Proceedings of the Seventh IASTED International Conference
POWER AND ENERGY SYSTEMS
August 29–31, 2007, Palma de Mallorca, Spain
ISBN Hardcopy: 978-0-88986-689-8 / CD: 978-0-88986-690-4

DETERMINANTS OF ENERGY SECTOR PERFORMANCE IN IRAQ, 2003 to 2005

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ABSTRACT
Rehabilitating the energy sector in Iraq has been a major objective of the Coalition from 2003 through 2005, with more than $5 billion in Iraqi, U.S. and other Coalition partner funds devoted to this effort. The energy sector rehabilitation program has focussed on three objectives: restoring Iraq's electricity and oil infrastructure and production to pre-war levels; delivering electricity and refined fuels for domestic consumption; and delivering electricity and oil security. The insurgency has attempted to limit Coalition success in meeting these three objectives. This study provides an analysis of the impact of Coalition efforts and insurgent activities on energy sector performance using time-series models. The study finds that while Coalition investments have significantly improved energy sector performance while insurgent attacks have significantly retarded energy sector progress.

KEY WORDS
Time-series models, least squares estimation, maximum likelihood estimation.

1. Introduction

Rehabilitating the oil sector and rebuilding energy security in Iraq has been a major objective of the Coalition from 2003 through 2005. More than $5 billion in Iraqi, U.S. and other Coalition partner funds have been devoted to this effort. The energy sector rehabilitation program has focussed on three objectives: restoring Iraq's electricity and oil infrastructure and production to pre-war levels; delivering electricity and refined fuels for domestic consumption; and delivering electricity and oil security. The insurgency has attempted to limit Coalition success in meeting these three objectives.

The nature, consequences and implications of the Iraqi insurgency have been examined in several recent papers. Cordesman [1] provides a comprehensive chronology of the conflict and lessons learned. He notes that insurgents can fight below the threshold of U.S. conventional force superiority and minimize their own costs while maximizing the costs to the US. Metz [2] argues that the U.S. made several miscalculations in planning for the occupation of Iraq. First, it underestimated the effort required to secure, stabilize and reconstruct Iraq; second, it overestimated Iraqis' abilities to govern themselves while underestimating the spread of crime and breakdown of order; third, it underestimated how long it would require before the presence of an occupying force would lead to violence. Beckett [3] compares the Iraqi insurgency with previous insurgencies in Palestine, Aden, Algeria and Lebanon. He states that key requirements for a successful counterinsurgency include the recognition of the need for a political and not just a military response and the need to address the grievances that led to the insurgency.

Hoffman [4] argues that Iraq is not a classical guerrilla war and fails to fit any of the criteria in the CIA's Analysis of Insurgency. Instead the insurgency may represent a new form of warfare with no clear leadership, no attempt to permanently gain and hold territory and no unifying ideology or political program. Ruvalcaba [5] notes that unlike conventional warfare, the Iraq war did not produce a formal surrender from any senior official of the former Ba'athist regime. This had substantial negative consequences when the Iraqi army was disbanded and thousands of former officers and enlisted men were left without a stable source of income, with poor short-term job prospects and with resentment towards the occupying force. Econometric studies of the impact of the insurgency in Iraq are still rare, but Tiedemann [6,7] examine the impact of the Iraqi insurgency on military and civilian casualties respectively, and these papers find that the elasticities of violent incidents, bombings, injuries and deaths with respect to Coalition force levels are large and negative, so that larger Coalition force levels would enhance Iraqi security.

Some early energy sector reports focussed on initial successes in restoring oil production and exports following the invasion. Hoyos and Morrison [8] noted that Iraq stepped back into the international market on June 4, 2003 by offering 10 million barrels of oil from storage at auction. Zorpette [9] provided a detailed analysis of successes and failures in re-engineering electricity infrastructure in Iraq. He noted that despite restoration of capacity to pre-war levels, demand substantially outstrips supply and that the sector faces major financial, technical, operational and maintenance challenges. Lenz noted that following early insurgent success in disrupting supplies, oil was at least temporarily flowing again by the end of June 2003 [10]. But attacks by insurgents continued on an on-going basis and Stockman [11] notes that some 300 major insurgent attacks have eroded the impact of U.S. investment in the Iraqi oil industry and reduced government revenues by $11 billion through January 2006.

