Appendix B: Measuring Stock Changes during Disruptions.

Posted at http://dahl.mines.edu/B&D17spr/B&D18AppxB.pdf

to Accompany

Bai, Yang and Carol A. Dahl (forthcoming 2018) Evaluating the management of U.S. strategic petroleum reserve during oil disruptions. *Energy Policy*, Special Issue Oil Supply Disruptions, U.S. Economic Activity and Oil Security.

Having identified the disruptions om Appemdix A, we next consider stock changes, which can help mitigate the effects of disruptions. Figure B1 shows historical U.S. stock patterns from 1956-2014. One thing we find the most striking is the substitution away from private sector stocks as the government increased its stockpiles. They show crude stocks relatively flat until around 1970, then gently rising through 1977, while product stocks more sharply and steadily rose from 1956 to 1977. However, as the SPR commenced building, product stocks fell and then remained relatively flat, while private crude stocks trended down more gently through the early 2000s, before starting to trend up. Private crude oil stocks had only regained 1981 levels by 2014.

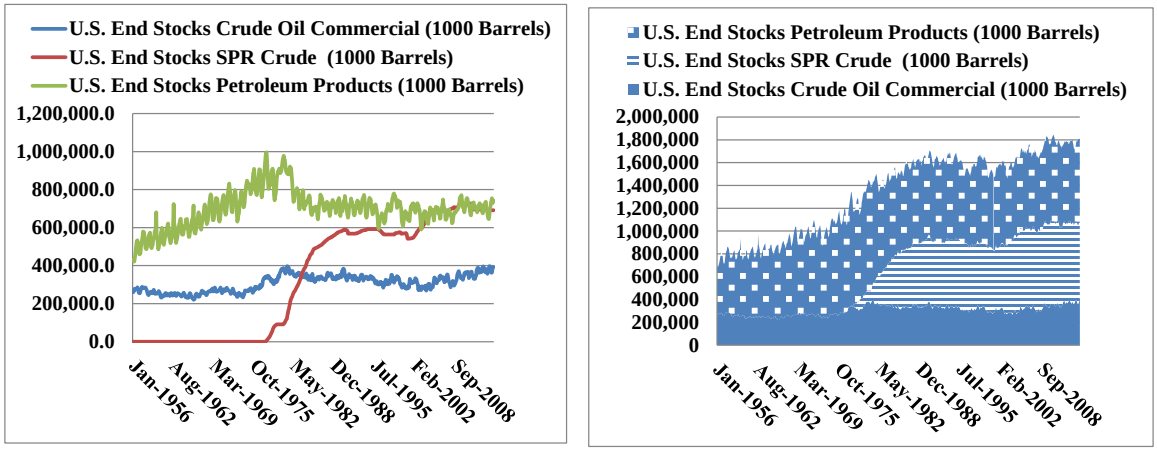

Figure B1 Monthly stocks of U.S. government crude oil, private sector crude oil and private sector oil products.

Source: https://www.eia.gov/dnav/pet/PET_STOC_TYP_C_NUS_EPC0_MBBL_M.htm

A second thing to note is the variation in commercial crude and product reserves across time, which appears to have a seasonal component. We will come back to these seasonal affects later.

For the U.S., almost all of the government SPR stocks are for crude oil. Although there are two small separate reserves: a Northeast Heating Oil Reserve of one million barrels created in 2000 and a more newly minted gasoline reserve of one million barrels created in 2014. https://energy.gov/fe/services/petroleum-reserves. We have not found the data for the Rest of the OECD (ROO) as plentiful but, thus far have been able to create quarterly numbers from the IEA Oil Market Report. https://www.iea.org/media/freepublications/security/EnergySupplySecurity2014_PART1.pdf. The following figure shows that oil products play a much more prominent role in public security stockpiles in the rest of the OECD and the stock statistics, we have compiled show total OECD stocks of crude and products broken out into publicly controlled and private commercial stocks.

