Shale oil and gas booms: Consequences for agricultural and biofuel industries

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Abstract

This paper examines and quantifies the consequences of increases in supplies of oil and gas from shale resources for the US economy and its agricultural and biofuel industries using a computable general equilibrium modeling framework under alternative economic conditions and emissions reduction policies. It shows that increases in supplies of oil and gas from shale resources generate enormous gains for the US economy. The question is do we use it all for higher economic growth or do we allocate part of it for reducing future global warming. This paper shows that we can sacrifice about 43% of the gains to reduce GHG emissions by 27%. Finally, the results of this paper indicate that in the presence of shale resources elimination of biofuel mandates negatively affect biofuels and crop industries. However, the impact is not huge because using shale resources increases national income and that generates a higher demand for food (including livestock product) which eventually prevents a big fall in demand for crops.

Key Words: Shale Resources, Biofuels, Agriculture, General Equilibrium, Emissions Reduction.

1. Introductions

In recent years supplies of oil and gas from shale resources have significantly increased in the US. The Department of Energy projections [1] indicate that producing energy from shale resources will continue to grow in decades to come. These projections suggest that by 2030 North America will be self-sufficient in petroleum. Recently, a limited number of studies have examined the economic and environmental consequences of using shale resources for the US economy [2-6]. However, none of these studies have examined the implications of oil shale resources on the US energy market for the agricultural and biofuel industries.

The consequences of producing energy from shale resources for US agriculture will not be limited to savings in costs of energy and fertilizer. Producing energy from shale resources has the potential to negatively affect the profitability of producing biofuels from agricultural resources and curb supply of these types of biofuels. This can reduce demands for agricultural products. Today, about 40% of US corn (27% net of by-product credits) and 24% US soybean oil (4.4 % of the soybean crop since oil is about 18.3%) are used for ethanol and biodiesel. Any reduction in demand for these biofuels would negatively affect demand from feedstock for biofuel production. On the other hand producing energy from shale resources has the potential to increase national income, improve employment, and generate higher demand for food products which eventually lead to more demand for agricultural commodities. This can eliminate the negative impacts of reduction in demand for feedstock for biofuels. The impacts of producing energy from shale resources can vary with changes in government policies as well. For example, massive production of energy from shale resources could reduce public supports for biofuels mandates. In this case biofuel and crop industries will suffer more. On the other hand producing more natural gas from shale resources could increase public interests in more aggressive environmental policies to cut greenhouse gas emissions.

This paper examines and quantifies the consequences of increases in supplies of oil and gas from shale resources for the US economy and its agricultural and biofuel industries using a computable general equilibrium modeling framework under alternative economic conditions and environmental regulation policies.

This paper has three main objectives. First, we provide an estimate of the impacts of availability of the shale technology to the US economy. Our base case is the economy without shale resources but with the Renewable Fuel Standard (RFS). Then, we shock the model for the availability of the shale oil and gas resources. Thus, the first objective is to estimate the impacts of shale oil and gas. The second objective is to estimate what would happen with the shale oil and gas resources but with the RFS repealed. Third, we combine the shale oil and gas gains with a set of possible environmental policies that would help reduce the adverse environmental impacts of increased fossil fuel usage. Here, we refer to policies aimed at reducing greenhouse gas (GHG) emissions. The first policy is a carbon tax applied to the entire economy. In the US, at least in the near term, it is not likely that a carbon tax will be implemented. Therefore, we also apply a set of policies aimed at reducing emissions in the electric power and transportations sectors.

At present, the US has a Corporate Average Fuel Economy Standard (CAFE) that takes fleet fuel economy from 27.5 miles per gallon (MPG) today to 54 MPG by 2025. This is a huge change in fuel economy and therefore would imply a very large reduction in emissions in the transportation sector. In addition, the US has a policy of significantly reducing GHG emissions from the electricity sector. Under this policy, essentially no new coal fueled power plants will be constructed, and many older plants will be phased out. The electricity and transportation sectors are the major GHG emitters in the US with 40 and 34 percent of total emissions respectively [7].

Thus it is understandable that these sectors would be targeted by current US policy. The combined goal of the existing regulatory policies (including the average fleet efficiency (CAFE) standard, RFS, and clean energy standard (CES) for electricity is to reduce CO_2 emissions in 2035 by 26.5%, compared to 2007 [8]. Here we focus on electricity and transportation because the RFS has a much smaller impact than the other policies.

