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The Impact of the Shale Oil Revolution on U.S. Oil and Gasoline Prices

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Abstract: This article examines how the shale oil revolution has shaped the evolution of U.S. crude oil and gasoline prices. It puts the evolution of shale oil production into historical perspective, highlights uncertainties about future shale oil production, and cautions against the view that the U.S. may become the next Saudi Arabia. It then reviews the role of the ban on U.S. crude oil exports, of capacity constraints in refining and transporting crude oil, of differences in the quality of conventional and unconventional crude oil, and of the recent regional fragmentation of the global market for crude oil for the determination of U.S. oil and gasoline prices. It discusses the reasons for the persistent wedge between U.S. crude oil prices and global crude oil prices in recent years and for the fact that domestic oil prices below global levels need not translate to lower U.S. gasoline prices. It explains why the shale oil revolution unlike the shale gas revolution is unlikely to stimulate a boom in oil-intensive manufacturing industries. It also explores the implications of shale oil production for the transmission of oil price shocks to the U.S. economy.

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1. Introduction

The production of shale oil (also referred to as tight (rock) oil) exploits technological advances in drilling. It involves horizontal drilling and the hydraulic fracturing (or fracking) of underground rock formations containing deposits of crude oil that are trapped within the rock. The hydraulic fracturing causes cracks and fissures in the rock formation that allow the crude oil to escape and to flow into the borehole, where it can be recovered. In some cases, advanced microseismic imaging is used to maximize the effects of hydraulic fracturing. This process is used to extract crude oil that would be impossible to release by conventional drilling methods designed for extracting oil from permeable rock formations.¹ The rapid expansion of U.S. shale oil production after 2003 was stimulated by the high price of conventional crude oil, which made this new technology competitive. Shale oil production is capital intensive. Production levels are primarily determined by the availability of suitable drilling rigs and skilled labor, which is one of the reasons why the U.S. shale oil boom so far has been difficult to replicate in other countries.

The expansion of U.S. shale oil production soon captured the imagination of policymakers and industry analysts and fuelled visions of the U.S. becoming independent of oil imports, of a rebirth of U.S. manufacturing, and of net oil exports improving the U.S. current account. At the same time, energy experts were forced to revise their models and forecasts to incorporate U.S. shale oil production. By 2012, the International Energy Agency projected that the United States would become the world's leading crude oil producer, overtaking Saudi Arabia by the mid-2020s and evolving into a net oil exporter by 2030 (see International Energy Agency 2012). Figure 1 examines the evidence to date. The left panel plots the average annual production of crude oil of the three largest crude oil producers in the world from 1973 until

¹ The terms *shale oil* and *tight oil* do not have a precise geological definition, but are commonly used by the oil industry and by government agencies to refer generically to crude oil produced from shale, sandstone and carbonate formations characterized by low permeability.

2014.² It shows that Russia, Saudi Arabia and the United States all increased their oil production after 2002. There is no indication to date of U.S. crude oil production catching up with that of Saudi Arabia. As of 2014, not only Saudi Arabia is producing more crude oil than the United States, but so is Russia, which in fact has become the world's largest producer of crude oil.³

The plot also shows that the United States has in fact been the world's largest oil producing country repeatedly during 1973-2014. This has not, however, protected the United States from being exposed to major oil price shocks in the past. For example, the United States was the world's leading oil producer, ahead of Saudi Arabia, during the first major oil crisis of 1973/74. The vulnerability of the U.S. economy to oil price shocks in 1973/74 is not surprising upon reflection. Although U.S. oil production at the time was the highest in the world, it was not sufficient to meet U.S. domestic demand for crude oil. Thus, there was no spare capacity to allow the United States to deal with a global shortfall of oil production, exposing the U.S. economy to shocks to the price of imported crude oil. U.S. oil production also exceeded that of Saudi Arabia during 1981-1990, mainly because Saudi Arabia reduced its oil production in the early 1980s in an effort to prop up the price of oil. The larger volume of U.S. oil production did not prevent the United States from being exposed to the 1990 oil price spike, following the invasion of Kuwait. These examples suggest that there is limited comfort in being the leading oil producer in the world.

The right panel of Figure 1 highlights the fact that all three leading oil producers account for only a small fraction of global oil production, with the United States reaching about 10% in

² Production data for the former Soviet Union have been excluded to maintain consistency over time and because the Soviet Union was not a major participant in global oil markets. Data for 2014 are based on averages until July 2014.

³ The Financial Times recently reported that, as of September 2014, U.S. liquid petroleum production exceeded that of Saudi Arabia and Russia (see Crooks and Raval 2014). This comparison includes natural gas liquids in addition to crude oil and condensate. Because natural gas liquids tend to be used as feedstocks for the petrochemical industry rather than for producing fuel, they are excluded from our analysis of the crude oil and gasoline markets. It should be noted, however, that some natural gas liquids can be used in gasoline blending and as feedstocks in gasoline production.

2014. This means that the additional oil production in the United States in recent years, although important from a domestic point of view, has been small compared with the size of the global oil market. This fact is important to keep in mind in discussing the impact of the U.S. shale oil revolution. The price of oil is largely determined in global markets. As dramatic as the increase in U.S. shale oil production has been by historical standards, the right panel of Figure 1 reminds us that it is unrealistic to expect these changes in U.S. oil production to have a large impact on global oil prices (also see Alquist and Guénette 2014).

2. The Evolution of U.S. Shale Oil Production

So far we have examined overall U.S. crude oil production. Figure 2 traces in more detail the evolution of the production of U.S. shale oil. Two observations stand out. First, shale oil production initially increased exponentially, but the trend growth has become nearly linear as of late. Second, much of shale oil production is concentrated in a few geographic regions of the United States. By far the most productive shale oil plays are Eagle Ford and the Permian Basin in Texas and the Bakken in Montana/Dakota, which alone account for considerably more than half the output.⁴ To gauge how big these production numbers really are, it is useful to observe that in March 2014 the U.S. economy produced on average 8.2 millions of barrels/day (mbd) and imported an additional 7.3 mbd to meet its oil needs. Of the total 15.5 mbd of crude oil only about 3.6 mbd were produced from shale oil. In other words, as of March 2014, shale oil accounted for almost half of U.S. oil production, but only about a quarter of the total quantity of oil used by the U.S. economy. This magnitude is far from negligible, but to understand the excitement about shale oil one has to consider projections of future U.S. shale oil production.

Figure 3 displays EIA production estimates and projections for all forms of U.S. crude oil

⁴ A shale oil play refers to a geographical area suitable for shale oil production, whereas oil fields refer to areas suitable for conventional crude oil production.

production as of 2012. The projections shown are based on the reference case or business-as-usual trend estimate, given known technology and technological and demographic trends. There is no expectation that conventional onshore oil production (or for that matter off-shore oil production) will increase in the foreseeable future. At best they will remain stable at current levels in the long run. All of the growth in U.S. oil production going forward, if there is to be any, therefore must come from shale oil (referred to as “tight oil” in the figure). The projection shows a sharp increase in shale oil production until 2015, followed by zero growth until 2020 and a steady decline to today’s level of production by 2040.⁵

It has to be kept in mind that these projections are based on a host of assumptions most of which could be debated. Four concerns stand out. First, increases in shale oil production are not permanent. As Figure 3 illustrates, one would expect shale oil production to taper off after a few years, especially if the current level of investment cannot be sustained or if new promising shale oil plays cannot be found.

Second, the projected flow of shale oil production reflects estimates of the stock of shale oil that can be recovered using current technology that in turn are subject to substantial error.⁶ For example, in the summer of 2014 the EIA reduced its estimate of the recoverable Monterey shale oil stocks from 15.4 million barrels to 0.6 million barrels. This implied a 64% reduction in previous estimates of recoverable U.S. shale oil stocks. Clearly, such reductions in the stock of recoverable shale oil also affect the expected flow of shale oil production. This particular

⁵ Figure 3 also relates the peak level of U.S. oil production projected for the second half of this decade to the maximum level of U.S. oil production in 1970, shortly before the United States became dependent on crude oil imports for the first time in postwar history. There is little comfort in the fact that the United States is projected to reach this level again within a few years, however, given that the size of the U.S. industrial sector has more than doubled since then. Even accounting for higher oil efficiency, one would expect the U.S. economy to remain dependent on oil imports on that basis.