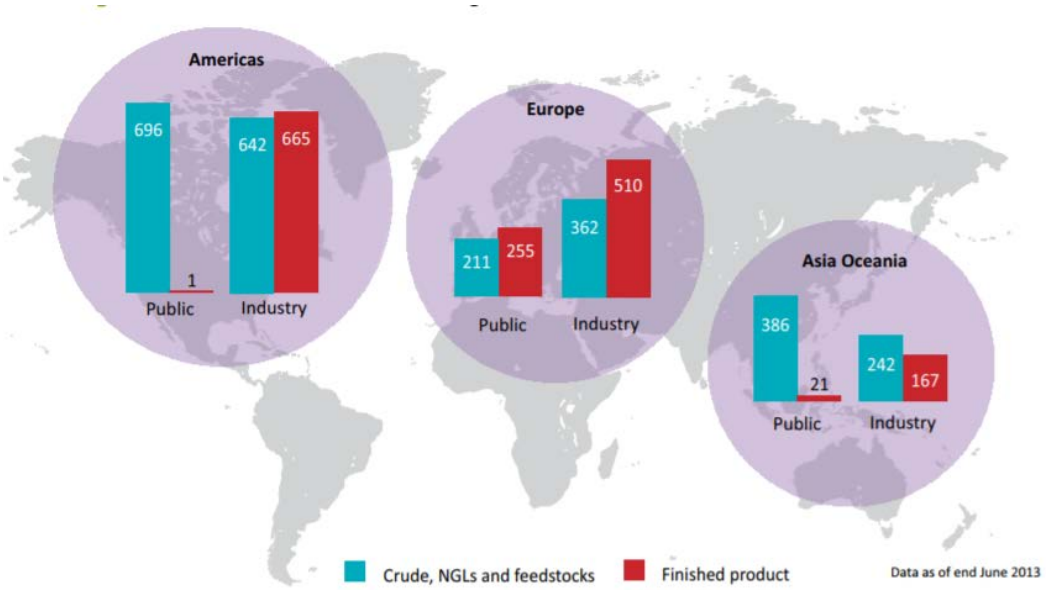

Figure B2: Total public (government) and private (commercial) oil and oil product stocks (2013)

Source: IEA (2015)

The figures below show the data we have compiled for the ROO with oil and product stocks combined. It is annual data at midyear from 1974-1990 and end of quarter data from 1990:II to 2014:IV. Again the left shows the levels with private stocks higher in the 1970s and then flattening out as the government controlled stocks increased. The right shows cumulative stocks.

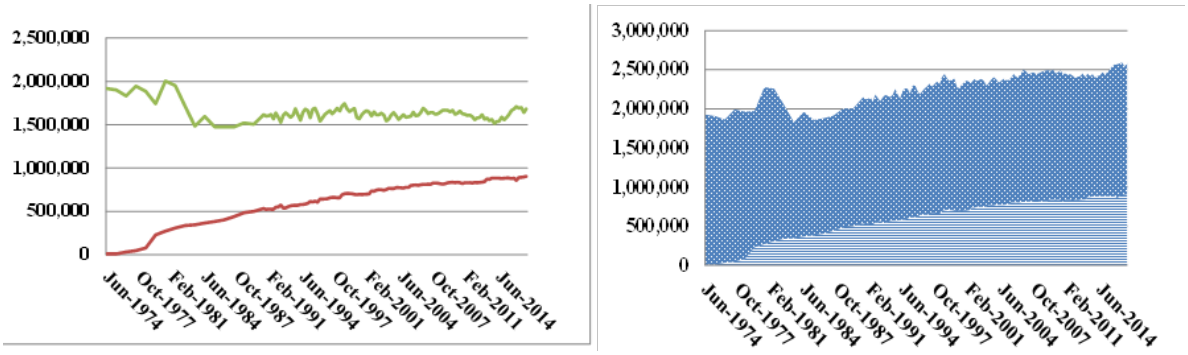

Figure B3 Rest of the OECD government and commercial crude oil and product stocks.