2. Research Methodology

The modeling framework used in this paper is an advanced version of the computable general equilibrium model developed by Taheripour, Sarica, and Tyner (Henceforth: TST) [6, 9]. These authors made major modifications in the original GTAP-E model developed at Purdue University [10, 11] to examine the economic and environmental impacts of using shale oil and gas resources. Details of the data base modifications are provided in Appendix A, while the GTAP-E model modifications are provided in Appendix B. While the modeling framework developed by TST has several advantages over its original version, it does not cover production and consumption of biofuels produced from agricultural resources. Following Taheripour et al. [12], Hertel et al. [13], and other related work in this area, we introduced biofuels into the TST modeling framework and its data base [14] which represents the world economy in 2007 to incorporate interactions between agriculture, biofuel, and traditional fossil fuel industries in our economic and environmental analyses.

Using the improved model and the DOE [1] projections on expansions in supplies of oil and gas from shale resources for the time period of 2007-35, several experiments are developed in this paper. These experiments quantify the consequences of increases in supplies of oil and gas for biofuel and agricultural industries under alternative demand structures for biofuels in the presence and absence of emission reduction policies and targets.

3. Experiments and their results

As mentioned above, we will be presenting the results of four cases in this paper:

- Case 1: Expansion of shale oil and gas resources with no change in RFS or environmental policy,
- Case 2: Shale expansion with repeal of the RFS, meaning biofuels enter on a market basis only,
- Case 3: Shale expansion with no RFS and an economy wide carbon tax,
- Case 4: Shale expansion with no RFS and a carbon tax equivalent applied only in the electricity and transportation sectors. In real world, the implementation of this policy would be through emissions reduction mandates, but in this practice we model the policy as a tax carbon tax with the same quantitative impact in emission reductions.

For cases 3-4, the emission reduction level in 2035 is targeted to be 26.5% less than 2007.

Table 1 provides the overall economic impact on the US economy for each of the four cases. In case 1, GDP increases 2.4% due to the shale oil and gas boom. That increase falls a bit when the RFS is eliminated due to a drop in employment with the elimination of the RFS (due to the flexible employment closure used in this analysis). The carbon tax case (3) results in an increase in GDP of 1.3%, a bit over half as large as the case with the shale expansion alone. Finally, the regulatory case (4) results in an even smaller GDP increase of 1.1%. The welfare increases follow similar patterns as GDP with welfare increasing $326 billion in case 1, but only $187 billion in case 3, and $160 billion in case four. Thus the carbon tax case reduces the shale oil and gas welfare gain by 43%. Alternatively, we can retain 57% of the shale oil and gas welfare gain yet at the same time reduce GHG emissions by 27%. The regulatory case causes welfare gain to fall about $26 billion, which can be viewed as the cost of taking the regulatory approach instead of the more efficient economy wide carbon tax.

While welfare increases for the US, the results (not shown here) for other regions are mixed, but follow expected patterns. The biggest gain outside the US is in the EU where welfare increased 6, 4, 13, and 10 billion dollars for cases 1-4 respectively. Welfare increases are higher in the emissions reductions cases because the EU is assumed not to have either the strong carbon tax or regulatory policies. The largest losses, as would be expected are in the Middle East North Africa region where welfare falls 9, 6, 11, and 9 billion dollars for the four cases respectively. While the welfare drop is higher for the emissions control cases, the difference is not as large as it is for the EU. This region loses markets regardless of the policy set in place. The changes in other regions were much smaller.

Table 1. Changes in Welfare and GDP for the Four Cases

Description	Case 1	Case 2	Case 3	Case 4
% Change in GDP at 2007 constant prices	2.38	2.21	1.25	1.08
Welfare change (mil.$)	325,723	301,975	186,525	160,193

Table 2, 3, and 4 provide some basic results for key commodities for the four cases. Percentage changes in quantity and price and changes in net trade are included in these tables. We will review the results case by case. Case 1 adds the shale oil and gas to the base case with RFS. The oil and gas quantities increased 31 and 39% in all four cases, which was the level of the shock. Coal production decreased a bit as would be expected. Electricity production increased 2.4% and price fell 1.2% due to the less expensive natural gas and economic growth.