The main official source of information on the reconstruction effort is the Quarterly Report on Measuring Stability and Security in Iraq published by the Department of Defence [12]. But some observers including Cordesman [13] have argued that the analysis provides a "fundamentally false picture of the political situation in Iraq", includes "economic analysis flawed to the point of absurdity" and offers "no meaningful analysis of oil developments, budget and revenue problems."

This purpose of this study is to provide a preliminary quantitative study of the impact of Coalition reconstruction efforts and insurgent activities on the reconstruction of the energy sector in Iraq using times-series models, estimated using both least squares and maximum likelihood methods. The models are fitted in double log form so that the regression coefficients have a natural interpretation as elasticities. Data used in the study comes from the detailed set of monthly time-series data for Iraq maintained by the Brookings Institution [14].

2. Model

We consider a simple three-equation model consisting of an insurgent attack equation (1), an investment equation (3), and a production function (5), where months are subscripted by m. Insurgent attacks (A_m) are positively related to insurgent force levels (I_m) through equation (1).

$$A_m = \gamma_1 (I_m)^{\delta} \quad (1)$$

Taking logs on both sides of (1), we have (2)

$$\log A_m = \log\gamma_1 + \delta \log(I_m) \quad (2)$$

To capture the slow initial start and then ramping up of foreign assistance, U.S. energy sector aid (S_m) is positively related to month through a linear spline (MS_m) that takes on the value zero for month one through eleven and then increases by one unit each month through month 30. The relationship between sector aid and the linear spline is given by equation (3).

$$S_m = \gamma_2 (MS_m)^{\lambda} \quad (3)$$

Taking logs on both sides of (3), we have (4)

$$\log S_m = \log\gamma_2 + \lambda \log(SM_m) \quad (4)$$

The production function for outputs or exports (P_m) is a Cobb-Douglas function in U.S. energy sector aid (S_m) and insurgent attacks (A_m), so that we have (5)

$$P_m = \gamma_3 (S_m)^{\alpha} (A_m)^{\beta} \quad (5)$$

Then taking logs on both sides of (5), we have (6)

$$(\log(P_m) = \log\gamma_3 + \alpha \log(S_m) + \beta \log(A_m), \text{ where } \alpha > 0, \beta < 0. \quad (6)$$

Since (2), (4) and (6) form a recursive model, we estimate the system using the single equation techniques of ordinary least squares (OLS) and maximum likelihood (ML), with the latter employing a first-order autoregressive scheme to allow for the possibility of autocorrelation in the residuals.

3. Background

Iraq has some 115 billion barrels of proven reserves of oil, the third largest reserves of petroleum after Saudi Arabia and Canada. A detailed overview of the Iraqi energy scene is contained in EIA [15] from which this introductory summary is heavily drawn. About two-thirds of the oil reserves are located in Southern Iraq. Much of the country has not been explored for oil, and the U.S. Geological Survey has estimated additional reserves of 45 billion barrels, while other estimates suggest that other reserves could be 100 billion barrels or more, for a total of perhaps 215 billion barrels. Iraq's reserves vary quite widely in quality, with API gravities ranging from 22° (heavy oil) to 35° (medium-light) and with sulphur content often in the 2% range or higher.

Current production is based on two main fields, the Rumaila field and the Kirkuk field. Southern oil production is based on the Rumaila field which borders Kuwait and produces Basra Light (about 34°API), Basra Medium (about 30°API) and Basra heavy (about 22° to 24° API). Northern oil production is based on the Kirkuk field which has remaining estimated proven reserves of 8.7 billion barrels. Quality is good with normal 35°API and 1.97% sulphur, but in the period before the Coalition invasion gravity had declined to 32° to 33°API, while sulphur content had risen to over 2%. There is some evidence that poor reservoir practices under the Saddam Hussein regime may have damaged Kirkuk. These practices included over pumping, intrusion of water into the oil reservoirs and re-injection of excess fuel oil, refinery residue and gas-stripped oil.