Notes: In the diagram on the left, the lower line is for government stocks and the upper line is for private stocks. In the diagram on the right, the lighter striped area is for government stocks and the darker hatched area is for private stocks.

Next we see how stocks have changed in response to our disruptions. Changes in government stocks are the most straight forward and we start with them. The authority for U.S. government stockpiling and drawdowns originated with the Energy Policy and Conservation Act with its subsequent amendments. See brief discussion in the paper. The authority for some OECD international coordination came in 1974, when the International Energy Agency (IEA) was formed as an autonomous organization within the Organization for Economic Cooperation and Development (OECD), to implement the 1974 International Energy Program (IEP). The provisions of the IEP international statutory agreement as amended in 1992 are available in full at https://www.iea.org/media/about/1ieahistory.pdf, p. 353-410. Its emergency response provisions essentially required countries to maintain 60 days (later extended to 90 days) of net import inventories in the form of crude oil or products with a sharing program to be triggered with a

disruption equal to 7% of world supply. It could also be triggered by smaller disruptions that were declared as emergencies by the Secretariat of the IEA. Each country was also to maintain a demand restraint program to be implemented during any declared emergency.

The first joint IEA drawdown was during 1991 Gulf war. The agreed commitments by country are given in Table B1. The original commitment was for about 2 million b/d beginning January 17th with a bit over half of that to come from the U.S.

Table B1 OECD Emergency Response Commitments

Adopted January 11, 1991 (1000 b/d), Activated January 17th, terminated March 6th, 1991

	Stockdraw	Demand Restraint	Fuel Switching	Increased Domestic Production	Total Response
Australia	0	33	0	13	46
Austria	6	5	5	0	16
Belgium	9	18	0	0	27
Canada		115		0	115
Denmark	11	2	0	0	13
Germany	169	18	0	0	187
Greece	9	9	0	0	18
Ireland	5	1	0	0	6
Italy	74	24	32	0	130
Japan	350	0	0	0	350
Luxembourg	0	2	0	0	2
Netherlands	3	0	1	3	7
New Zealand	5	7	0	0	12
Norway	25	7	0	0	32
Portugal	10	2	5	0	17
Spain	0	62	0	0	62
Sweden	0	21	0	0	21
Switzerland	6	12	1	0	19
Turkey	0	20	11	0	31
United Kingdom	120	0	0	0	120
United States	1125	0	0	0	1125

Total IEA	**1927**	**358**	**55**	**16**	**2356**
Finland	0	12	0	0	12
France	59	58	9	0	126
Iceland	0	1	0	0	1
Total OECD	**1986**	**429**	**64**	**16**	**2495**
Source: https://www.iea.org/about/history/ p. 154-158.					

In examining what actually happened, our estimate above is that the bulk of the disruption took place in the III and IV quarter of 1990 with a total reduction of 229.5 million barrels with an additional reduction of 15.5 in 1991:I . Our computation of government drawdowns computed from reported stock figures of the US EIA (https://www.eia.gov/dnav/pet/PET_STOC_TYP_C_NUS_EPC0_MBBL_M.htm) and the IEA World Oil Market Reports (https://www.iea.org/oilmarketreport/tables/_ are shown in Table B2, columns (3) and (4). As we did not have monthly figures for the ROO during this disruption, we computed all stock number changes on a quarterly basis.

It appears that the U.S. government was stockpiling a bit in 1990, quarter III as it prepared for war and did a test drawdown in 1990, quarter IV. Meanwhile the ROO governments drew down significant quantities of stocks over all three quarters, which were more than 4 times larger than U.S. government withdrawals.

Next we considered what was happening in the private sector. Our first estimates are straight forward computations of stock changes for oil and products. The U.S. private sector showed the most stock drawdown. Although in Europe the government drew down more, in the U.S. the private sector drew down more than 6 barrels for every U.S. government barrel and the U.S. private sector stock draw approached the overall amount drawn down by the ROO governments. However, the ROO private stocks summed over the three quarters showed a slight stock build. If we look at public and private stocks aggregated over all three quarters, the U.S. at 127 million barrels is not so different than the ROO at 116 million. However, the public private sector mix strongly leaned towards the private sector in the U.S. but towards the public sector in the ROO.