⁶ The EIA refers to these stocks as recoverable resources. This concept is distinct from the more conventional concept of oil reserves (which itself is a somewhat ambiguous concept) and less clearly defined. It should be noted that EIA estimates of recoverable resources in the past have been based more on information provided by industry sources than on independent in-depth geological studies.

revision resulted from the realization that the geology of the Monterey shale oil play made it technically more difficult and more costly to exploit than anticipated. It is important to stress that not all revisions of the stock of shale oil are necessarily downward. There is uncertainty in both directions. For example, there is evidence of significant productivity gains in fracking that could further lower the costs of recovering shale oil and raise future estimates of recoverable shale oil (see Covert 2014). There is also the possibility of further technological breakthroughs.

Third, the projected flow of shale oil production depends not only on the stock of recoverable shale oil below the ground, but also on the price of crude oil. Implicit in projections of the flow of shale oil production is the premise that the price of oil will remain high enough in the future such that continued investment in shale oil plays takes place. The decline in the price of WTI crude oil from about \$100 in July 2014 to below \$70 by the end of November 2014 has illustrated that the shale oil industry is vulnerable to downside oil price risk. Because the industry is capital intensive, it relies heavily on debt financing which may dry up when banks perceive the oil price risk to be too high, undermining the projections in Figure 3. At which price this happens differs across shale oil plays, making it difficult to quantify these effects in the aggregate. For example, Platts (2013) suggests that it may take oil prices below \$50 per barrel to shut down production at Eagle Ford. There also are indications that the marginal cost of shale oil production is declining at least in some locations, making the industry increasingly more robust to oil price declines, but such estimates are hard to verify and may not apply to other producers.

A final concern is that Figure 3 – by adding up barrels of oil as though all crude oil were the same – ignores the inherent differences in the quality of shale oil compared with conventional crude oil. The quality of crude oil can be characterized mainly along two dimensions. One is the oil's density (ranging from *light* to *heavy*) and is typically measured

based on the American Petroleum Institute (API) gravity formula; the other is its sulfur content (with *sweet* referring to low-sulfur content and *sour* to high-sulfur content). Figure 4 provides an overview of how commonly quotes crude oil benchmarks (including WTI and Brent) can be characterized along these dimensions. Shale oil consists of light sweet crude (at most 45 API), ultra-light sweet crude (about 47 API) and condensates (as high as 60API). Thus, not all shale oil is a good substitute for conventional light sweet crude oil such as the WTI or Brent benchmarks. The quality of the crude may affect the yield of refined products obtained in the refining process. Moreover, there have been reports that refining shale oil may cause technical problems in running refineries not encountered with conventional crude oil. This point is ignored in Figure 3.

To conclude, whether the United States will ever become independent of imported crude oil seems highly uncertain at this point. Such predictions are predicated on very rapid growth in shale oil production in years to come as well as stable production levels for conventional U.S. crude oil. There is considerable risk that shale oil production may decline much earlier than projected and that the U.S. may never become a net oil exporter. Even taking the projections in Figure 3 at face value, however, any aggregate analysis of the oil market is likely to be misleading given the regional and international fragmentation of the market for crude oil after 2010.

3. The Fragmentation of the Market for Crude Oil after 2010

Crude oil is purchased by refineries which convert the crude oil to refined products such a diesel, gasoline, jet fuel or bunker fuel. To understand the impact of the shale oil revolution on the U.S. price of oil, it is important to understand the structure of the U.S. refining market. Not all refineries are alike. Their technical configuration determines which type of crude oil they can process. Light sweet crudes are well suited for the production of gasoline, whereas heavy sour

crudes are best suited for producing diesel fuel and for producing heavier fuel oils sold at a discount to run ships or power plants. Refining heavy crude oil into gasoline requires advanced technologies and is more costly. Nevertheless, there are refineries that employ such expensive technologies because heavy sour crudes tend to be much lower priced than conventional light sweet crude oil such as the Brent or WTI.

U.S. refineries are heavily concentrated along the Gulf Coast and along the East coast with additional refineries located near major population centers (see Figure 5). Not all of these refineries are able to process heavy sour crudes. Whereas many refineries along the Gulf coast have invested in the advanced technologies required to produce gasoline from low-priced heavier crudes imported from Saudi Arabia, Venezuela and Mexico, U.S. refineries along the East Coast have traditionally relied on imports of high-priced light sweet crude oil (mainly from Nigeria, Angola and Algeria, but also from Europe) which are refined using more conventional technology.

It is against this backdrop that we need to view the shale oil revolution. Most shale oil is well suited for the production of gasoline. One would have thought that this additional supply of light sweet crude should have been easily absorbed by U.S. refiners, but instead the surge in shale oil production caught the U.S. refining industry off guard. For many years, there had been signs of light sweet crude oil becoming increasingly scarce in the world. As the composition of the grades of crude oil available in the market shifted toward heavy and sour crudes, many refiners in Texas invested in technology that allowed them to become the world leader in processing heavier crudes, despite their higher sulfur content. In contrast, European refiners much like the U.S. refineries along the East Coast continued to rely on imports of light sweet crude oil.

When shale oil was shipped in ever increasing quantities to the U.S. oil market hub in Cushing, OK, after 2010, the refiners most naturally suited to taking advantage of this opportunity were the refiners along the East Coast. Because traditionally these refiners supplied the interior of the country with refined product produced from imported light sweet crudes, however, there was no pipeline infrastructure in place to transport the shale oil to those refineries. Alternative means of transporting crude oil such as barges and rail cars simply were not up to the challenge of moving large quantities of shale oil to the East Coast, given the increased demand for oil transports in other parts of the country.

Likewise, it proved difficult to sell the shale oil to Texas refineries. Not only were many of those refineries not well-equipped to process light sweet crude oil on a large scale, given their investment in technologies for processing heavy crudes, but there were no oil pipelines running from Cushing to Texas as of 2010. Traditionally, the system of oil pipelines in that region was designed for transporting imported oil from the Gulf Coast ports to the interior, not from the interior to the refineries along the Gulf Coast. Because reversing and extending existing oil pipelines or building new pipelines is expensive and time consuming, and rail and barge transport could not cope with the required volume of shipments, a glut of light sweet crude oil developed in Cushing.

The glut was not limited to light sweet crude oil. The rise of shale oil coincided with the rise of imports of heavy Western Canadian crudes extracted from oil sands in Alberta and Saskatchewan. These oil imports from Canada are priced differently from conventional light sweet crude oil much like alternative heavy crudes imported from Venezuela or Saudi Arabia. As the production of shale oil was stimulated by high global oil prices, so was the production of heavy crudes from Canadian oil sands. Like most shale oil, Canadian crude oil was shipped by

pipeline, rail, or barge toward the hub of U.S. oil trade in Cushing, OK, where it failed to find enough buyers. One reason was that most East Coast refiners would not have been able to process heavy crudes, even if there had been a way of shipping the Canadian oil there. The other reason was that, at the same time, there was not enough transportation capacity from Cushing to the Texas refineries which actually would have been interested in purchasing heavy crudes.

The continued build-up of the supply of both light and heavy crude in Cushing resulted in a mismatch between the types of crude oil supplied to this market and the types of crude oil preferred by refiners buying in this market. Local refineries in the Midwest were simply not set up to process large quantities of unconventional types of crude oil. To the extent that refineries have the flexibility to modify their feedstock to process greater volumes of lighter crudes, for example, doing so often reduces their profitability. More generally, reconfiguring an entire refinery to allow it to process different grades of crude oil tends to be an expensive and time-consuming process.

The local excess supply of light sweet crude oil, in particular, put downward pressure on the U.S. price of oil, as measured by the WTI price of oil, relative to the Brent price benchmark, whereas the discounts on the price of heavy crude went unrecorded by conventionally used measures of the U.S. price of oil such as the WTI price. It is important to stress that this downward pressure on the U.S. price of oil arose not because unconventional crude oil helped satisfy the world's demand for gasoline (indeed the magnitudes in question alone argue against this interpretation), but because of a lack of demand for the oil available in Cushing from refineries operating in this market. The oil glut that first arose in the Midwest in 2011 coexisted with high demand for imported light sweet crude oil along the coast. In other words, the U.S. oil market had become fragmented regionally as well as distinct from the global oil market. It is

useful to review the origins of this development in more detail. Specifically, the decline in the U.S. price of oil can be traced to three constraints: the inability to export this crude oil, on the one hand, and capacity constraints in the transportation infrastructure and in the refining infrastructure, on the other.