Iraq's oil production peaked at 3.7 million bbl/day in December 1979, fell substantially and then regained a peak of 3.5 million bbl/d in July 1990, prior to the invasion of Kuwait. Production crashed in 1991 with the first Gulf war, increased to 0.6 bbl/d in 1996, and under the "oil-for-food" program rose to 1.2 million bbl/d in 1997, 2.2 million bbl/d in 1998 and 2.5 million bbl/d during 1999-early 2003. Iraq has substantial reserves of natural gas, with 110 trillion cubic feet (Tcf) of proven reserves and 150 trillion cubic feet (Tcf) of probable reserves. About 70 percent of natural gas reserves are associated with oil reserves, 20 percent of reserves are non-oil associated and 10 percent of reserves are in dome gas.

In the period prior to the Coalition invasion, natural gas production had plummeted from 215 Bcf in 1989 to 83 Bcf in 2003. Natural gas was used for domestic and industrial consumption, for electricity production, for re-injection to enhance oil recovery, for export or, in many cases, simply flared off. The gas being flared could meet about one-half of Iraq's current energy requirements for electricity production.

The electricity sector has also faced major challenges in recent years. More than 90 percent of electricity generating capacity was destroyed in the 1990-1991 Gulf War as generation capacity fell from 9,300 MW in December 1990 to just 340 MW in March 1991. The war also destroyed or damaged perhaps 90 percent of the national power grid, with Bagdad's ten substations and 30 percent of the 440 kV transmission system destroyed. About three-quarters of the transmission network was restored by 2002, and generation capacity was some 4,500 MW, or less than one-half of generation capacity in 1990.

4. Phases of the Insurgency

On May 1, 2003, President Bush announced an end to major combat operations in Iraq. But with the end of organized resistance on the part of the Iraqi army, the insurgency was beginning to find its feet. Table 1 provides the framework within which the evolution of the insurgency is briefly reviewed, with a focus on the impact on the oil and electricity sectors.

Table 1. Major Phases of the Insurgency and Reconstruction in Iraq

Phase	Date	Description
1. Beginning of the insurgency	May 03 to Sep 03	Beginning of small arms attacks on Coalition forces by insurgents. Oil output and exports fall to less than one-half of pre-war levels and electricity supply is extremely disrupted.
2. Initial bombing campaign	Oct 03 to Jun 03	Increased insurgent emphasis on improvised explosive devices. Oil output and exports rise to about 90% of pre-war levels while electricity capacity recovers significantly.
3. Escalation of the insurgency	Jul 03 to Jan 05	Dramatic increase in insurgent forces and incidents. Oil output and exports fall modestly while electricity capacity returns to pre-war levels.
4. Intra-Iraqi conflict	Feb 05 to Oct 05	Use of larger and more sophisticated improvised explosive devices. Oil output and exports fail to recover to pre-war peaks while electricity capacity and sales are unchanged.

Phase 1 (May 2003 – September 2003). Beginning of the Insurgency. American strategists underestimated the effort required to secure and stabilize Iraq, how quickly resentment of the occupation would lead to violence directed against coalition forces and how much the oil and electricity sectors had deteriorated before the invasion. Table 2 provides information on key measures of the impact of the reconstruction effort and the insurgency on the energy sector. During Phase 1, oil and electricity output was perhaps one-half of pre-invasion levels. Foreign aid consisted primarily of technical assistance, with little capital investment. Relatively little damage was sustained to oil infrastructure during the war per se, but there was major damage due to sabotage and looting of material and equipment. From May 2003 onward, the U.S. Army Core of Engineers took the lead in an effort to ramp up oil and electricity production in Iraq. Meanwhile sabotage efforts focussed on the country's 4,350 mile system of pipelines, including the critical Kirkuk-Ceyhan pipeline, and on electricity transmission towers. The U.S. military set up Task Force Shield to guard Iraq's energy infrastructure, and in August 2003, a South African security company won a $40 million contract to train 6,500 armed guards to protect oil wells, pipelines, refineries and power plants.

Table 2. Key Energy Sector Indicators

	Phase 1	Phase 2	Phase 3	Phase 4
Oil output (000 barrels/day)	1,098.4 (490.5)	2,241.3 (188.8)	2,213.7 (202.8)	2,105.6 (79.9)
Oil exports (000 barrels/day)	390.2 (426.0)	1,476.7 (243.0)	1,424.6 (187.7)	1,422.3 (114.4)
Gasoline (000 litres/day)	11.96 (4.82)	16.41 (3.29)	18.11 (2.77)	21.50 (2.11)
Diesel supply (000 litres/day)	8.82 (3.48)	16.28 (3.92)	16.30 (1.83)	18.72 (1.87)
Oil attacks (attacks per month)	4.20 (0.00)	6.00 (3.24)	18.43 (6.21)	9.33 (2.06)
Electricity (MWh per day)	59.9 (26.8)	80.8 (7.8)	93.3 (14.1)	93.4 (8.8)
US energy sector aid (US$ million)	0.00 (0.00)	0.44 (0.68)	2.39 (0.24)	2.78 (0.067)

Note. Standard deviations in parentheses.