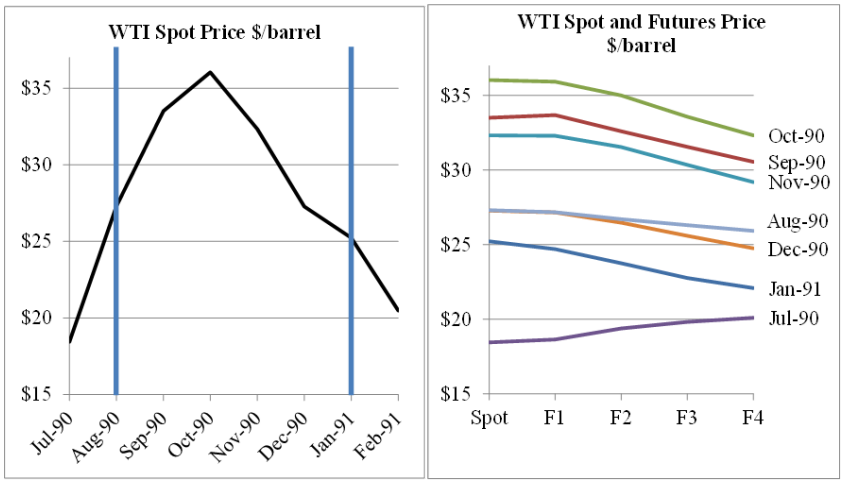

Figure B1: Monthly WTI Spot Price and Forward Curves July 1990-January 1991

Source: U.S. EIA, https://www.eia.gov/dnav/pet/PET_PRI_SPT_S1_D.htm, https://www.eia.gov/dnav/pet/pet_pri_fut_s1_m.htm.

The forward curve out 4 months was normal in July the 1990 before the disruption started. Once the disruption started, the spot price rose through October 1990 and then fell through Feb 1991. However all through the disruption the forward curve was inverted suggesting the spot price would ease as the market continued to fill in the production loss.

Table B2 Changes Strategic Government Stocks (G) and Private Stocks (Pv) of Oil (O) and Oil Products (OP) (million barrels) (drawdown <0, build > 0)

Time Period (Identified disruption in 10^6 barrels)	**Region and Stock Changes**					
Aug 1990 - Dec 1990 (1.5 mb/d @153 days =229.5 mb) and Jan, 1991 (0.5 mb/d @ 31 days = 15.5 mb)	**U.S. G 10^6 b**	**Rest of OECD (ROO) G 10^6 b**	**U.S. Private O&OP 10^6 b**	**ROO PV O&OP 10^6 b**	**U.S. Pv with Seasonal Adj O&OP 10^6 b**	**ROO Pv with Seasonal Adj O&OP 10^6 b**
1990:III	2.9	-15.7	10.3	-14.7	-0.8	-63.4
1990:IV	-3.9	-68.7	-73.7	1.3	-10.3	50.0
1991:I	-17.2	-32.0	-45.8	16.2	-45.8	16.2
Sep 2005 - Oct. 2005 (0.3 mb/d@61 days=18.3 mb)						
Sep	-7.10	-9.70	-4.60	21.65	-9.70	15.45
Oct	-8.40	-10.00	20.40	36.86	29.30	47.92
Mar. 2011 - July. 2011 (0.8 @ 153 days =122.4 mb)						
Mar	0.0	0.1	-4.5	-16.6	-4.5	-16.6
Apr	0.0	0.0	2.8	25.3	2.8	25.3
May	0.0	1.7	27.2	-9.0	27.2	-9.0
Jun	0.0	1.5	2.0	-10.7	-23.4	-10.7
Jul	-8.3	-4.9	15.5	0.2	5.0	-34.6
Aug	-21.8	1.0	1.9	-13.6	2.9	-12.4

Source: Computed from data in IEA World Oil Market Report (https://www.iea.org/oilmarketreport/tables/_ ar) and U.S. EIA (https://www.eia.gov/dnav/pet/PET_STOC_TYP_C_NUS_EPC0_MBBL_M.htm).