There are small positive quantity changes especially for grain, livestock, food and chemical industry. Those changes are driven by the higher income levels due to the shale oil and gas expansion. The prices of oil and gas fall, and there were quite modest price increases for most of the other commodities driven again largely by the economic gain from the shale oil and gas. In conclusion, in the presence of RFS, the expansion in shale oil and gas generates higher demand for grains, food, and livestock products and that leads to small positive impacts on output of US agriculture. The higher demand for agricultural output increases commodity and food prices slightly (see Table 3).

Table 2. Changes in sectoral outputs
(Average of 2007-35 compared with 2007)

Commodity	Case 1	Case 2	Case 3	Case 4
Grains	0.28	-4.67	-5.09	-5.25
Oilseeds	-0.05	-1.91	-1.90	-1.89
Livestock	1.60	1.76	1.00	1.01
Food	1.77	1.78	0.99	0.96
Coal	-1.29	-1.73	-34.27	-37.55
Oil	30.80	30.80	30.80	30.80
Gas	38.90	38.90	38.90	38.90
Biodiesel	0.00	-32.57	-30.49	-33.31
Ethanol	0.00	-33.00	-32.55	-35.67
Electricity	2.43	1.70	-4.92	-7.88
Chemical Ind.	0.86	0.63	-1.17	-0.81

There were large increases in net exports of oil and gas, as would be expected. There is no biofuel trade in the model, so no change there. There is a large decrease in net exports of the chemical industry, largely to feed the economic growth associated with the shale boom. There was also a decrease in agricultural commodity and food net exports because of the economic growth and higher domestic demand for these products.

There are somewhat different results for case 2, which is removal of the RFS. The biggest change is that biodiesel and ethanol production each fall by about one-third. Production of grains, oilseeds, and coal all fall, while livestock and food increase modestly. Electricity increase falls to 1.7%. The price decreases for oil and gas are similar to case 1. Food went up 0.45% in case 1, and the increase falls to 0.22% in case 2 due to the elimination of the RFS demand for food commodities. Ethanol and biodiesel prices went up modestly in case 1, and they fall modestly in case 2. Chemical industry output falls in case 2 relative to case one largely because of the decline in fertilizer use for corn production.

These results of case 2 indicate that the elimination of RFS negatively affect outputs of biofuels and crop industries. However, in this case the livestock and food industries gains. While the RFS removal negatively affects crop industries, the overall impact is not large because using shale resources increases income and that generates a higher demand for food which prevents a big fall in demand for crops.

Table 3. Percent changes in prices
(Average of 2007-35 compared with 2007)

Commodity	Case 1	Case 2	Case 3	Case 4
Grains	0.46	-1.30	-1.19	-1.75
Oilseeds	0.67	-0.65	-0.78	-1.07
Livestock	0.64	-0.15	-0.10	-0.43
Food	0.45	0.22	0.40	0.16
Coal	0.30	0.21	-4.18	-4.98
Oil	-7.77	-6.97	-8.74	-7.95
Gas	-11.30	-11.29	-12.68	-11.64
Biodiesel	0.55	-0.40	0.06	0.01

Ethanol	0.27	-0.47	1.19	1.44
Electricity	-1.24	-1.27	8.40	11.31
Chemical Ind.	-0.04	-0.04	0.50	0.30

Case 3 is the carbon tax and no RFS. Most of the quantity results were similar to case 2 except for coal production, which fell by about a third. Oil and gas prices fall more in case 3 than in case 2 because of the reduction in income induced by the carbon tax. Coal prices fall 4%. Electricity production falls 4.9% and price increases 8.4% due to the carbon tax. Net exports of coal, oil, and gas increase considerably in case 3, again due to the reduced economic expansion induced by the carbon tax. Grain exports increase, and food exports decrease less than in case 2. Electricity net exports fall in both cases 3 and 4 because trading partners have less expensive electricity.