3.1. The Role of Oil Exports

Under normal circumstances one would have expected the excess supply of unconventional crude oil to be resolved by oil exports from the United States to the rest of the world. This did not happen for several reasons. It is useful to start with the case of the heavy Canadian crudes. The reason these Canadian crudes are being exported to the United States in the first place is that Canada lacks sufficient pipeline capacity to transport its oil production to ports, from where it could be exported. Efforts to build additional pipelines to the Pacific coast are bogged down over disputes with the First Nations peoples owning the land in question. In practice, Canada's only option for now is to use existing pipelines in the center of the country to move most of its crude oil production to the United States.

It may seem that there should be a market for this crude oil in Europe. European refiners, however, are used to processing light sweet crude oil and hence have no use for heavy Canadian crude oil. There is no indication of European countries being willing or able to adapt their refining industry to be able to handle heavier crudes such as the Canadian oil. Another potential market would be East Asia, but exporting this oil from the United States to Asia would require pipelines from the central plains to the Pacific coast. There are no such pipelines at this point and the existing rail capacity does not suffice to support large scale shipments of crude oil to the Pacific coast. An additional problem is that Asian countries are used to processing lighter crudes from the Middle East. A recent study by Hackett et al. (2013) concludes that without Canada

demonstrating its ability to provide a continuously high volume of heavy crude, Asian countries will not invest in the additional refining infrastructure required to process heavy Canadian crudes, while the construction of suitable pipelines relies on there being evidence of sufficient demand and refining capacity for heavy crudes in Asia. In contrast, Platts (2013) notes that some Asian refiners, particularly in China, have the capacity to run the heavy Canadian crude oil. Either way, the difficulty of reaching the Pacific other than by rail remains.

One alternative would be to ship this crude oil from the Gulf coast, but this would require shipping the oil around the Cape of Good Hope or around Cape Horn, significantly increasing transit time. The added cost of shipping would put these exports to Asia at a competitive disadvantage compared with Asia's oil suppliers in the Middle East (see Figure 6). Moreover, shipping oil over such long distances economically would require the use of large oil tankers known as very large crude carriers (VLCCs) or ultra large crude carriers (ULCCs). Servicing such large tankers would require considerable investment in infrastructure along the Gulf Coast including off-shore loading facilities for ULCCs and pipelines to ensure a steady flow of oil. It is not clear whether such facilities will be built, unless the price of oil is expected to remain very high.

One way of shortening this route would be to ship the oil through the Panama Canal. Historically, the Panama Canal has been of little relevance for oil trade. The largest oil tankers currently in use are nearly five times larger than the maximum capacity of the canal. Although the Panama Canal Authority has embarked on a program to widen the Canal, which is scheduled to be completed in 2015, even after this expansion the canal will not be able to accommodate VLCCs or ULCCs, suggesting that the Canal will remain of limited importance for oil shipping (see U.S. Energy Information Administration 2014).

For these reasons, it is unlikely that Canadian oil will ever be re-exported from the Gulf Coast on a large scale, although in the current environment such re-exports would be perfectly legal. The problem is not only for this crude oil to reach the Gulf Coast in large quantities, but to find buyers abroad. At the same time, U.S. law prohibits the export of domestically produced crude oil (with some exemptions at the discretion of the Commerce Department), making it nearly impossible to export either conventional light sweet crude oil or shale oil from the continental United States. There has been some recent discussion of rescinding this export ban, which was put in place in 1975, following the experience of the 1973/74 oil crisis, in an attempt to insulate the United States from foreign oil price shocks. Leaving aside the question of whether this ban ever achieved its objective, the case can be made that even if the ban were lifted today, few exports would take place in the short run. As with Canadian oil, one problem is that this oil would have to be shipped long distances adding to its price. The key difference is that the light sweet crude could be shipped to Europe, and the European market would be much closer than the East Asian market, ameliorating this problem. Another problem is that the United States lacks the transportation capacity for large-scale oil exports from the Gulf of Mexico at this point, although some of the pipelines from Eagle Ford to the Corpus Christi on the Gulf Coast currently have excess capacity.⁷ Nevertheless, in the long run, one would expect these problems to be resolved. Allowing exports would raise the price of oil received by domestic producers, and reduce the rents currently received by U.S. refiners at the expense of U.S. oil producers.

⁷ Recently, this port has already been used to move shale oil up the Gulf Coast and even to the East Coast, following the conversion of some refineries there which used to process imported light sweet crude (see Platts 2013). The oil tankers used for this purpose are U.S. flagged Panamax vessels (i.e., vessels small enough to fit through the Panama Canal rather than the VLCCs or ULCCs used for long-distance shipping). Platts (2013) notes that additional docks and tankers may be needed to relieve the bottleneck in shipping that is already developing at Corpus Christi. One constraint is the Jones Act that necessitates the use of U.S.-flagged vessels for transporting goods between U.S. ports, restricting the number of vessels available and inflating oil tanker rates on these routes.

3.2. Implications for the Price of Oil

One creative response of the U.S. oil industry to the glut of light sweet crude oil has been to blend heavy crudes and shale oil in the right proportion to mimic mid-grade crude oil of the type traditionally imported and refined along the Gulf Coast. Refineries along the Gulf Coast are among the most sophisticated refineries when it comes to blending crudes. Refiners use linear programming techniques to determine the optimal mix of crude oil purchases based on the relative cost of different crudes and the yields of different products. Refining blends of crude oil is not without drawbacks, however. It requires more sophisticated equipment than processing conventional crudes, raising the cost of refining. This is why blending has not played an important role in U.S. refining traditionally. The incentives for blending changed with the availability of low-priced heavy crude from Canada and low-priced domestic light sweet crude. The low prices of these crudes made the blending process economically viable.

The practice of blending crude oil has allowed refiners along the Gulf Coast to process more of the rising supply of shale oil, alleviating price pressures on the WTI price relative to Brent. Such blends, however, can only be processed to the extent that the oil in question can be transported to Texas by rail or by pipeline. The challenge for the refining industry has been that with the increased production and imports of unconventional oil, many existing pipelines were in the wrong location or were running the wrong way, sustaining local oil shortages in some locations, while creating gluts in others. Initially, the glut was concentrated in Cushing, OK, the hub of U.S. oil pipelines. Cushing had effectively become landlocked, with more and more oil flowing in from Bakken and other shale oil plays as well as Canada. This oil had to be sold at a discount or stored in inventories in the absence of a buyer.

One indication of this bottleneck in the transportation infrastructure is the fall in the WTI

price of crude oil below the global price of crude oil, as measured the Brent price, starting in 2011 (see Figure 7). This price difference reflected the excess supply of light sweet crude in Cushing, Oklahoma, where the WTI price is measured. The problem was not a lack of final demand for refined products, but rather a lack of effective demand from refineries. Another indication is the unprecedented spread between the price of Louisiana Light Sweet (LLS) and WTI crude oil beginning in 2011. LLS is produced on the Gulf coast close to where many U.S. refineries are located. Because there was a shortage of light sweet crude oil along the coast, LLS traded at a premium reflecting the price of oil imports in the Gulf region. As a result, the price of LLS closely tracked that of Brent crude oil with the comparatively high price of Brent reflecting the tightness of global oil markets, as Asia came to rely on Brent oil imports. The price discount on WTI crude oil after 2011, in contrast, reflected the fact that this oil was in the wrong location and hence traded at a discount.