Notes: We have found only quarterly data for Non-U.S. OECD Stocks in 1990-91.

As noted above, the private stocks seemed to display seasonal patterns. We took a stab at measuring this seasonality with some regression analysis and using it to adjust our commercial stock changes for seasonality. We regressed total oil and product stocks in thousands of barrels for the U.S. and for the ROO on a constant, quarterly dummies (D2, D3, D4) for quarters II, III, and IV, the price of West Texas intermediate crude oil (P_WTI) and the three month futures contract for WTI (F3) from 1990:II to 2014:IV. These preliminary results are shown below. For the U.S., everything else equal, stocks are statistically lowest 1st and 4th quarter and around 50 to 60 million barrels higher in 2nd and 3rd quarter. As expected if the current price increases, stocks fall to take advantage of higher current prices, and if the futures price increases, stocks go up to take advantage of the higher price in the future.

Table B3 Regression of U.S. Commercial Oil and Oil Product Stocks on Quarterly Data

US_OOP_Pv=C(1)+C(2)*D2+C(3)*D3+C(4)*D4++C(13)*P_WTI+C(14)*F3

Dependent Variable: US_OOP_PV

Method: Least Squares

Date: 09/18/17 Time: 16:07

Sample (adjusted): 1990Q2 2014Q4

Included observations: 98 after adjustments

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	971925	12034	80.764	0.000
C(2)	52318	13501	3.875	0.000
C(3)	63378	13391	4.733	0.000
C(4)	18144	13417	1.352	0.180
Spot Price	-15527	3439	-4.515	0.000
Futures Price	15858	3409	4.652	0.000

R-squared	0.378	Mean dependent var	1022640.000
Adjusted R-squared	0.344	S.D. dependent var	57664.290
S.E. of regression	46712.550	Akaike info criterion	24.401
Sum squared resid	201000000000	Schwarz criterion	24.559
Log likelihood	-1189.633	Hannan-Quinn criter.	24.465
F-statistic	11.163	Durbin-Watson stat	0.393
Prob(F-statistic)	0.000		

Similar estimates for the ROO show a bit less statistical seasonality with estimated higher stocks (~49 million barrels) only in the 3rd quarter.

Table B4 Regression of ROO Commercial Oil and Oil Product Stocks Quarterly Data

ROO_OOP_Pv=C(1)+C(2)*D2+C(3)*D3+C(4)*D4++C(13)*P_WTI+C(14)*F3

Dependent Variable: ROO_OOP_PV

Method: Least Squares

Date: 09/18/17 Time: 16:03

Sample (adjusted): 1990Q2 2014Q4

Included observations: 98 after adjustments

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1625100	9279	175.128	0.000
C(2)	15344.52	10410	1.474	0.144
C(3)	48682.24	10326	4.715	0.000

C(4)	6552.144	10346	0.633	0.528
Spot Price	-12882.74	2652	-4.858	0.000
Future Price	12330.33	2629	4.691	0.000
R-squared	0.381	Mean dependent var		1618911.000
Adjusted R-squared	0.347	S.D. dependent var		44571.200
S.E. of regression	36019.940	Akaike info criterion		23.881
Sum squared resid	119000000000	Schwarz criterion		24.039
Log likelihood	-1164.159	Hannan-Quinn criter.		23.945
F-statistic	11.305	Durbin-Watson stat		1.071
Prob(F-statistic)	0.000			

We can estimate the same regression for U.S. monthly data on a slightly longer sample, January 1986 to December 2014. The fit is not at tight as measured by the Rbar squared and the F statistics but the regression generally supports the quarterly results except to shift the higher stock period by 2 months from 2nd and 3rd quarter to be from June through November.