Table 4. Changes in trade balances: Million $)
(Average of 2007-35 compared with 2007)

Commodity	Case 1	Case 2	Case 3	Case 4
Grains	-372.07	231.03	220.75	426.84
Oilseeds	-196.13	14.58	64.11	111.80
Livestock	-236.50	-109.03	-59.30	-2.09
Food	-3418.56	-2761.88	-2454.53	-1713.21
Coal	-192.03	-166.32	836.31	1030.59
Oil	21760.02	14986.93	31360.81	24575.01
Gas	34554.61	34860.18	43739.89	37409.79
Biodiesel	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00
Electricity	-14.75	3.42	-1069.99	-1317.89
Chemical Ind.	-8990.90	-7644.78	-10634.30	-7526.36

Finally, case 4 is the combined set of regulatory policies in the transportation and electricity sectors. These policies reduce GHG emissions the same percentage as the carbon tax in case 3, but all the reductions are forced on these two sectors. Electricity production falls 7.9% while electricity price increases 11.9%. Both of these changes are larger than case 3 because more of the emissions reduction is forced on the electricity sector. Coal and biofuel consumption falls even more in this case than in cases 2 or 3. Most price changes are fairly similar to the previous cases. Oil and gas net export changes are more than cases 1 and 2 but less than case 3. Coal, grain, oilseed, and livestock net export changes are higher in this case than any other. Food and chemical industry net exports fall less in this case than any other.

4. Conclusions

Now we turn to some closer examination of key differences among the four policy alternatives. In all cases there is a welfare gain for the US economy. For the shale expansion only, the gain is on average $326 billion/year. In the other three cases there is a lower economic gain, but the difference is small for case 2, which is elimination of the RFS. In cases 3 and 4 the economic gains are considerably smaller, but there is also a substantial gain in reduction in GHG emissions. Clearly the carbon tax is the most efficient means of accomplishing that GHG reduction. Case 4 with all the reduction coming from transportation and electricity costs the US economy about $26 billion/year compared with the carbon tax approach. As would be expected, an economy-wide carbon tax that spreads the cost of emission reductions and achieves the reductions at lowest cost to the economy is the most efficient.

Coal and electricity output and prices are significantly impacted by the policy differences. With shale expansion alone electricity output actually grows a bit while price declines. For coal there is almost no change with shale expansion alone. The big changes, of course, occur with the emission policy implementations. Electricity output declines, and price increases under both policy options with the largest changes under the policy targeted at electricity and transportation exclusively, and the smallest for the economy-wide carbon tax. Interestingly, oil and natural gas prices decline about the same under all policy measures. Basically, the decline in income would depress prices, but the emission's policies would increase them, so the two effects basically offset each other. Most of the other price and quantity changes move in the directions one would expect.

Equally interesting, though, is that policies that welcome shale oil and gas development and at the same time cause substantial reduction in GHG emissions still result in a substantial welfare and GDP gain for the economy. In a sense, we can more than pay for the reduction in GHG emissions with the economic gains from shale oil and gas. Of course, some will argue that we should forego the shale oil and gas and achieve the GHG reductions regardless of the cost to the economy. What we have attempted to do here is to highlight the alternative policy options and the consequences of each. The shale "dividend" is large. The question is do we use it all for higher economic growth or do we allocate part of it for reducing future global warming. In current lingo, do we "pay forward" to get a lower carbon economy with part of the gain from the shale boom?

Finally, the results of our simulations indicate that in the presence of shale resources elimination of RFS negatively affect biofuels and crop industries. However, in this case the livestock and food industries gains. While the RFS removal negatively affects crop industries, the impact is not large because using shale resources increases income and that generates a higher demand for food (including livestock product) which eventually prevents a big fall in demand for crops.

Appendix A

Modifications in GTAP data base version 8

The US shale gas boom is expected to cause major changes in energy markets at national and international level and affect the US and world economies, significantly. The GTAP-E model which is designed to analyze energy-economy-environment-trade linkages is an appropriate modeling framework to use in assessing the economic and environmental consequences of the expected expansion the US gas shale industry. In a preliminary work using a modified version of the GTAP-E model developed based on the GTAP data base version 8 we realized that the model does not provide sensible simulation results in response to the expected expansion in natural resources used in gas industry. Following a detective work we realized the GTAP data base version 8 suffers from major deficiencies in representing monetary values associated with the "gas" and "gdt" sectors and in particular ignores gas sales from "gas" to "gdt" for distribution. This Appendix outlines these deficiencies and implements several steps to fix them. In addition the GTAP version 8 does not explicitly represent production and consumption of biofuels. As explained in this appendix, we introduced biofuels into the data base.

