's total energy consumption is growing at a faster rate than that in the United States. We can decompose the major components of energy demand in our convergence-based forecasts. Consumption of petroleum products in the various countries used in our forecasts is based on Energy Balances of OECD Countries, 1994-1995 and Energy Statistics and Balances of non-OECD Countries, 1994-1995 (OECD Paris, 1997a, 1997b). Catch-up time is used to forecast the consumption of petroleum products as with the forecasts of total energy consumption in coal equivalents. We summarize our forecasts at the regional and world level and the estimates from the U.S. Department of Energy's Energy Information Administration in Tables 3 and 4. These show remarkable overlap. Clearly our modeling effort has succeeded in closely replicating the forecasts from the Department of Energy, an agency of the federal government with substantially more resources than those devoted to our modeling exercise.

Forecasts for the year 2005 and 2010 reveal that if production from non-OPEC provinces continues to grow at a rate commensurate with expansion seen over the past decade, the amount of oil from the Middle East needed to meet rising world oil demand requirements could be significantly reduced. Non-OPEC production has expanded by 1-1.5% per annum on average since 1988 through a combination of technological advances in drilling systems and unearthing new basins in South America in deep water and elsewhere. Should this trend continue, non-OPEC production would likely reach 54 million b/d by 2005 and 58 million b/d by 2010 including rising Caspian Basin production.

Under this moderate non-OPEC expansion scenario, oil markets could be expected to be oversupplied by 2005-2010 under both high- and low-demand growth cases. The period is likely to witness a substantial increase in the amount of production capacity that will have to be shut in by OPEC or other producers to defend even moderate price levels. Under this scenario, Caspian Basin oil production will not be critical for maintaining moderate oil prices for at least another decade, assuming, as seems reasonable, that historically persistent competition continues within OPEC.

The above conclusion is illustrated in Table 6 (Table 5 shows the low-growth forceasts), which projects anticipated production levels for various players in the international oil market under a moderate production growth scenario that matches historical trends for price and rate of capacity expansion. The non-OPEC figures assume that non-OPEC growth will continue at 1.4% per annum, the rate of the past decade, and provide a forecast of non-OPEC production of 54 million b/d in 2005 and 58 million b/d in 2010. By adding government-projected outputs for OPEC countries, it is possible to illustrate the overall surplus between OPEC’s production goal and the volume of OPEC oil necessary to balance supply with demand. The discrepancy between the two, as expressed in the line for the residual share left for Saudi Arabia, serves as a measure of market oversupply. It can be assumed that Saudi Arabia will want to produce at levels similar to the 1997 base case or some amount above that level. In many cases shown, Saudi Arabia’s residual share is indicated as a negative number or a number substantially below the 8.7 million b/d that the kingdom is producing today. This result implies that under many scenarios, Saudi Arabia and other Persian Gulf producers will have to shut in significant volumes of production capacity to balance supply with demand and defend oil price levels.

However, in a high-demand scenario where oil use rises by 3% per annum between 2000 and 2010, subtracting Caspian oil would lead to a significant tightening of oil markets from current levels. In other words, rising exports from the Caspian Basin could play a significant role as a marginal supplier in arresting a jump in the price of oil under conditions of strong oil demand and high growth.

The implications of this forecast for oil producers seeking to raise output between 2005 and 2010 are relatively pessimistic. Under a scenario where oil demand growth reaches 80 million b/d in 2005 and 89 million b/d in 2010, oil markets could wind up oversupplied by a wide margin. For example, the residual share for Saudi Arabia is negative in all scenarios, including those where increases in production from the Caspian Basin are assumed to be zero. Such an outcome will obviously not occur. However, the analysis suggests that Saudi Arabia and other members of OPEC will have to shut in significant volumes of productive capacity—ranging from 12 million b/d to 15 million b/d—to balance supply with demand in 2005 and 2010 under a moderate non-OPEC growth scenario. By comparison, OPEC only has around 1 to 2 million b/d a day of production capacity shut in at present.