Table B5 Regression of U. S. Commercial Oil and Oil Product Stocks Monthly Data

Dependent Variable: U.S._STK_OP+STK_O

Method: Least Squares

Date: 09/21/17 Time: 12:24

Sample (adjusted): 1986M01 2014M12

Included observations: 348 after adjustments

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1008947	9945.854	101.444	0
D2	-19455.1	13121.75	-1.48266	0.1391
D3	-21194.4	13108.55	-1.61684	0.1069
D4	-10835.8	13162.82	-0.82322	0.411
D5	14151.03	13137.75	1.077127	0.2822
D6	25412.1	13092.51	1.940964	0.0531
D7	35917.63	13094.07	2.743046	0.0064
D8	34962.77	13096.61	2.669605	0.008
D9	40146.74	13093.45	3.066169	0.0023
D10	31324.03	13098.81	2.391364	0.0173
D11	30922.39	13100.13	2.360464	0.0188

D12	-1318.91	13160.4	-0.10022	0.9202
P_WTI	-60915.4	16126.51	-3.77735	0.0002
F1	61045.47	16111.13	3.789024	0.0002
R-squared	0.191627	Mean dependent var		1028185
Adjusted R-squared	0.160164	S.D. dependent var		54387.7
S.E. of regression	49842.29	Akaike info criterion		24.51051
Sum squared resid	8.30E+11	Schwarz criterion		24.66549
Log likelihood	-4250.83	Hannan-Quinn criter.		24.57221
F-statistic	6.090441	Durbin-Watson stat		0.130468
Prob(F-statistic)	0			

Although these results are far from final, they are suggestive and we adjust our commercial stocks for quarters or months by taking away the normal seasonal effect to see how seasonally adjusted commercial stocks changed for the U.S. and the ROO. These are the last two columns in Table B2.

Moving on to the second disruption, the first hurricane hit in late August, 2005 and the 26 IEA members agreed to a response much faster. On September 2, they agreed to drawdown an additional combined stock draw of almost 2 mb/d of oil and product for 30 days with following breakdowns: (1,289, 000 b/d crude oil, 683,000 b/d product stock of which 369,000 b/d, motor gasoline, 276,000 b/d middle distillates, and 38,000 b/d fuel oil. Regionally the commitments were 52% from North America, 30% from Europe and 18% from the Asia-Pacific region. (https://www.iea.org/newsroom/news/2005/september/2005-09-07-.html. (Paris) — 7 September 2005) The total commitments are summarized in Table B6.

Table B6 IEA Disruption Commitments Agreed to September 2, 2005 (mb)

	Stockdraw	Demand Restraint	Fuel Switching	Increased Domestic Production	Total Response
26 IEA Countries Total	59.22	1.89	0.00	1.89	63.00
26 IEA Countries Crude	38.67				
26 IEA Countries Products	20.49				
IEA North America					32.76
IEA Europe					18.90
IEA Pacific					11.34
https://www.iea.org/newsroom/news/2005/september/2005-09-07-.html					

The second hurricane hit in late September leading to another month of disruption. Again we use reported stock statistics to determine the actual stock changes over the estimated September through October 2005 disruption. We estimated the total disruption over the two periods to be 18.3 million barrels, with the

total OECD government drawdowns of almost twice that amount (35.2 mb). The actual government draws were significantly less than the original commitment of almost (60 mb) as the need for less oil became apparent. As the market appeared to be pretty well supplied, the private sector had net additions to stocks over the two months with a U.S. stock build of 16.2 mb and a ROO build of a considerably larger net amount of 58.5 mb. Again we did our best to estimate seasonally adjusted stock changes as well. As we do not yet have monthly regressions for ROO, we used the quarterly regression with monthly prorating using the U.S. monthly stock regressions. These seasonal adjustments do not change our perception that the private sector was more than mopping up the surplus government stocks sloshing about the world.

Again we consider the spot price and forward curve to shed some light on what market expectations might have been. Spot price increases were much more modest this go around. They had already been rising through August and only increased slightly in September. Thereafter they commenced to fall over the disruption. The forward curves were generally normal from August to November and were flat or gently rising during the two disruption months. The forward curve become steeper in November, likely with the expectation that the price would increase more steeply as the market absorbed the excess barrels in the market.