A1. Production and distribution of GAS in GTAP database version 8

To examine the data base we begin with provided information on consumption and trade of "gas" and "gdt" in millions of tonnes of oil equivalent (Mtoe) as shown in Table A1. This table shows that the US consumption of gas (imported and domestic gas distributed by "gas" and "gdt" sectors and used by industries and households) was about 610.7 Mtoe in 2007. This figure is not very different from the corresponding figure reported by the DOE for this year, 596.2 Mtoe.

Table A1. Consumption of gas by industry and household in 2007 (Mtoe)

Description		Gas used by industry			Gas used by household			Total gas used		
		US	Non US	Total	US	Non US	Total	US	Non US	Total
Domestic	Gas	81.6	888.0	969.6	0.0	20.1	20.1	81.6	908.1	989.8
	Gdt	305.3	516.8	822.1	108.7	194.7	303.5	414.0	711.5	1125.5
Imported	Gas	109.2	484.5	593.7	0.0	55.0	55.0	109.2	539.4	648.7
	Gdt	1.0	59.2	60.2	4.7	39.3	44.1	5.8	98.5	104.3
Total		497.2	1948.3	2445.6	113.5	309.2	422.7	610.7	2257.6	2868.2

Source: GTAP data base headers obtained from CEDF, CEIF, CEDP, and CEIP headers.

This table also shows that about 113.5 Mtoe of the distributed gas in US in 2007 is used by households. Again this figure is not very different for the corresponding figure reported by the DOE (i.e. 121.9 Mtoe). These comparisons indicate that the GTAP data base fairly represents the amount of gas used in US. Since the source of GTAP on energy is IEA, we can trust GTAP figures on consumed gas for other regions as well. However, as explained later in this section, the GTAP data base does not appropriately represent values of gas produced and consumed. In addition it misrepresents the link between the “gas” and “gdt” sectors in the regional input-output (I-O) tables.

To determine the source of these issues consider now another aspect of the data on gas consumed in US as shown in Table A2. In this table the intermediate consumption of gas (sold either by “gas” or “gdt”) are divided into gas used by “gdt” and “non-gdt” sectors. This table shows that the “gdt” sector (as a gas using industry) is used 27.5 Mtoe gas. On the other hand this sector (i.e. “gdt”) sold 419.8 Mtoe of gas as a gas seller. Since “gdt” does not use resources to produce gas, this shows that transferred gas from “gas” sector to “gdt” sector is not included in the GTAP energy data in physical terms. Of course nothing is wrong here if we use this information to represent the net use of gas (as a source of energy) by sector. However, as it is evident from the GTAP regional I-O tables, if we use this data to measure the value of gas sold to the "gdt" sector in I-O tables, then the results will be misleading.

Table A2. US consumption of gas by major users in 2007 (Mtoe)

Description		Intermediate		Household	Total
		Used in gdt	Used in Non-gdt		
Domestic	gas	13.8	67.8	0.0	81.6
	gdt	9.9	295.4	108.7	414.0
Imported	gas	3.8	105.4	0.0	109.2
	gdt	0.0	1.0	4.7	5.8
Total		27.5	469.7	113.5	610.7

According to the GTAP data base the value of gas sold to "gdt" in US (VDFM + VIFM) in 2007 is about $4.8 billion. This is about the value of net gas used in "gdt" as a source of energy (27.5 Mtoe reported in Table A2). This indicates that the US I-O table is missing the value of gas transferred from "gas" to "gdt" for distribution. The I-O tables of other regions suffer from the similar deficiency as well. Because of this deficiency, the cost share of gas in the cost structure of "gdt" is negligible in many regions in the GTAP data base as shown in Table A3. This deficiency undermines the linkages between the "gas", "gdt", and other sectors and badly affects the credibility of GTAP simulation results in response to the expansion in gas industry.

The GTAP data base version 8 misrepresents the monetary value of gas used by households also. As shown in tables A1 and A2, the GTAP data base shows that US households used about 113.5 Mtoe gas (gas plus gdt) in 2007. This is not very different for the corresponding figure reported by the DOE. However, the GTAP data base shows that US households purchased about $30 billion gas (domestic plus imported "gas" and "gdt") in 2007, and this is very different from the corresponding reported value by DOE which is about $62 billion. This simple comparison shows that the GTAP data base badly underestimates values of gas used by households. Missing the value of gas transferred from "gas" to "gdt" causes this issue as well.