Under a low non-OPEC growth scenario forecast by the U.S. Department of Energy, OPEC would have to shut in between 5 to 7 million b/d of capacity, except under the high-growth scenario for 2010, where emerging production from the Caspian Basin is set to zero. Under this high-growth scenario, OPEC can get by shutting in an incremental 2 million b/d. This forecast also indicates that maintenance of moderate prices is feasible for the period between 2005 and 2010 even if a major non-OPEC province is removed. In other words, under the convergence forecast scenario and other scenarios, Caspian Basin production will not be critical for maintaining moderate oil prices for at least another decade, assuming, as seems reasonable, that historically persistent competition continues within OPEC.

Conclusions

In closing, we note that performing growth accounting with only the common factors of production is not sufficient to explain the growth process. This may not be true in the long run, if we define the "long run" as the point when technology has diffused to all nations and countries’ rates of growth are only functions of input accumulation. However, this steady state story does not hold presently, as countries are different in levels of technology. We therefore see a need to model these heterogeneities.

Our model contains three growth effects in addition to varying accumulation rates. Each nation is faced with a technology gap approximated by the difference to the leader in per worker output, which can increase the productivity of capital. This is interpreted as the catching-up potential described in Abramovitz (1986). Also, we include heterogeneous absorption capacities and adoption rates in the growth. Thus a nation might not take advantage of the catch-up potential if it either fails to adopt foreign technology or technology absorption is seriously compromised due to the nation’s level of inefficiency. The new model provides a mechanism for explaining why some countries forge ahead and others fall behind while maintaining all the steady state predictions of the neoclassical model.

Estimations of our model yields results comparable to previous research as well as significant country heterogeneities and regional adoption rates. For example, Europe, Latin America, and East Asia faced on average a technology gap of 0.58, 1.34 and 1.65, respectively, over the 1960-85 period. Including adoption rate and inefficiencies, the net annual growth effect is roughly 0.5% for Europe, 0.6% for Latin America, and 2.0% for East Asia. Hence, East Asia has taken advantage of its catch-up potential even with its low technology adoption rates, while Europe and Latin America have done less well.

Also, East Asia, together with Europe, had high accumulation rates, while Latin America struggled in this aspect as well.

Another way to discuss our findings is in terms of catch-up times. We found the required times for the nations to catch up with both their inefficiency frontiers and to the leader's frontier, the latter requiring declining inefficiency levels. We found that Europe and East Asia have mostly caught up with their inefficiency frontiers, while Latin America is still approaching theirs. Thus, unless Europe and East Asia reduce their inefficiency levels, they must rely on higher accumulation rates to continue to catch up with the United States.

We have used these heterogeneous catch-up times to benchmark the rates of growth of different countries within the world economy to the standard of energy intensity used in the Unites States. Based on the hypothesis that countries within the world economy are converging to the energy intensive production technology utilized in the Unites States we have constructed forecasts of energy use and have decomposed these into specific demand forecasts for oil demand. These are found to be in close agreement with those generated from the Department of Energy's Energy Information Agency.

Our forecasts show that world oil demand will grow to 80 million b/d by 2005 and 89 million b/d by 2010, up from 65.6 million b/d in our base year of 1994. The implications of this forecast for oil producers seeking to raise output between 2005 and 2010 is relatively pessimistic. Given projections for the rise in oil production from countries OPEC, oil markets could wind up oversupplied by a large margin. OPEC or some other coalition of countries will likely have to shut in a significant portion of their productive capacity to balance available supply to the world's requirement for oil consumption. Energy security is enhanced in markets where there is considerable competition within and without OPEC, and where large amounts of shut-in productive capacity exists.