Phase 2 (October 2003 – June 2004). Bombing Campaign. In Phase 2, the insurgency reduced its emphasis on small arms and grenade attacks on coalition forces. Increased levels of bombings were the response to the technical superiority of Coalition forces, but as early as August 2003 the propaganda value of bombings was demonstrated with the destruction of the United Nations compound and the consequent removal of United Nations officials. By spring 2004, the Coalition faced opposition from the Sunnis in central Iraq and the Shiites in the south, and there were increased levels of daily attacks on oil and electricity infrastructure. Rehabilitation of the oil and electricity sectors began in earnest, although spending was already well behind planned levels.

Phase 3 (July 2004 – January 2005).Escalation of the Insurgency. Through the second half of 2004, the insurgents escalated the conflict as the number of Zarqawi-led attacks increased, and there was evidence of infiltration of Iraqi security forces. There were increased attacks on foreign nationals, Iraqi contractors and Iraqi civilians. Attacks on oil infrastructure peaked at over 16 per day, but reconstruction efforts matched the levels of attacks. A number of major generation projects were completed.

Phase 4 (February 2005 – December 2005). Intra-Iraqi Conflict. With the elimination of major insurgent strongholds, Coalition efforts in Phase 4 focused on clearing insurgent forces from the area bordering Syria. The Coalition strategy of lighting raids to kill or capture insurgents had the advantage of preventing the insurgents from establishing permanent safe havens but the disadvantage of failing to create safe and secure zones for Iraqis. Indeed, in Phase 4, the insurrection began to take on the character of a low-level civil war with increasing attacks by Sunnis on Shiite civilians leading to revenge attacks by Shiites on Sunni civilians. Planned expenditures for rehabilitation were largely completed, but with oil and electricity production still below pre-war levels.

It is worth noting that pipeline thefts have been a major and increasing problem as detailed in a recent Wall Street Journal article [16]. The article notes that one stretch of pipeline linking the Kirkuk field with the key Turkish Mediterranean port of Ceyhan pumped oil for only 43 days in 2006 due to leaks through dozens of drilled holes. The article further noted that in addition to its current production of 180,000 barrels of oil per day, the Kirkuk field could produce an additional 400,000 barrels per day worth $20 million or about one fifth of Iraq's current annual budget of $32 billion.

Iraq's oil production has apparently reached a plateau at a low level of about 2.1 million barrels per day. This is some fifteen percent below the typical pre-war production level of 2.5 million barrels per day, which itself reflected the negative impacts of the first Gulf War and United Nations sanctions as well as several years of government neglect of petroleum and natural gas sector maintenance, exploration and development activities.

5. Regression Results

Table 3 examines the effect of determinants of the log of U.S. aid to the oil sector and the log of insurgent force levels on the log of oil production. The results for the ordinary least squares regression are shown in the second column, while the results of the maximum likelihood regression are shown in the third column.

The regression coefficients are the elasticities of oil production with respect to the independent variables, with the standard errors of the coefficients in parentheses below the coefficients. The probability for F is shown below the F value in parentheses. Finally one, two or three asterisks on the coefficient indicate that the coefficient is significant at the 10%, 5% or 1% level respectively.

In both the OLS and ML models, the coefficients have the expected signs but only the coefficient on the constants and on log of United States aid in the ML regression are statistically significant. Several observations on these results are in order. First, the elasticity of oil production with respect to the amount of U.S. aid is 0.23 for the OLS model and 0.46 for the ML model. Second, the elasticity of oil production with respect to the log of insurgent attacks is about -0.031 for the OLS model and -0.043 for the ML model. This suggests that increasing Coalition oil sector aid levels could have a significant impact on the level of oil production, while reducing insurgent oil sector bombings is also important in stabilizing and increasing sector output. Third, the ML regressions using a first-order autoregressive scheme reduces autocorrelation.