Table A3. Share of gas in the cost structure of "gdt" in GTAP data base version 8 by region

USA	EU27	BRAZIL	CAN	JAPAN
4.4	5.8	53.1	1.5	1.1
CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia
15.2	0.3	27.8	13	10.4
Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS
3.3	8.3	1.2	0.7	10.5
Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania	
5.7	3.8	9.9	11.3	

In addition to the above problems the split of gas between "gas" and "gdt" is counter intuitive. In general, the gas industry (including production and distribution) produces gas and sells it to major users such as power plants, major industries, commercial users, and households. In this process major users such as power plants and industries pay lower prices, and the commercial users and households pay a higher price. In general, the commercial and household users pay more because the distribution of gas through pipeline is costly. Now consider the implicit regional prices of gas sold by “gas” and “gdt” sectors, both obtained from the GTAP data base and presented in table A4. This table shows that the US implicit prices of gas sold by “gas” and “gdt” are about 304 $/toe and 269 $/toe with an average of 275 $/toe. According to the DOE data bases the US gas prices for household and power plants were about 507 $/toe and $283 $/toe, respectively, with an average of 359 $/toe in 2007. These figures show that the price of gas sold to households is much higher than the price of gas sold to power plants. But in GTAP the price of gas sold by “gas” is much higher than the price of gas sold by “gdt”. In addition, these figures indicate that the GTAP implicit average price of gas is significantly below the actual average price of gas in US. Table A4 shows that the relationship between the gas prices sold by “gas” and “gdt” in some regions (e.g. EU and Canada) is consistent with what we expect to observe.

In conclusion, the above analyses indicate that:

- The GTAP data base ignores the link between “gas” and “gdt” and does not capture the values of gas sold from “gas” to “gdt” for distribution,
- The GTAP data base underestimates gas values used by commercial firms and households,
- The “gas” and “gdt” sectors in GTAP do not properly represent the production and distribution of gas as they operate in world.

Since these issues could affect the GTAP simulation results we modify the GTAP data base as outlined in the next sections.

Table A5. Implicit prices of gas sold by “gas” and “gdt” (values are in $/toe)

Region	implicit price of gas sold by “gas”	implicit price of gas sold by “gdt”	Average implicit price of gas
USA	304.1	269.1	274.9
EU27	623.2	303.9	371.3
BRAZIL	169.7	172.5	170.7
CAN	509.2	216.1	468.4
JAPAN	310.3	310.3	310.3
CHIHKG	98.9	115.1	106.7
INDIA	236.2	236.3	236.3
C_C_Amer	318.0	198.4	249.8
S_o_Amer	106.0	71.2	90.4
E_Asia	123.7	416.8	237.9
Mala_Indo	685.5	222.6	419.3
R_SE_Asia	877.7	301.5	403.1
R_S_Asia	289.1	286.7	287.4
Russia	147.5	260.6	180.9
Oth_CEE_CIS	487.4	303.9	395.0
Oth_Europe	1475.7	396.1	1446.1
MEAS_NAfr	335.9	150.7	266.9
S_S_AFR	613.9	225.5	474.1
Oceania	496.1	235.2	369.5

A2. Corrections in gas and gdt sectors

Step 1: In this step we pooled the “gas” and “gdt” together and created a new sector which covers both production and distribution of gas. In addition, regions are aggregated to 19 categories following the GTAP-BIO model aggregation scheme. The FlexAgg program is used in this step.

Step 2: Then we made the following adjustment in the data base with the pooled gas and gdt activities:

a. The GTAP regional values of gas sold to commercial users (services) and households are corrected according and the available data. We used the *GTAPAdjust* program to introduce the corrected values in the data base and maintain its balances.
b. The modified gas sector is divided into two sectors of "Gas" and "Gas-D" so that the former sells gas to industries, and the latter sells gas to services and households. The *Split.com* program is used to accomplish this task.
c. The values of gas sold from "Gas" to Gas-D" in each region are estimated and included in the data base, again using the *GTAPAdjust* program.

The regional market values of gas sold by "Gas-D" inflated by 65% to represent the price difference between the price of gas for industries and commercial firms and household. The *GTAPAdjust* is used several times to handle this modification and reconstruct the cost structures of the new "Gas" and "Gas-D" sectors.

A3. Introducing biofuels in GTAP data base version 8

Table A6 represents the global production of biofuels in 2007 by 19 GTAP regions defined in this paper. We followed Taheripour et al. [15] and Tyner and Taheripour [16] to introduce biofuels into the data base version 8 .