Notes

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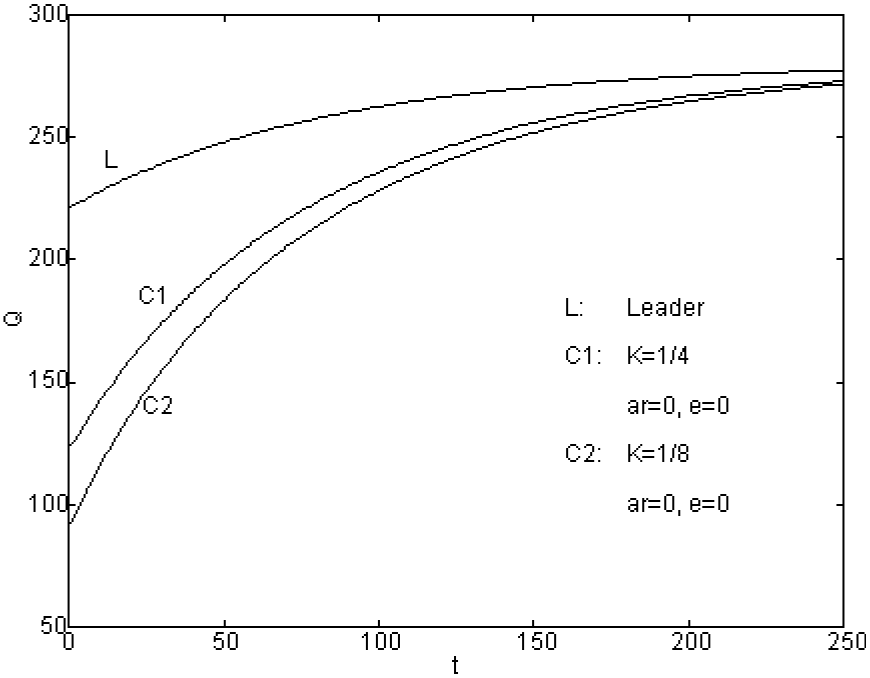
Appendix 1

Figure 1. Simulations of Growth Paths: Neoclassical Model



The fact that the convergence time will be identical to the Solow-Swan model, but that the convergence path is very different can be seen if our model is simulated (see Figures 2, 3, 4 and 5). The simulations show the effect on the convergence path when an economy does or does not adopt technology when we assume identical steady states for all economies (i.e. identical saving rates). Figure 2 shows a simulation of the traditional Solow-Swan model using three economies which differ in initial capital stock, while

Figure 3 shows the effect of different adoption rates and Figure 4 shows the effect of differing inefficiency levels. Figure 5 adds technology adoption to one of the follower countries and assumes that the income leader is also the technological leader. We see that this changes the convergence paths dramatically without changing the economies' steady states. However, although the same steady state is reached, the economy which adopts technology will have a higher level of income at any point in time until the steady state is reached.