Table 3. Log Oil Production

	OLS	ML
Constant	7.38*** (0.19)	7.13*** (0.36)
Log United States aid	0.23 (0.17)	0.46* (0.28)
Log insurgent attacks	-0.031 (0.11)	-0.043 (0.044)
Adjusted R-squared	0.07	-
F test	2.06 (0.15)	-
Log-likelihood	-	16.4
Durbin-Watson	0.21 (0.90)	1.17 (0.42)

Table 4 examines the effect of the log of U.S. aid to the oil sector and the log of insurgent attacks on the log of diesel production. In both the OLS and ML models, the coefficients have the expected signs but only the coefficient on the constants and on log of United States aid in the OLS regression are statistically significant. Note that the elasticity of diesel production with respect to the amount of U.S. aid is 0.44 for the OLS model and 0.35 for the ML model, and also that the elasticity of diesel production with respect to the log of insurgent attacks is -0.038 for the OLS model and -0.031 for the ML model.

Table 4. Log Diesel Production

	OLS	ML
Constant	2.55*** (0.17)	2.51*** (0.23)
Log US aid	0.44*** (0.16)	0.35 (0.28)
Log insurgent attacks	-0.038 (0.10)	-0.031 (0.064)
Adjusted R-squared	0.27	-
F	6.24 (0.01)	-
Log-likelihood	-	8.37
Durbin-Watson	0.46 (0.77)	2.01 (0.00)

Table 5 examines the effect of the log of U.S. aid to the oil sector and the log of insurgent attacks on the log of gasoline production.

In both the OLS and ML models, the coefficients have the expected signs but only the coefficient on the constants and on log of United States aid in the OLS regression are statistically significant. Note that the elasticity of gasoline production with respect to the amount of U.S. aid is 0.58 for the OLS model and 0.56 for the ML mode and that the elasticity of gasoline production with respect to the log of insurgent attacks is -0.15 for the OLS model and -0.12 for the ML model.

Table 5. Log Gasoline Production

	OLS	ML
Constant	2.83*** (0.16)	2.68*** (0.23)
Log US aid	0.58*** (0.14)	0.56** (0.28)
Log insurgent attacks	-0.15* (0.092)	-0.12* (0.077)
Adjusted R-squared	0.37	-
F	9.7 (0.00)	-
Log-likelihood	-	3.4
Durbin-Watson	0.77 (0.62)	1.80 (0.00)

Table 6 examines the effect of the log of U.S. aid to the oil sector and the log of insurgent attacks on the log of oil exports. In both the OLS and ML models, the coefficients have the expected signs but only the coefficient on the constants and on log of United States aid in the OLS regression are statistically significant. Note that the elasticity of oil exports with respect to the amount of U.S. aid is very large at 1.79 for the OLS model and 1.89 for the ML model while the elasticity of oil exports with respect to the log of insurgent attacks is also substantial at -0.39 for the OLS model and -0.57 for the ML model.

Table 6. Log Oil Exports

	OLS	ML
Constant	6.53*** (1.06)	5.64*** (1.98)
Log US aid	1.79* (0.95)	1.89 (2.03)
Log insurgent attacks	-0.39 (0.63)	-0.57 (0.34)
Adjusted R-squared	0.07	-
F	2.2 (0.14)	-
Log-likelihood	-	-44.4
Durbin-Watson	0.38 (0.81)	1.69 (0.16)

Table 7 examines the effect of the log of U.S. aid to the oil sector and the log of insurgent attacks on the log of electricity production.

Table 7. Log GWh Produced

	OLS	ML
Constant	11.21*** (0.21)	11.03*** (0.28)
Log US aid	0.41** (0.19)	0.54* (0.32)
Log insurgent attacks	-0.065 (0.13)	-0.051 (0.12)
Adjusted R-squared	0.13	-
F	3.1 (0.06)	-
Log-likelihood	-	-9.23
Durbin-Watson	0.97 (0.38)	0.73 (0.63)

In both the OLS and ML models, the coefficients have the expected signs but only the coefficient on the constants and on log of United States aid are statistically significant. Note that the elasticity of electricity production with respect to the amount of U.S. aid is 0.41 for the OLS model and 0.54 for the ML model while the elasticity of electricity production with respect to the log of insurgent attacks is -0.065 for the OLS model and -0.051 for the ML model.