Table A6. Global biofuel production in 2007

Regions	Ethanol	Biodiesel
USA	7.642	0.510
EU27	1.027	1.715
BRAZIL	5.930	0.096
CAN	0.222	0.023
JAPAN	0.029	0.000
CHIHKG	0.972	0.000
INDIA	0.550	0.029
C_C_Amer	0.016	0.000
S_o_Amer	0.059	0.121
E_Asia	0.000	0.000
Mala_Indo	0.069	0.150
R_SE_Asia	0.000	0.000
R_S_Asia	0.000	0.000
Russia	0.000	0.000
Oth_CEE_CIS	0.012	0.135
Oth_Europe	0.000	0.000
MEAS_NAfr	0.000	0.000
S_S_AFR	0.004	0.011
Oceania	0.026	0.080
Total	16.558	2.870

Appendix B

Modifications to the GTAP-E model

Firms' demand for energy items

As explained in TTS a major and direct substitution between coal and gas has been observed in firms' demand for energy in recent years. Given the expected expansion in gas resources, this phenomenon is anticipated to prevail in the future as well. To make the GTAP-E consistent with this recent phenomenon, we introduced a new nesting structure for firms' energy demand as presented in Figure B1. The production function associated with this nesting structure is presented in Table B1.

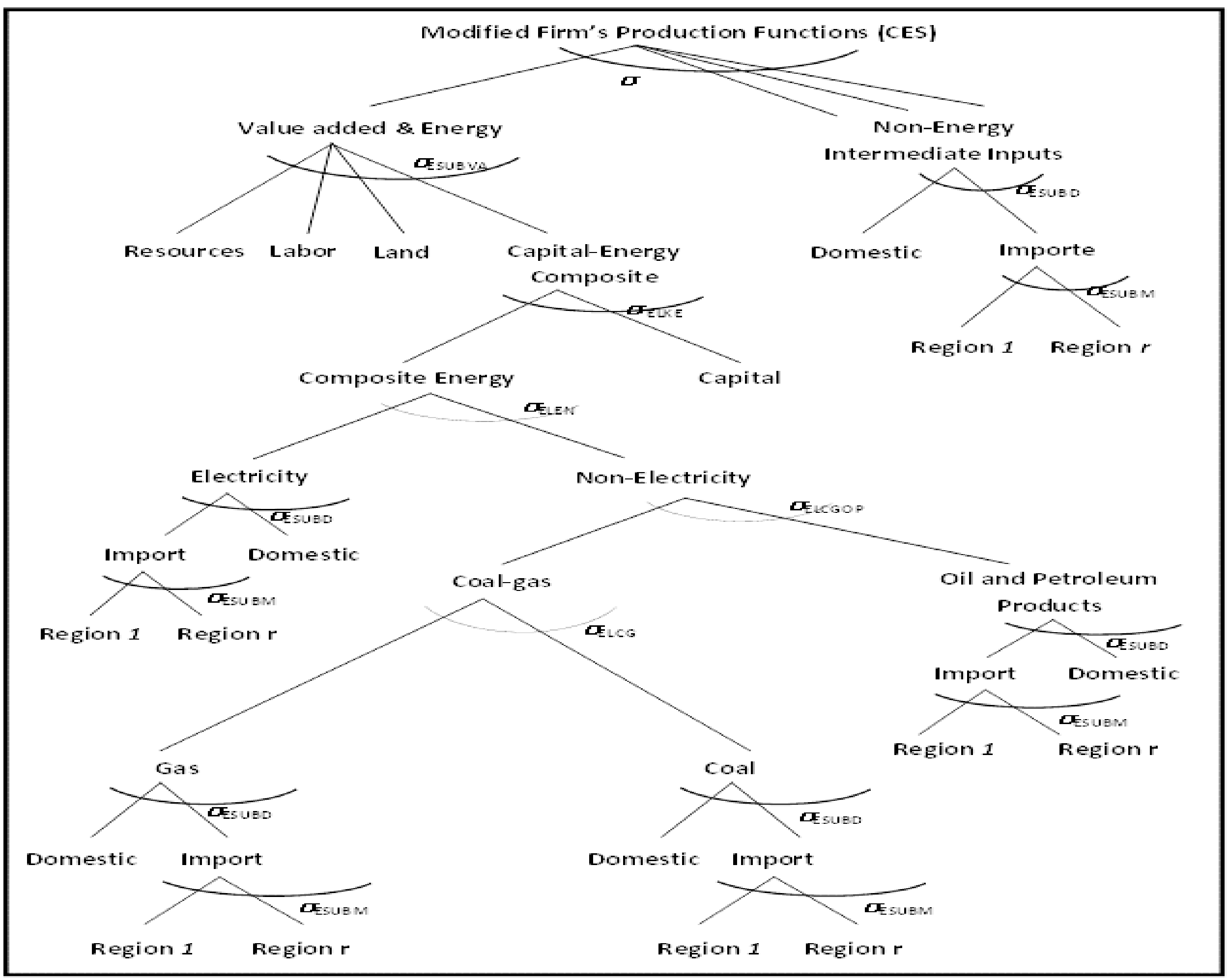

Table B1. A representative production function in modified GTAP-E model

Top nest	$Y = \left(\propto_{VE} VE^{(\frac{\sigma_1 - 1}{\sigma_1})} + \alpha_{NEI_1} NEI_1^{(\frac{\sigma_1 - 1}{\sigma_1})} + \cdots + \alpha_{NEI_n} NEI_n^{(\frac{\sigma_1 - 1}{\sigma_1})} \right)^{(\frac{\sigma_1}{\sigma_1 - 1})}$
	Where: $\propto_{VE} + \alpha_{NEI_1} + \cdots + \alpha_{NEI_n} = 1$ and $\sigma_1 = \sigma_{ESUBT}$
Value added and energy nest	$VE = \left(\alpha_R R^{(\frac{\sigma_2 - 1}{\sigma_2})} + \alpha_L L^{(\frac{\sigma_2 - 1}{\sigma_2})} + \alpha_M M^{(\frac{\sigma_2 - 1}{\sigma_2})} + \alpha_{KE} KE^{(\frac{\sigma_2 - 1}{\sigma_2})} \right)^{(\frac{\sigma_2}{\sigma_2 - 1})}$