Figure 2. Simulations of Growth Paths: Different Adoption Rates

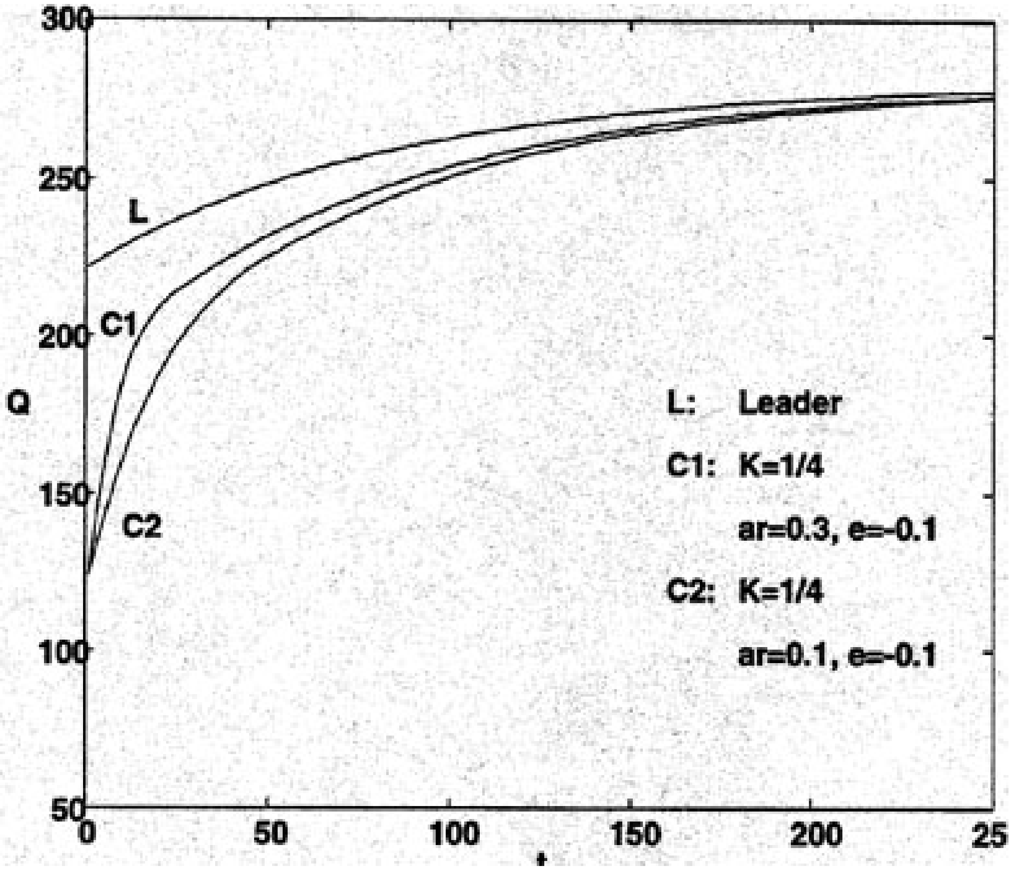


Figure 3. Simulations of Growth Paths: Different Inefficiency Levels

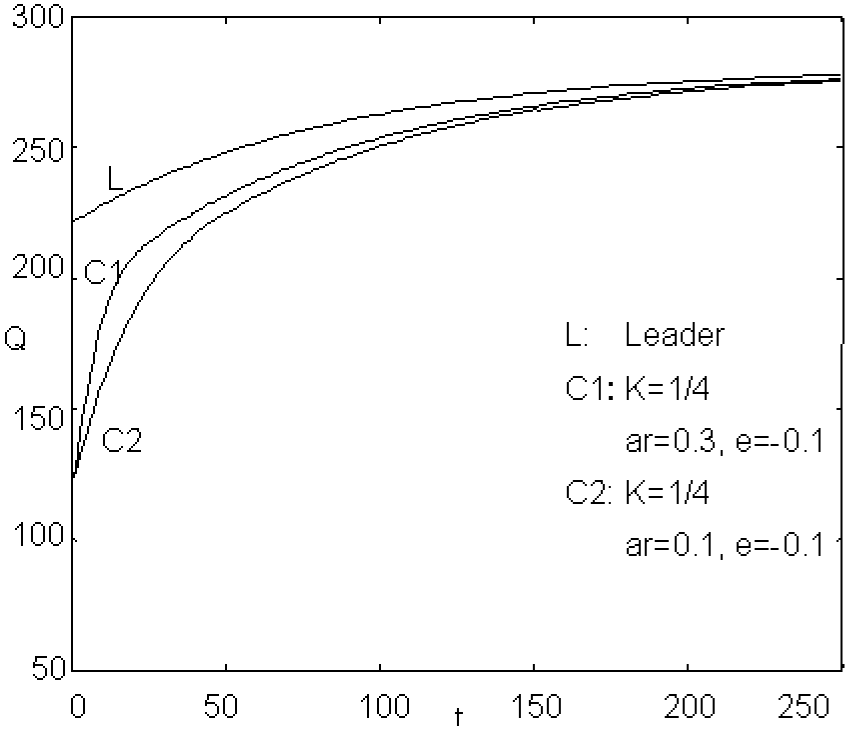


Figure 4. Simulations of Growth Paths: Leapfrogging

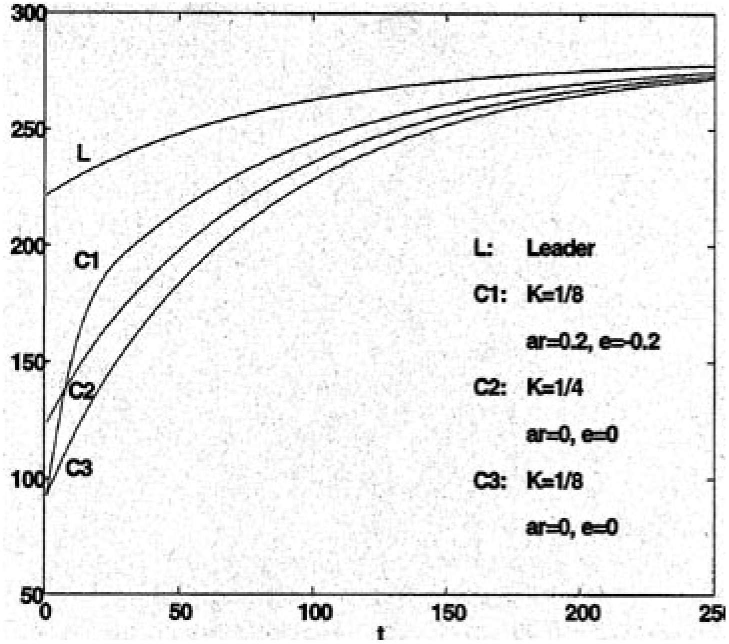
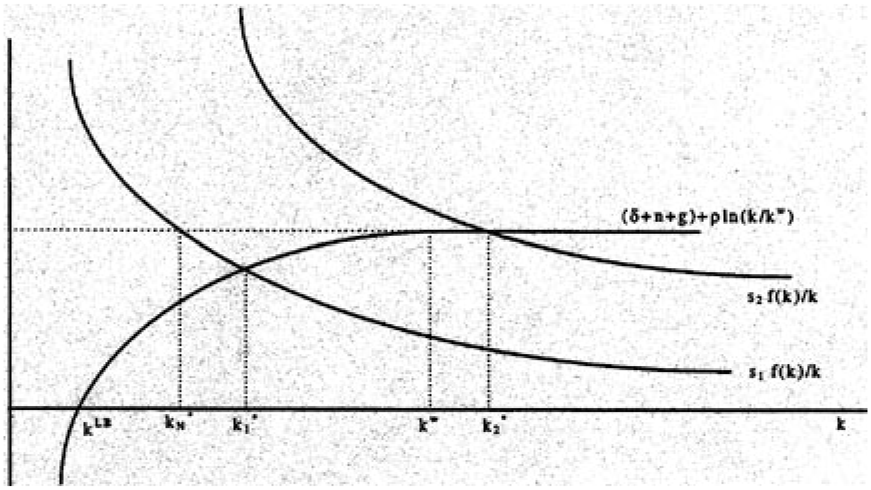


Figure 5. Basic Growth Diagram



Appendix 2

Table 3

World Total Oil Consumption by Region

(Forecasts Based on Convergence in World Per Capita Energy

Use To U. S. 1997 Levels-Million Barrels per Day)

Region	History			Projections				Average Annual Percent Change, 1994-2015
		1994		2000	2005	2010	2015	
Western Europe		13.3		14.9	16.3	18.1	20.1	2.4
Asia		16.9		18.7	20.8	23.1	25.8	2.5
EE/FSU		6.1		6.5	7.0	7.6	8.2	1.6
Africa/Rest of World		6.0		6.4	7.4	8.3	9.3	2.6
Western Hemisphere		23.4		25.8	28.6	31.9	35.8	2.5
Total World		65.6		72.4	80.1	89.0	99.3	2.4