The oil glut in Cushing was finally alleviated starting in mid-2013, as existing pipelines originally running from Texas to Cushing were reversed, new pipelines to Texas refineries opened, and rail transport increased (see Platts 2013). Just as the spreads between WTI, Brent and LLS prices were shrinking in late 2013, however, the situation changed again. A sellers' market from the point of view of oil producers along the Gulf coast turned into a buyers' market from the point of view of refiners. As new pipelines from Cushing to the Gulf Coast allowed oil to flow more freely to the Texas refineries, oil inventories in Cushing declined. At the same time shale oil production at Eagle Ford accelerated and began competing with LLS along the Gulf Coast. With the increased availability of both light sweet and heavy crude oil from the interior of the country, refineries chose to pay less for this oil rather than match high prices for oil imports. Because domestic and Canadian oil producers were unable to export their oil production on a

large scale, they had little choice but to acquiesce. The continued influx of shale oil resulted in domestic light sweet crude, including both WTI and LLS benchmarks, trading at a discount compared with the Brent price. In contrast, high-priced imports of crude oil declined, freeing up this crude for markets abroad, and reducing U.S. net oil imports.

The overall glut in the central part of the United States was compounded by the opening of an important segment of the Keystone XL pipeline in January of 2014. The Keystone XL pipeline consists of several distinct parts (see Figure 8). One is a pipeline connecting the oil sands in Alberta with Cushing, OK. It is unclear at this point whether this pipeline will ever receive approval by the U.S. government, but this has not prevented Canadian oil from being transported along the less direct route from Alberta via Saskatchewan and Manitoba. Another (and arguably more important) part of the Keystone XL project is a pipeline connecting Cushing, OK, with the oil refineries in Texas. This part of the pipeline started operating in early 2014, with an additional extension to Houston scheduled to be completed in 2015. The additional transport capacity amplified the flow of crude from Cushing to the Texas Gulf Coast, sustaining the price wedge between the global and the U.S. price of light sweet crude.

Today, there is growing concern in the market about the prospect of capacity shortages in refining light sweet crude oil, given the sustained glut of light sweet crude oil on the Gulf Coast, but there also are signs of the refining market adapting. Some refiners have found ways of processing more shale oil, and there continue to be improvements in the oil transportation infrastructure that allow some of this oil to reach refiners along the East Coast. If this process continues, one would expect the price spreads in Figure 7 to erode over time with WTI and LLS ultimately reaching Brent levels, at least unless U.S. shale oil production grows faster than the ability to transport and process this crude oil. This convergence should be strengthened on the

margin to the extent that lower U.S. demand for imports of light sweet crude oil will, all else equal, permit more of this oil to be shipped to Asia, allowing Brent prices to decline. More realistically, however, this glut will only be resolved by adding pipeline capacity to East Coast refineries or by increasing the use of oil tankers shipping oil from the Gulf Coast to the East Coast. Alternatively, a downturn in the production of heavy Canadian crudes and in the production of U.S. shale oil, triggered by the general decline in all oil prices after mid-2014, could also alleviate the glut of unconventional crude oil in the U.S. market. Finally, a change in U.S. policy toward oil exports, allowing conventional light sweet crude oil to be exported, would in the long run restore arbitrage between WTI, LLS, and Brent prices.

In contrast with the market for light sweet crude oil, effective demand for heavy crudes has been strong, once sufficient pipeline capacity to the Gulf Coast had become available. One reason is, of course, that this oil has been less expensive than imported heavy crudes and that many refineries in Texas are eager to recoup their earlier investments in heavy crude refining technology. In addition, some refineries in the Midwest have begun to increase their processing capacity for heavy crude by retrofitting refineries. In fact, this oil no longer has to be shipped to Cushing, reducing the cost of transportation. Heavy crude traditionally has traded at a discount of between 20% and 50% relative to the WTI price. The increased demand for heavy crudes over time is likely to reduce the discount applied to heavy crudes without eliminating it, given the higher cost of producing gasoline from heavy crude.

From the Canadian point of view this development alleviates concerns about not being able to export (or re-export) Canadian crudes. In fact, it is not clear who else in the world would buy such crudes, given the unique capabilities and expertise of Texas oil refineries in processing heavy crudes. Although Canadian crude sells at a discount in the United States, this would likely

be the case as well if it were exported elsewhere, not to mention the additional discounts for transportation costs, if Canadian oil had to be shipped around the globe.

3.3. The Role of the Refining and Transportation Infrastructure

Restoring arbitrage between domestic and global oil markets will require the development of a suitable transportation infrastructure for crude oil. It will also require relaxing regional capacity constraints in refining specific grades of crude oil. Developing this infrastructure is a slow and costly process. All indications are that future changes in the transportation infrastructure will be incremental only.

In recent years, there has been considerable investment in expanding, reversing and converting existing pipelines to increase the flow of crude oil to the refineries along the Gulf Coast, yet – with the exception of several new pipelines connecting to Texas refineries (including the lower segment of the Keystone XL pipeline) – there has been remarkably little new construction of oil pipelines in the United States. A review of ongoing and proposed pipeline projects can be found in Platts (2013). How many of these projects will be approved and how many will remain economically viable if oil prices continue to fall, as they have in recent months, remains to be seen. It is also worth noting, that none of these projects address the concern that there is no pipeline network capable of transporting crude oil from Cushing to the East Coast, which would seem the single most important investment to alleviate the excess supply of light sweet crude in the central part of the country short of promoting U.S. oil exports.

Instead, many refineries, in particular along the East Coast and Pacific Coast, have favored leasing rail cars for moving shale oil to refineries. In 2013 nearly twice as many carloads of crude oil were transported by rail than in 2012 and more than 40 times as many as in 2008 (see Esser 2014). Although only 10% of U.S. crude oil production moves by rail, the shipping of

shale oil relies heavily on rail (and to a much lesser extent on trucks). As Esser (2014) points out, nearly 70% of crude oil produced in North Dakota, for example, is moved by rail. One reason is the greater flexibility of rail transport. Although transporting oil by rail is more costly than by pipeline, it is easier to obtain regulatory approval and to adjust the volume of shipping up or down, as needed. Another reason is likely to be the uncertainty about the future prospects of shale oil. Pipeline construction requires a commitment from producers and financiers for many years. A particular concern in building new pipelines to connect shale oil plays to existing crude oil pipelines in the center of the country has been that production in shale oil plays declines at a faster rate than in conventional oil fields and may cease before the capital costs of a new pipeline will have been recouped. The use of rail transport is not without drawbacks, however. For example, the ability to use rail cars is limited by the current rail infrastructure, including the condition of the tracks and the rolling stock as well as the availability of sidings to speed up traffic. It is also limited by the lack of competition on some routes.

An alternative and complementary strategy has been to build new refineries (or expand existing refineries) where the oil is produced or stored. Although the opening of new pipelines helped relieve the local glut of oil in Cushing by 2014, a more accurate description of events would be to say that it helped spread the glut to include the Gulf Coast region. Texas oil refiners absorbed some of the excess light sweet crude, but their ability to process large quantities of light sweet crude oil has been limited, which is reflected in the discounted prices of both LLS and WTI after late 2013. One reaction to the glut of shale oil has been to build new refineries in close proximity to shale oil plays, right where the shale oil is being produced. These refineries supply high-end products such as diesel (which is used both by locomotives, trucks and drilling rigs) to the local economy with the residual being sold as feedstocks for other refineries. In

addition to old plants having been reopened, there are three new refineries under construction in Texas, North Dakota and Utah. These refineries, however, are small in size. They process under 50,000 barrels/day, and their product is transported mainly by truck and rail to the end-user or, alternatively, to the closest refiner or to connecting point with oil pipelines or with barges on rivers and coastal waterways (see Fowler 2014).

One difficulty in scaling up these operations has been the lack of a suitable pipeline infrastructure; another has been the fact that environmental regulations become more stringent, the larger the refinery. Moreover, concerns that the export ban on oil may be lifted or that shale oil production in a given location may diminish for one reason or another, has prevented larger-scale investments in the refining infrastructure from taking place. The lack of infrastructure has been less a concern for shale oil plays such as Eagle Ford in Texas, for example, than for the Bakken or other more remote shale oil plays.

In the end, these developments are no substitute for additional refining capacity closer to the population centers where the refined product is needed. Building this infrastructure will not only require investments in refineries capable of processing lighter crude oils, but also additional investment in the transport infrastructure for crude oil and refined products. The only alternative to expanding refining capacity for lighter crudes would be a lifting of the export ban, but even that strategy would require major investments in transportation infrastructure.