	Where: $\alpha_R + \alpha_L + \alpha_M + \alpha_{KE} = 1$ and $\sigma_2 = \sigma_{ESUBVA}$
Capital and energy nest	$KE = \left(\propto_E E^{(\frac{\sigma_3 - 1}{\sigma_3})} + \alpha_K K^{(\frac{\sigma_3 - 1}{\sigma_3})} \right)^{(\frac{\sigma_3}{\sigma_3 - 1})}$
	Where: $\alpha_E + \alpha_K = 1$ and $\sigma_3 = \sigma_{ELKE}$
Energy nest	$E = \left(\propto_{EL} EL^{(\frac{\sigma_4 - 1}{\sigma_4})} + \alpha_{NEL} NEL^{(\frac{\sigma_4 - 1}{\sigma_4})} \right)^{(\frac{\sigma_4}{\sigma_4 - 1})}$
	Where: $\alpha_{EL} + \alpha_{NEL} = 1$ and $\sigma_4 = \sigma_{ELEN}$
Coal-Gas and Oil-Petroleum nest	$NEL = \left(\propto_{CG} CG^{(\frac{\sigma_5 - 1}{\sigma_5})} + \alpha_{OP} OP^{(\frac{\sigma_5 - 1}{\sigma_5})} \right)^{(\frac{\sigma_5}{\sigma_5 - 1})}$
	Where: $\alpha_{CG} + \alpha_{OP} = 1$ and $\sigma_5 = \sigma_{ELCGOP}$
Coal and gas nest	$CG = \left(\propto_C C^{(\frac{\sigma_6 - 1}{\sigma_6})} + \alpha_G G^{(\frac{\sigma_6 - 1}{\sigma_6})} \right)^{(\frac{\sigma_6}{\sigma_6 - 1})}$
	Where: $\alpha_C + \alpha_G = 1$ and $\sigma_6 = \sigma_{ELCG}$

Definitions: The variables and parameters used in the above equations are: α_i's represent share parameters; σ_i's show substitution elasticities; variables G, C, OP and EL demonstrate energy inputs including gas, coal, oil and petroleum products, and electricity, respectively; variables R, L, M, K stand for primary inputs including resources, labor, land, and capital, respectively; NEI_i's presents non-energy intermediate inputs; and finally Y is the final output.

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