Table 4

World Total Oil Consumption by Region

(Forecasts Based on Energy Information Administration-Million Barrels per Day)

Region/Country	History			Projections				Average Annual Percent Change, 1995-2015
	1990	1994	1995	2000	2005	2010	2015	
Industrialized								
North America	20.4	21.3	21.3	23.4	25.1	26.4	27.4	1.3
United States[a]	17.0	17.7	17.7	19.4	20.7	21.6	22.1	1.1
Canada	1.7	1.7	1.7	1.9	2.0	2.1	2.3	1.4
Mexico	1.7	1.8	1.8	2.1	2.4	2.7	3.0	2.6
Western Europe	12.9	13.6	13.9	14.3	14.8	15.1	15.4	0.5
Industrialized Asia	6.2	6.8	7.0	7.7	8.3	8.9	9.4	1.5
Japan	5.1	5.7	5.7	6.4	6.9	7.3	7.8	1.5
Australasia	1.0	1.2	1.3	1.3	1.4	1.6	1.7	1.4
Total Industrialized	39.5	41.7	42.2	45.4	48.2	50.4	52.3	1.1
EE/FSU								
Former Soviet Union	8.4	4.8	4.4	4.9	5.8	6.7	7.7	2.7
Eastern Europe	1.6	1.2	1.3	1.5	1.5	1.7	2.0	2.0
Total EE/FSU	10.0	6.1	5.8	6.4	7.3	8.5	9.6	2.6
Developing Countries								
Developing Asia	7.6	10.5	11.1	13.9	17.6	20.9	24.9	4.1
China	2.3	3.1	3.3	4.4	5.5	6.9	8.6	4.9
India	1.2	1.4	1.6	1.9	2.4	2.8	3.3	3.8
Other Asia	4.2	5.9	6.2	7.6	9.7	11.2	13.0	3.7
Middle East	3.4	3.9	4.1	4.4	4.9	5.4	6.0	1.9
Africa	2.1	2.3	2.3	3.1	3.6	4.0	4.4	3.2
Central and South America	3.4	3.8	3.9	4.7	5.6	6.5	7.5	3.3
Total Developing	16.5	20.5	21.4	26.0	31.7	36.8	42.7	3.5

Total World	66.0	68.3	69.4	77.8	87.2	95.6	104.6	2.1

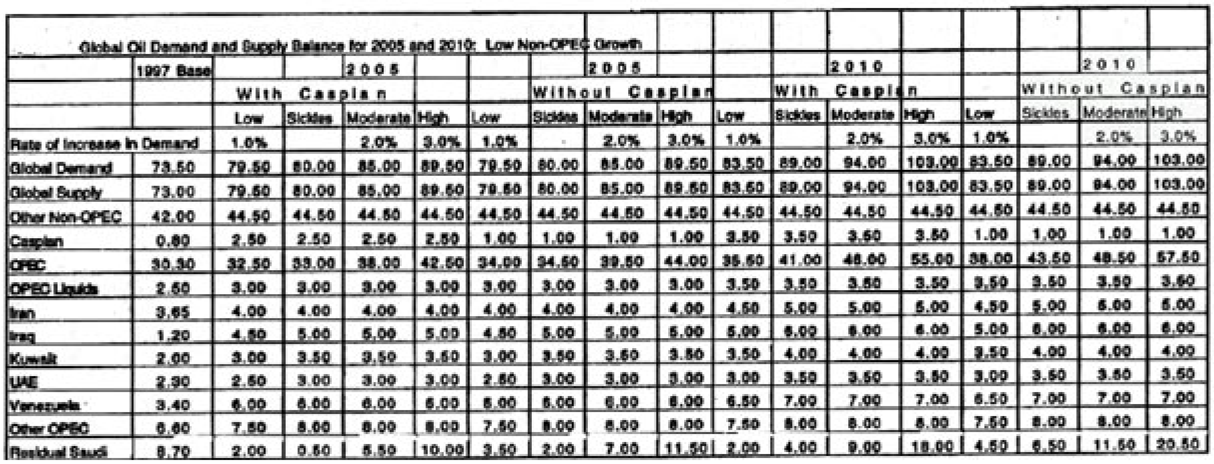
[a] Includes the 50 States and the District of Columbia. U.S. Territories are included in Australasia.