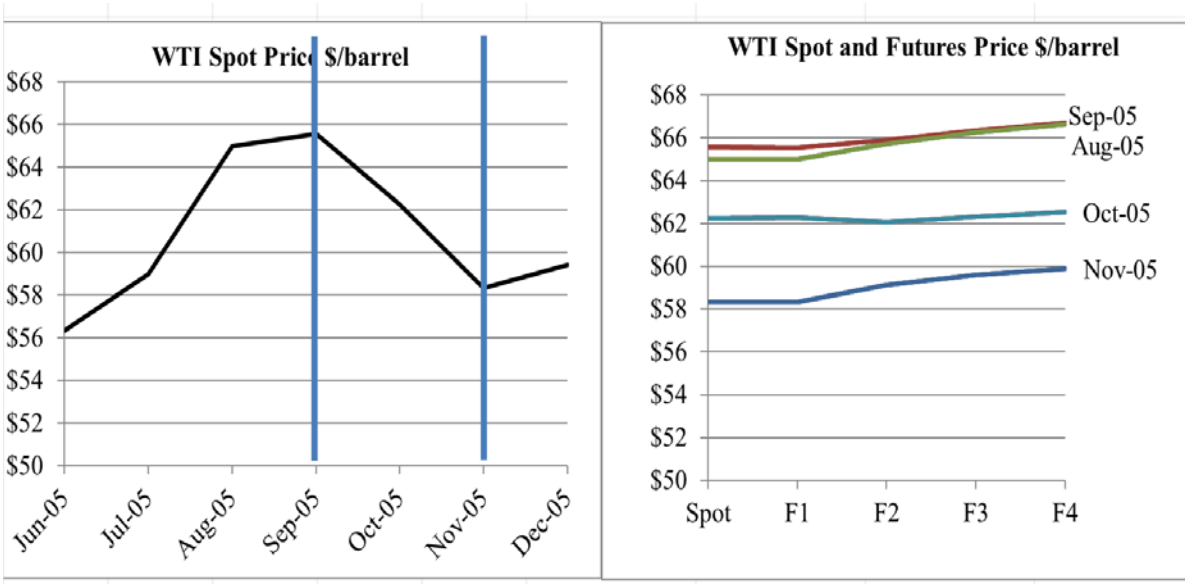

Figure B2: Monthly WTI Spot Price and Forward Curves June –December 2005 and Some Forward Curves

Source: U.S. EIA, https://www.eia.gov/dnav/pet/PET_PRI_SPT_S1_D.htm, https://www.eia.gov/dnav/pet/pet_pri_fut_s1_m.htm.

Last was the Libyan disruption. We contend that the disruption started in March, 2011 and lasted through July with a total disruption amount of 122.5 million barrels. The IEA international agreement for the 8 largest members of the IEA relating to this disruption was not concluded until June 23, 2011. The government commitments were for 60 million barrels with about a 40/20 crude/product split. Since most government product stocks are required holdings in the private sector, the government crude to reduced private sector commitment mix is about the same as the crude/product split.

Table B7 IEA Disruption Commitments Agreed to June 23, 2011

23-Jun-11	stock draw (mb)

8 Larger Member IEE	60
Government Stocks Crude	38
Reduced Private Requirements	22
Crude	40
Products	20

Source: https://www.iea.org/publications/freepublications/publication/EPPD_Brochure_English_2012_02.pdf

Before the June agreement (March-June), the U.S. government made no acquisitions and the ROO governments saw a small build of 3.3 mb. Both drew down in July (the U.S. drew down 8.3 million barrels and the ROO drew down 4.9 million barrels). The U.S. continued to draw down another 21.8 million barrels in August after we argue the market had largely taken care of the problem. The total government stock offset during our estimate of the disruption was around 10 million barrels or somewhat over 30 million barrels, if we count the late contribution of the U.S. SPR. For the private sector, there was an immediate stock draw of 4.5 million barrels for the U.S. and 16.6 million barrels for the ROO in March. Then things get more puzzling. The U.S, private sector commenced to stockpile for the remainder of the disruption (April – July) summing to about 43 million barrels. With seasonal adjustment their stock build falls considerably but does not become a drawdown as we expected. The ROO private sector overall built more stocks in April (25.3 million barrels) than their subsequent cumulative stock draws in May and June. Overall they showed a cumulative stock draw of 10.8 million over the disruption, which became a more substantial draw of 45.5 million barrels when seasonally adjusted.