4. Implications for the Price of Gasoline

For the time being, U.S. crude oil is likely to trade at a discount relative to global oil prices, as measured, for example, by the Brent price of crude oil. At first sight, lower oil prices might seem welcome from the point of view of consumers of gasoline. The decline in WTI and LLS prices below the global oil price level, however, does not mean that U.S. gasoline prices will fall. A

recent study by Borenstein and Kellogg (2014) explains that to the extent that the marginal gallon of gasoline in the Midwest is still imported from the East Coast, gasoline produced in the Midwest from low-cost domestic crude oil will cost the same as gasoline produced from high-cost imported crude oil. This argument can be taken a step further. Although there is an export ban on crude oil, this ban does not extend to refined products. In fact, there has been a surge in exports of diesel fuel and gasoline from the United States. The pipeline network for refined products is distinct from that for crude oil and refineries have not had any difficulty in exporting their products. This point is important because, to the extent that the fuel produced in the Midwest may be exported, refiners will charge the same fuel price that they can sell at in world markets, adjusted for transportation costs. Thus, all rents from lower crude prices in the Midwest accrue to refiners and the U.S. consumer does not get a reprieve at the gas pump. The key difference is that gasoline and diesel markets have remained integrated with the global economy, even as the global market for crude oil has fragmented. This observation has far-reaching implications for the U.S. economy.

5. Implications for the Transmission of Oil Price Shocks

Unexpected oil price increases matter for U.S. real GDP mainly for two reasons (see Kilian 2014). One is that wealth is being transferred abroad, when the price of imported crude oil (and hence the price of domestic fuel) increases. In other words, higher fuel costs act as a tax on the U.S. economy. Some of that tax may be rebated, as foreign oil producers import goods from the United States, but there remains a loss of welfare. Given that net imports of crude oil have declined with increased shale oil production, this tax and its recessionary effect would be expected to diminish. Moreover, the increased export of refined products will further improve the terms of trade compared with the past. There still will be a redistribution of wealth within the

U.S. economy, of course, but these distributional effects are far less clear-cut than the effects of a reduction in aggregate demand associated with higher costs of oil imports. Thus, the shale oil revolution is good news from the point of view of policymakers concerned with positive global oil price shocks.

Figure 9 illustrates that the degree to which the U.S. economy has become less vulnerable to such shocks largely depends on one's view of future shale oil production. The figure plots U.S. net petroleum imports (defined to include both crude oil and refined products). Not too long ago, the EIA projected a steady increase in net petroleum imports. In 2010, it dramatically lowered its forecast after the data showed a sharp reduction in net imports (reflecting mainly reduced oil consumption, as the price of oil surged, but also an increase in U.S. oil production). By 2014, the EIA again drastically lowered its forecast of net imports to levels last seen in the late 1980s, taking account of the rapid growth of shale oil production. Whether the latter forecast was too optimistic, time will tell, but there can be no doubt that the trajectory for net petroleum imports has changed in ways that were inconceivable just a few years ago.

Figure 9 also highlights that the U.S. oil and refining industry has effectively managed to bypass the ban on exports of crude oil by instead exporting refined products. Rather than shipping crude oil to Asia or to Europe, the United States is refining the excess oil locally, taking advantage of access to low-cost crude oil and selling the refined product at a competitive price abroad. The primary export destination for distillate, diesel, and gasoline products is Western Europe, with Latin America and the Asia-Pacific region a likely growth market. One would expect this trend to gather momentum, as domestic rail and barge transportation capacities for crude oil as well as international tanker capacity for refined products increase in the coming years. The increased reliance on petroleum exports is not without a downside, however, because,

as a result, the U.S. economy has become more exposed to unexpected declines in the price of crude oil, as the recent decline in the price of oil has illustrated. Whatever the stimulating effect of shale oil production on the economy is, this effect is at risk of being undone if the price of crude oil drops enough to make continued shale oil production unprofitable. This point is important because it suggests that energy independence is an illusory concept in an integrated global economy, no matter how much oil the U.S. economy produces.⁸

A second channel of transmission from oil price shocks to the U.S. economy operates through changes in the relative price of gasoline and other fuels. This channel has been emphasized in particular by Hamilton (1988). There is an ongoing debate about the quantitative importance of this channel in the data (see, e.g., Kilian and Vigfusson 2011). From the point of view of the shale oil debate, what we can say is that this operation of this channel remains unchanged, whatever the effects may be, given that gasoline prices continue to reflect the global price of crude oil rather than the domestic price.

6. Implications for the U.S. Economy

Independently of the question of how the rising shale oil production affects the transmission of oil price shocks, one of the hopes has been that shale oil would revive the manufacturing sector in the United States. Much of this manufacturing sector has moved to emerging economies in recent decades to take advantage of lower labor costs abroad. The hope of an industrial revival is based on the premise that manufacturing relies on energy and that shale oil provides a source of inexpensive energy that will give the United States a competitive edge compared with emerging

⁸ It is worth pointing out that U.S. shale oil production, all else equal, lowers the global price of oil even in the presence of the U.S. oil export ban because U.S. exports of refined products such as diesel or gasoline reduce the demand for crude oil in the rest of the world. In this sense, trade in refined products is a substitute for trade in crude oil. Of course, the effect of exporting these refined products on the global price of oil cannot exceed that of exporting the crude oil directly, and the latter effect is likely to be negligible, given the small magnitude of the surge in U.S. oil production compared with global oil production levels.

economies. Proponents of this view are hoping for a return of blue collar jobs to the United States, as firms reevaluate the costs and benefits of outsourcing. The flaw in this argument is that it is based on the premise of lower fuel costs, but, as has been shown, there is no reason for the U.S. prices of gasoline or diesel to mirror the decline in the price of domestic crude oil. Thus, there is little reason for the shale oil revolution to stimulate oil-intensive industrial activities on a large scale.

This conclusion stands in marked contrast to the natural gas sector. Although the shale oil revolution at first sight is closely related to the shale gas revolution, there is one important difference. Unlike in the gasoline and diesel market, there has been a noticeable decline in the U.S. wellhead price of natural gas since 2008 (notwithstanding a partial reversal in recent years). Access to inexpensive natural gas benefits in particular the petrochemical industry. One reason for low U.S. natural gas prices is that the natural gas market has never been a global market. Natural gas is transported by pipeline. Although natural gas may be cooled down and liquefied, allowing it to be shipped as liquefied natural gas (LNG) to any port in the world, the cost of LNG shipping is high and the infrastructure required to load and unload LNG is expensive. This fact has prevented the integration of regional natural gas markets and the emergence of a global price so far.⁹ As a result, the price of U.S. natural gas for the time being has been determined by domestic demand rather than global demand, allowing for a greater price response to increased domestic supply.

Thus, the main beneficiary from the U.S. shale oil revolution has been not gasoline consumers or oil producers, but the U.S. refining industry, which enjoys a competitive advantage

⁹ This situation may change as early as 2015 with the construction of new loading terminals in the United States that will allow U.S. shale gas to be exported. There is no ban on natural gas exports, so the ability to export U.S. natural gas in the long run will only be limited by the availability of unloading facilities for LNG tankers abroad and by how competitively this natural gas can be priced.

compared to diesel and gasoline producers abroad because of its access to low-cost crude oil. In fact, refiners have every incentive to preserve the status quo and to prevent a lifting of the U.S. ban on exports of domestically produced crude oil. There is an obvious conflict between the interests of U.S. refiners and of U.S. crude oil producers. An additional beneficiary of the shale oil revolution has been the transportation sector, notably the railroad industry, and the industries directly serving the oil sector.

Although these effects are concentrated in very few sectors of the economy, this does not mean that there are no macroeconomic effects from additional shale oil production. Clearly, the oil sector contributes to the value added of the U.S. economy.¹⁰ It is important to keep in mind, however, the comparatively small magnitude of this contribution to U.S. real GDP. There is no data on real value added in shale oil extraction, but even the contribution to real GDP of all mining activities in the U.S. economy (which includes in addition conventional oil, conventional and unconventional natural gas, coal, metals and minerals) is negligible, as illustrated in Figure 10. Moreover, there has been no noticeable increase in this contribution since shale oil production took off in 2009, so one would not expect large aggregate effects of shale oil production on the U.S. economy, even taking account of potential multiplier effects on other sectors.¹¹

This is not to deny that there are important effects on the economy at the local and state level in areas where shale oil plays are located (see, e.g., Hunt and Keniston 2014). Of particular interest has been the effect of increased shale oil production on employment. These local

¹⁰ An industry's value added is equal to its gross output (which consists of sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (which consist of energy, raw materials, semi-finished goods, and services that are purchased from domestic industries or from foreign sources).