Notes: EE/FSU = Eastern Europe/Former Soviet Union. Totals may not equal sum of components due to independent rounding. The electricity portion of the national fuel consumption values consists of generation for domestic use plus an adjustment for electricity trade based on a fuel's share of total generation in the exporting country.

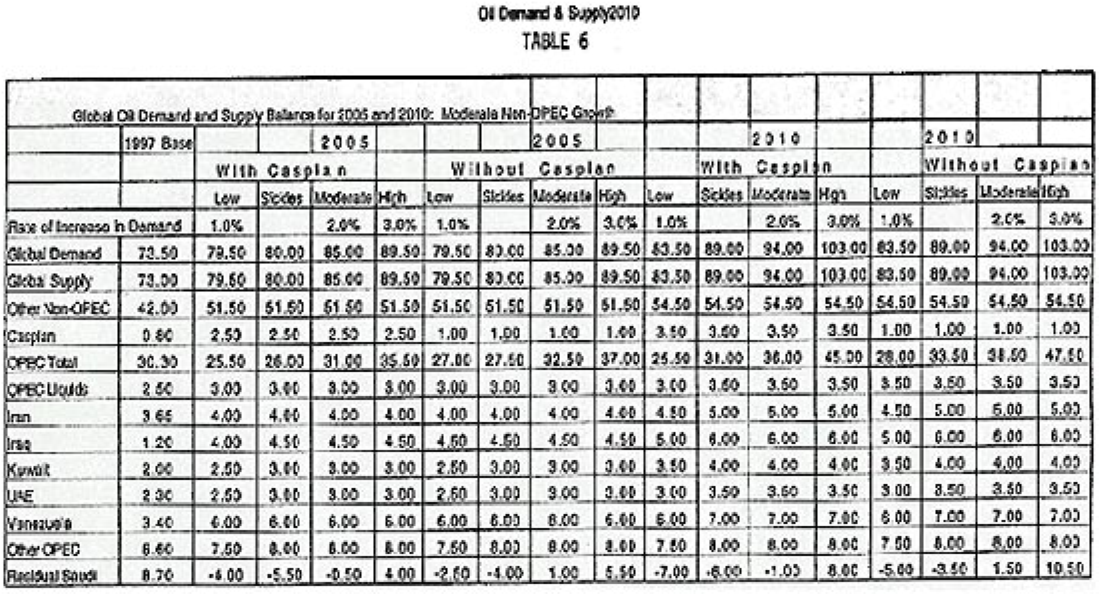
Sources: History: Energy Information Administration (EIA), International Energy Annual 1995, DOE/EIA-0219(95) (Washington, DC, December 1996). Projections: EIA, Annual Energy Outlook 1997, DOE/EIA-0383(97) (Washington, DC, December 1996), Table A21; and World Energy Projection System (1997).