Table 8 examines the effect of the log of insurgent force levels on the log of insurgent attacks. In both the OLS and ML models, the coefficients have the expected signs and are significant at the one-percent level. A one-percent increase in the insurgent force level leads to a 0.81 percent increase in the level of insurgent attacks on oil infrastructure.

Table 8. Log Oil Attacks

	OLS	ML
Constant	-5.50*** (1.18)	5.45*** (1.31)
Log insurgent force	0.81*** (0.13)	0.81*** (0.14)
Adjusted R-squared	0.58	-
F	41.1 (0.00)	-
Log-likelihood	-	-18.3
Durbin-Watson	1.74 (0.13)	2.00 (0.00)

Table 9 examines the trend in the log of U.S. energy sector aid and the effect of the log of insurgent force levels on the log of insurgent attacks. In both the OLS and ML models, the coefficients have the expected signs and are significant at the one-percent level. After an initial eleven month period with little expenditure, expenditure levels rapidly ramped up.

Table 9. Log US Aid

	OLS	ML
Constant	0.12** (0.050)	0.096 (0.16)
Spline	0.065*** (0.0055)	0.056*** (0.012)
Adjusted R-squared	0.83	-
F	140.7 (0.00)	-
Log-likelihood	-	-35.5
Durbin-Watson	0.15 (0.093)	1.55 (0.22)

6. Conclusion

We noted above that rehabilitating the energy sector in Iraq has been a major objective of the Coalition from 2003 through 2005, with more than $5 billion in Iraqi, U.S. and other Coalition partner funds devoted to this effort. This study provides an analysis of the impact of Coalition efforts and insurgent activities on energy sector performance using time-series models. The study has eight main findings as follows.

First, U. S. expenditures on oil infrastructure appear to have been relatively efficiently spent. The estimated production elasticities with respect to U.S investment are between 0.2 and 0.6, depending on the model used, which suggests a reasonably high level of impact for marginal investments. Despite major concerns raised by the General Accounting Office and by the Special Inspector

General for Iraq Reconstruction, the sector is recovering after years of neglect.

Second, the impact of new U.S. funded investment on domestic supplies of gasoline and diesel fuel is significant, although the impact is much smaller than for oil production and exports. This appears to reflect two factors: first, greater success in rehabilitating oil fields and pipelines than in rehabilitating refineries, and, second, policy emphasis placed on restoring exports and earning foreign exchange as opposed to providing petroleum products for domestic use.

Third, marginal investments in the electricity sector have been relatively effective with production elasticities between 0.41 and 0.54. However, some decisions have reduced the medium-term effectiveness of these investments. These decisions include extremely low residential electricity prices which discourages conservation, inadequate fuel supplies for newly natural gas installed turbines, and centralization of decision making regarding generation, transmission and distribution rehabilitation which has slowed recovery efforts.

Fourth, the insurgency has had a significant and measurable impact on the petroleum rehabilitation effort, and bombings and related attacks have significantly slowed recovery of the oil sector. The oil production and oil export elasticities with respect to insurgent attacks are quite high, again depending on the model, suggesting a substantial payoff to the insurgency.

Fifth, insurgent attacks have had a significant negative impact on domestic supplies of gasoline and diesel fuel, comparable in magnitude to those for oil production and exports. This has retarded the recovery of the economy and on-going fuel shortages and length line-ups for gasoline purchases have likely increased domestic opposition to the on-going occupation of Iraq by the Coalition forces.

Sixth, insurgent attacks have had more limited success, and elasticities of electricity production with respect to insurgent attacks are small. Although the attacks have been effective in the short term, it has been possible to repair much of the damage they have caused in a reasonably expeditious manner.

Seventh, the elasticity of oil infrastructure attacks with respect to the size of the insurgency is quite high at 0.8. This suggests that although the insurgency has a near capacity to strike at will, reducing the size of the insurgency could significantly reduce attacks on oil infrastructure.

Eighth, the ramp-up of the energy sector aid effort was initially quite slow, but it accelerated quite quickly once it started. Effectiveness of aid has been hampered, however, by the need to spend a significant share of funds on providing security for domestic and international contractors. In addition, widespread theft of oil from pipelines has reduced the profitability and net cash flow of the oil sector, reduced central government revenues and placed considerable revenues in the hands of individuals and groups opposed to the current government of Iraq.

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