¹¹ A number of macroeconomic studies including International Monetary Fund (2013) and Manescu and Nuño (2014) have examined the quantitative effects of the shale oil revolution on economic growth in the United States and elsewhere. These studies rely on stylized general equilibrium models of the global economy that make no allowance for differences in the quality of crude oil from different sources or for the transportation and refining bottlenecks highlighted in this article. Hence, their results are at best illustrative.

employment gains sometimes are not as large as public debate would suggest. In some example, industry and government estimates of new jobs created by shale drilling differ by a factor of 12. A detailed review of common errors in measuring the employment effects of shale drilling can be found in Mauro et al. (2013). Apart from the effect on employment, states containing shale oil plays also benefit from substantial increases in tax revenues.

For the average American, nevertheless, the shale oil revolution has changed little. As we already observed, gasoline prices at the pump have remained largely unaffected by increased shale oil production. One way of profiting from shale oil for someone living outside of Texas, Oklahoma, New Mexico, Colorado, North Dakota or Montana would be to own stocks of the refining companies that are able to buy crude oil at discounted prices, yet sell gasoline at undiscounted prices. Another way would be through private ownership of mineral rights. Fitzgerald and Rucker (2014) estimate gross royalties to private owners from oil and natural gas production combined at \$22 billion per year, as of 2012. These royalties are paid to U.S. citizens residing in every state of the Union. It has been suggested that perhaps 3% of the population are recipients of such royalties, although the distribution is unclear. Notwithstanding these qualifications, it is fair to say that there is no support for the notion that shale oil is a game changer for the U.S. economy.

7. Concluding Remarks

Although the increase in U.S. shale oil production since 2003 has been impressive, there remains much uncertainty about the persistence and scope of the shale oil boom. Visions of the United States becoming independent of oil imports, of a rebirth of U.S. manufacturing, and of net oil exports improving the U.S. current account seem far-fetched, when compared to the reality of the U.S. oil market today. Although there has been a widely noted decline in U.S. domestic oil

prices relative to international benchmarks such as Brent, this price decline is not being passed on to the consumer, ruling out a rebirth of U.S. manufacturing on the basis of low-cost gasoline and diesel fuel. The discrepancy between domestic and global oil prices has resulted from a breakdown of arbitrage reflecting the current U.S. ban on exporting crude oil and an inadequate transportation infrastructure that prevented the oil from being shipped to refineries able to process it.

The mismatch between the supplies of crude oil and the available refining and transportation capacity arose because the shale oil boom caught the refining industry by surprise. The U.S. shale oil boom was preceded by a growing shortage of light sweet crude oil in world markets. U.S. refiners responded to this trend by expanding their capacity to handle heavy crudes that remained in abundant supply, becoming the world leader in this field. They were therefore taken by surprise, when the U.S. market was inundated with light sweet crude recovered from shale oil plays after 2010. Not only was much of the refining structure ill-equipped to process this oil, but parts of the pipeline infrastructure developed over the preceding forty years became obsolete. As a result the U.S. oil market fragmented into regional markets, and became distinct from the global market for crude oil.

There are signs that the U.S. refining industry is gradually responding to the price differentials between domestic and imported crude oil. Reconfiguring the U.S. refining and transportation infrastructure, however, is a costly and slow process. Moreover, long-term investments in infrastructure are likely to be held back by uncertainty about the future of U.S. shale oil production, especially in light of recent declines in the price of crude oil. For the time being, therefore, the evolution of the U.S. price of oil is inextricably tied to the development of the U.S. refining, pipeline and rail infrastructure. Modelling these connections will become

increasingly important for understanding and forecasting the evolution of the domestic price of oil in the United States. It seems less important for analyzing U.S. retail fuel prices, however, which remain firmly integrated with the world economy and may be priced relative to international benchmarks.

Some observers have suggested that shale oil may have become victim of its own success, attributing the overall decline in the global price of oil in recent months to increases in shale oil production. Similar declines, however, also occurred in other commodity prices, suggesting that the causes have not been specific to the oil sector, but mainly reflect a weakening global economy. The most visible effect of shale oil production has been the decline in the WTI price relative to Brent. The persistent divergence between these prices since 2011 increasingly calls into question the use of the WTI price as a benchmark in pricing crude oil. The price of LLS, which during 2011-13 was considered a plausible alternative benchmark, since 2014 has closely tracked the WTI price, indicating that the U.S. market for light sweet crude oil is no longer fully integrated with the world market.

It may seem that Brent crude oil prices would be an obvious alternative benchmark, except for the fact that Brent suffers from its own drawbacks. One requirement of a global benchmark is sufficient liquidity. As Brent oil production declined over time, the definition of the Brent benchmark had to be broadened repeatedly, including successively lower grades of crude oil within the benchmark. It is unclear whether there remains enough oil in the North Sea to sustain a Brent benchmark in the long run. An interesting question is how global financial markets will deal with this situation. One possible solution would be a return to regional markets, ending a history of forty years of global market integration. Such a development would indeed be striking given the prevailing trend toward globalization in recent decades. Another

potential solution would be for the U.S. to remove its export ban on crude oil, which in the long run would be expected to reestablish arbitrage between alternative prices for light sweet crude oil.