Oil Demand & Supply

TABLE 5



Global Oil Demand and Supply Balance for 2005 and 2010: Low Non-OPEC Growth																	
	1997 Base	2005				2005				2010				2010			
		With Caspian				Without Caspian				With Caspian				Without Caspian			
		Low	Sickles	Moderate	High	Low	Sickles	Moderate	High	Low	Sickles	Moderate	High	Low	Sickles	Moderate	High
Rate of Increase in Demand		1.0%		2.0%	3.0%	1.0%		2.0%	3.0%	1.0%		2.0%	3.0%	1.0%		2.0%	3.0%
Global Demand	73.50	79.50	80.00	85.00	89.50	79.50	80.00	85.00	89.50	83.50	89.00	94.00	103.00	83.50	89.00	94.00	103.00
Global Supply	73.00	79.50	80.00	85.00	89.50	79.50	80.00	85.00	89.50	83.50	89.00	94.00	103.00	83.50	89.00	94.00	103.00
Other Non-OPEC	42.00	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Caspian	0.80	2.50	2.50	2.50	2.50	1.00	1.00	1.00	1.00	3.50	3.50	3.50	3.50	1.00	1.00	1.00	1.00
OPEC	30.30	32.50	33.00	38.00	42.50	34.00	34.50	39.50	44.00	35.50	41.00	46.00	55.00	38.00	43.50	48.50	57.50
OPEC Liquids	2.50	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Iran	3.65	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.50	5.00	5.00	5.00	4.50	5.00	5.00	5.00
Iraq	1.20	4.50	5.00	5.00	5.00	4.50	5.00	5.00	5.00	5.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00
Kuwait	2.00	3.00	3.50	3.50	3.50	3.00	3.50	3.50	3.50	3.50	4.00	4.00	4.00	3.50	4.00	4.00	4.00
UAE	2.30	2.50	3.00	3.00	3.00	2.50	3.00	3.00	3.00	3.00	3.50	3.50	3.50	3.00	3.50	3.50	3.50
Venezuela	3.40	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.50	7.00	7.00	7.00	6.50	7.00	7.00	7.00
Other OPEC	6.60	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00
Residual Saudi	8.70	2.00	0.50	5.50	10.00	3.50	2.00	7.00	11.50	2.00	4.00	9.00	18.00	4.50	6.50	11.50	20.50



Oil Demand & Supply2010

TABLE 6

Global Oil Demand and Supply Balance for 2005 and 2010: Moderate Non-OPEC Growth

	1997 Base	2005								2010							
		With Caspian				Without Caspian				With Caspian				Without Caspian			
		Low	Sickles	Moderate	High	Low	Sickles	Moderate	High	Low	Sickles	Moderate	High	Low	Sickles	Moderate	High
Rate of Increase in Demand		1.0%		2.0%	3.0%	1.0%		2.0%	3.0%	1.0%		2.0%	3.0%	1.0%		2.0%	3.0%
Global Demand	73.50	79.50	80.00	85.00	89.50	79.50	80.00	85.00	89.50	83.50	89.00	94.00	103.00	83.50	89.00	94.00	103.00
Global Supply	73.00	79.50	80.00	85.00	89.50	79.50	80.00	85.00	89.50	83.50	89.00	94.00	103.00	83.50	89.00	94.00	103.00
Other Non-OPEC	42.00	51.50	51.50	51.50	51.50	51.50	51.50	51.50	51.50	54.50	54.50	54.50	54.50	54.50	54.50	54.50	54.50
Caspian	0.80	2.50	2.50	2.50	2.50	1.00	1.00	1.00	1.00	3.50	3.50	3.50	3.50	1.00	1.00	1.00	1.00
OPEC Total	30.30	25.50	26.00	31.00	35.50	27.00	27.50	32.50	37.00	25.50	31.00	36.00	45.00	28.00	33.50	38.50	47.50
OPEC Liquids	2.50	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Iran	3.65	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.50	5.00	5.00	5.00	4.50	5.00	5.00	5.00
Iraq	1.20	4.00	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00
Kuwait	2.00	2.50	3.00	3.00	3.00	2.50	3.00	3.00	3.00	3.50	4.00	4.00	4.00	3.50	4.00	4.00	4.00
UAE	2.30	2.50	3.00	3.00	3.00	2.50	3.00	3.00	3.00	3.00	3.50	3.50	3.50	3.00	3.50	3.50	3.50
Venezuela	3.40	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00
Other OPEC	6.60	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00	7.50	8.00	8.00	8.00
Residual Saudi	8.70	-4.00	-5.50	-0.50	4.00	-2.50	-4.00	1.00	5.50	-7.00	-6.00	-1.00	8.00	-5.00	-3.50	1.50	10.50

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