In Fig. B3, we can see the corresponding price changes and forward curves. The spot price in February was about the same as it was in January but then jumped from under $90 per barrel to over $100 in March and spiked at close to $110 in April but generally plunged to pre-crisis levels by August. The forward curve in Feb was normal. It remained normal throughout the disruption period but only gently higher than the current spot price. By August, the WTI price had returned to below pre-crisis levels and the forward curve suggested an expectation that prices would remain near that price.

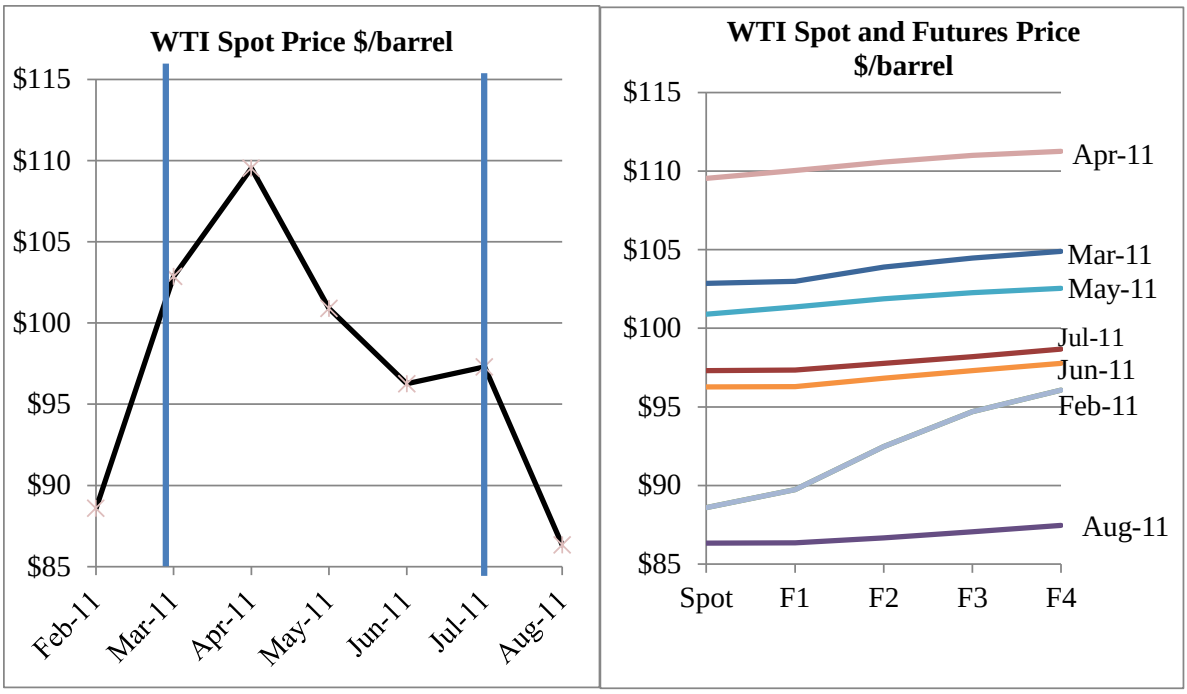

Figure B3: Monthly WTI Spot Price and Forward Curves, February – August 2011 and Some Forward Curves

Source: U.S. EIA, https://www.eia.gov/dnav/pet/PET_PRI_SPT_S1_D.htm, https://www.eia.gov/dnav/pet/pet_pri_fut_s1_m.htm.

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