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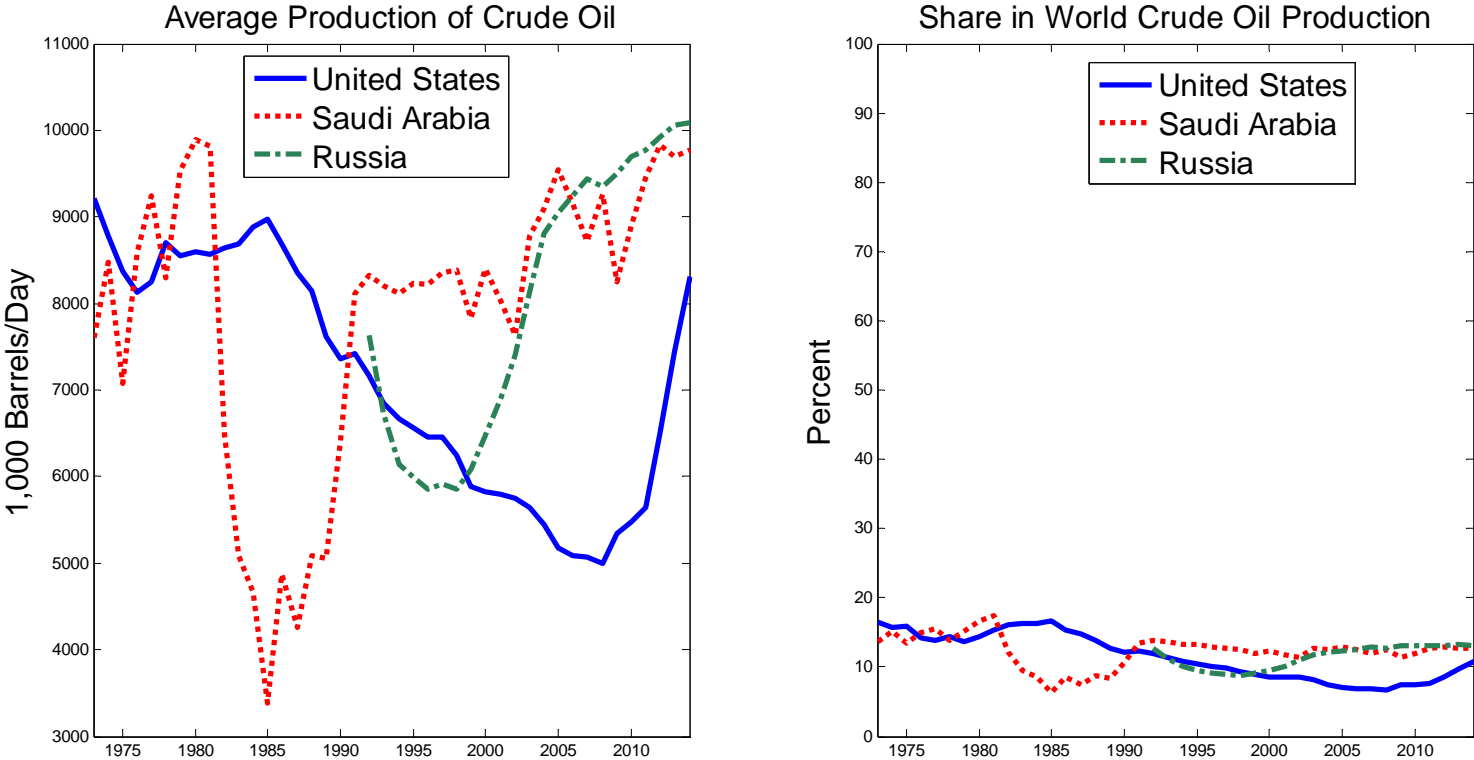
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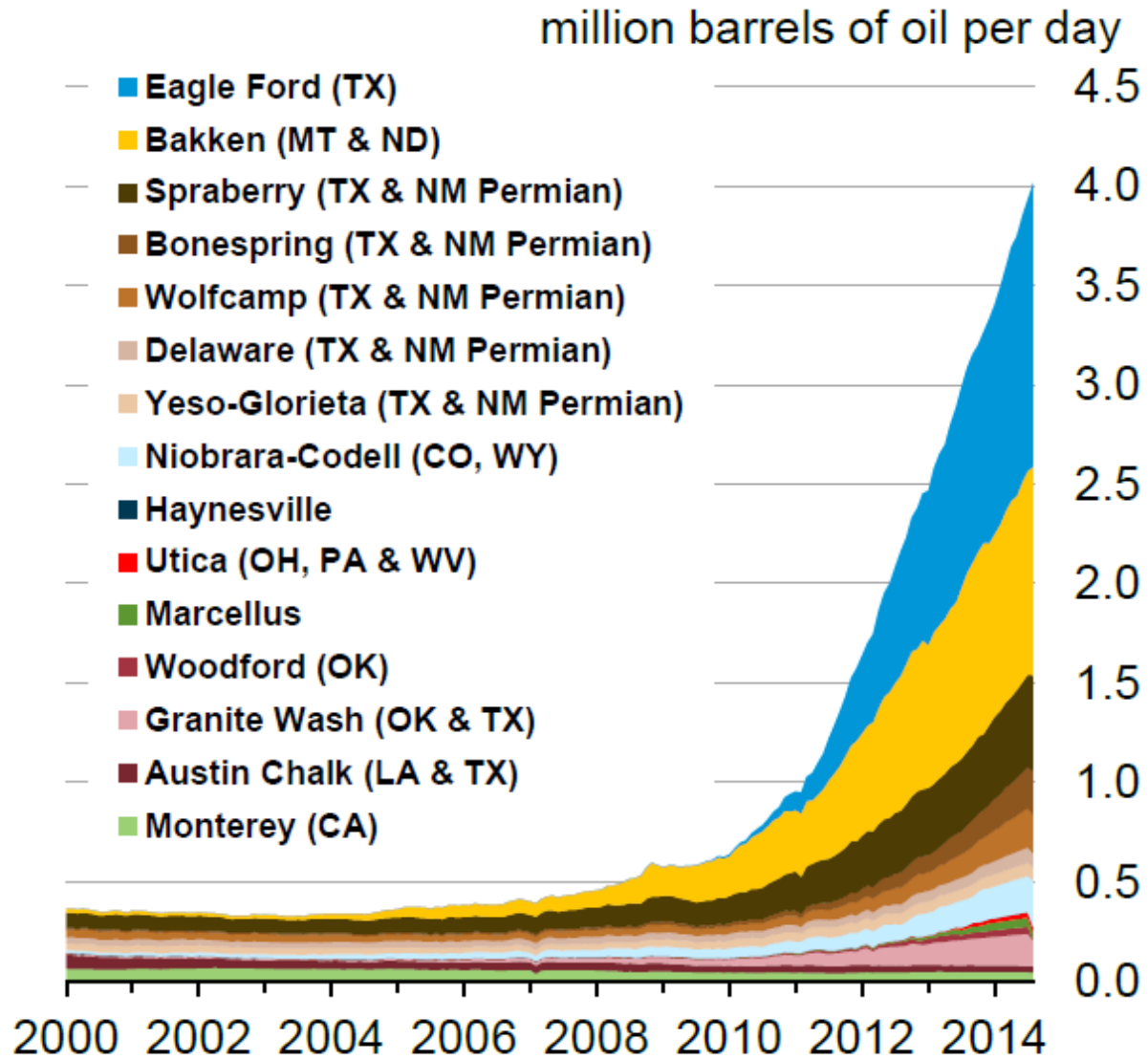
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Figure 1. The World's Largest Oil Producers during 1973-2014



NOTES: All data are from the EIA's *Monthly Energy Review* for October 2014. The 2014 data are based on the 7-month average for the year to date. Production data are for crude oil and lease condensate, but exclude natural gas plant liquids.

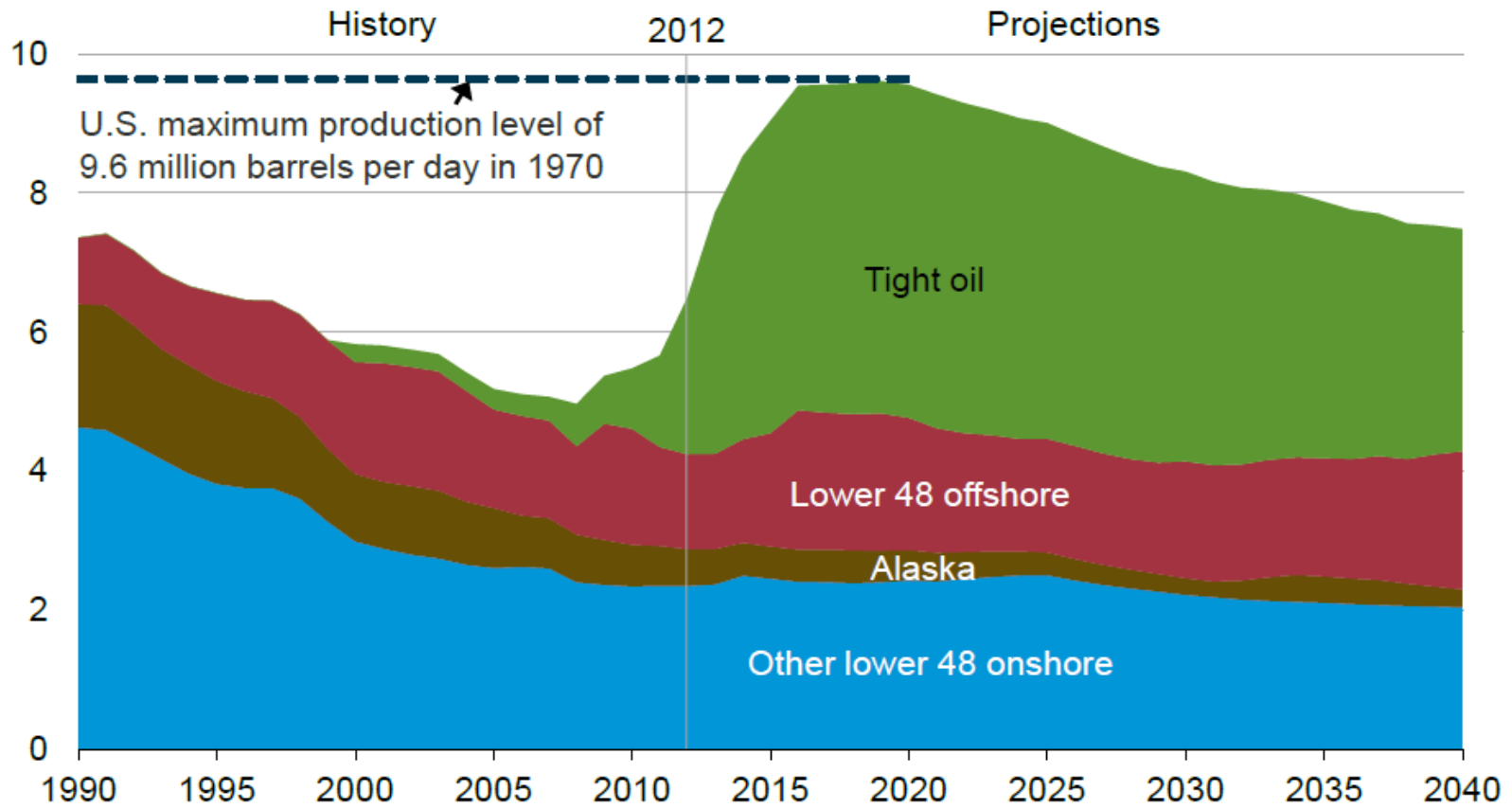
Figure 2. EIA Estimates of U.S. Shale Oil Production



Source: Official EIA estimates derived from state administrative data collected by DrillingInfo Inc. as reported in Sieminski (2014).

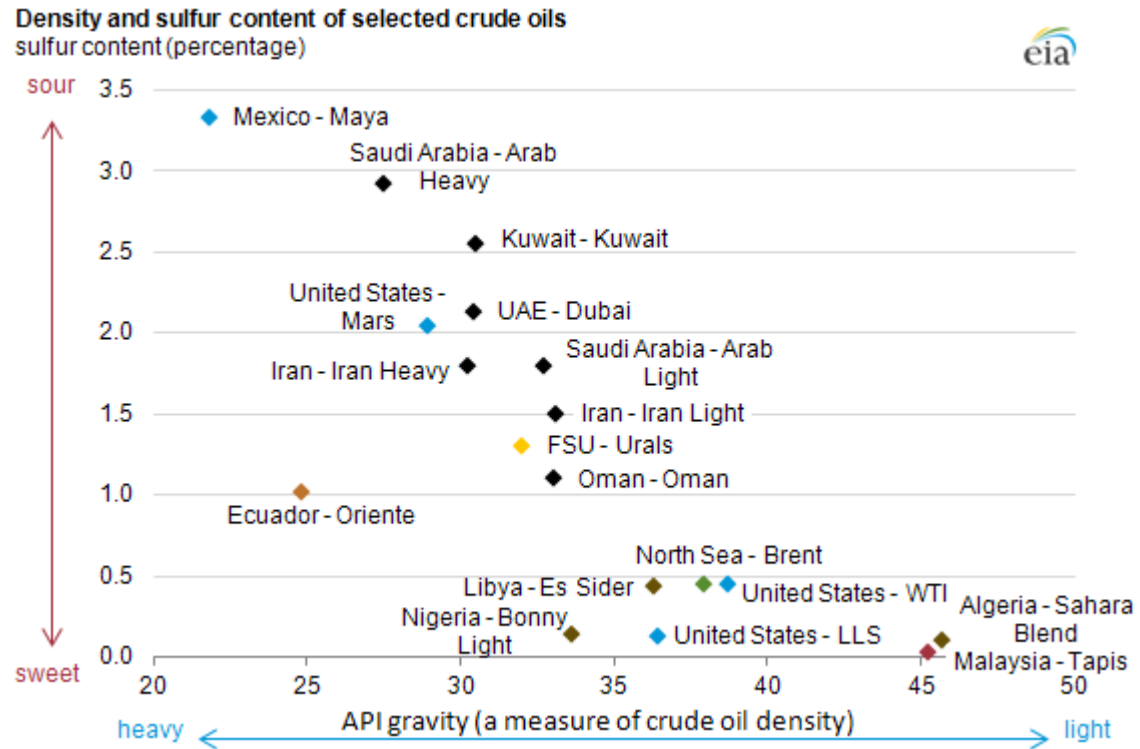
Figure 3. 2014 EIA Outlook for U.S. Crude Oil Production

U.S. crude oil production
million barrels per day



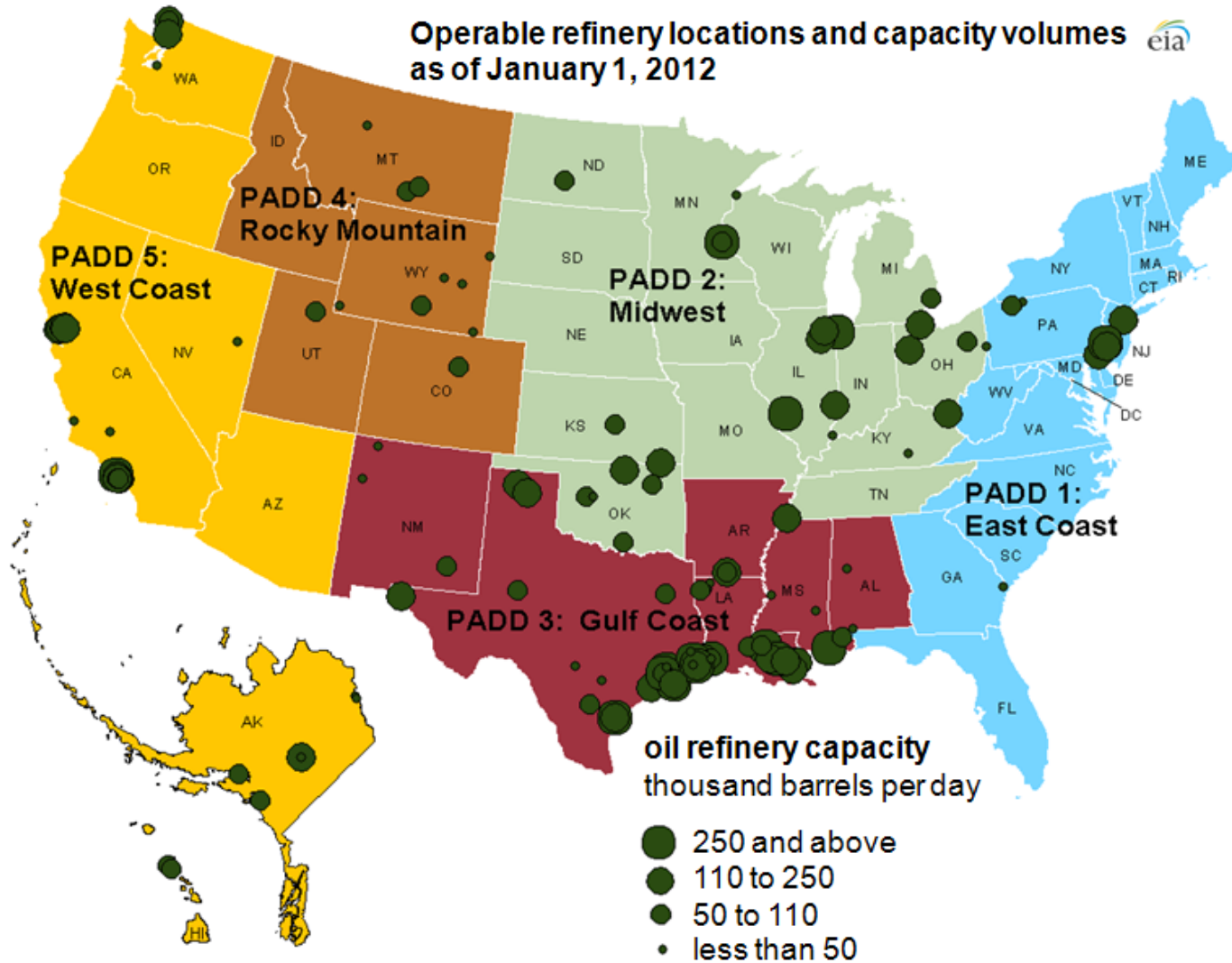
Source: EIA *Annual Energy Outlook* 2014 Reference case.

Figure 4: Classification of Conventional Crude Oil Benchmarks



Source: U.S. Energy Information Administration. MARS refers to an offshore drilling site in the Gulf of Mexico. WTI = West Texas Intermediate. LLS = Louisiana Light Sweet. FSU = Former Soviet Union. UAE = United Arab Emirates.

Figure 5. Location of U.S. Refineries



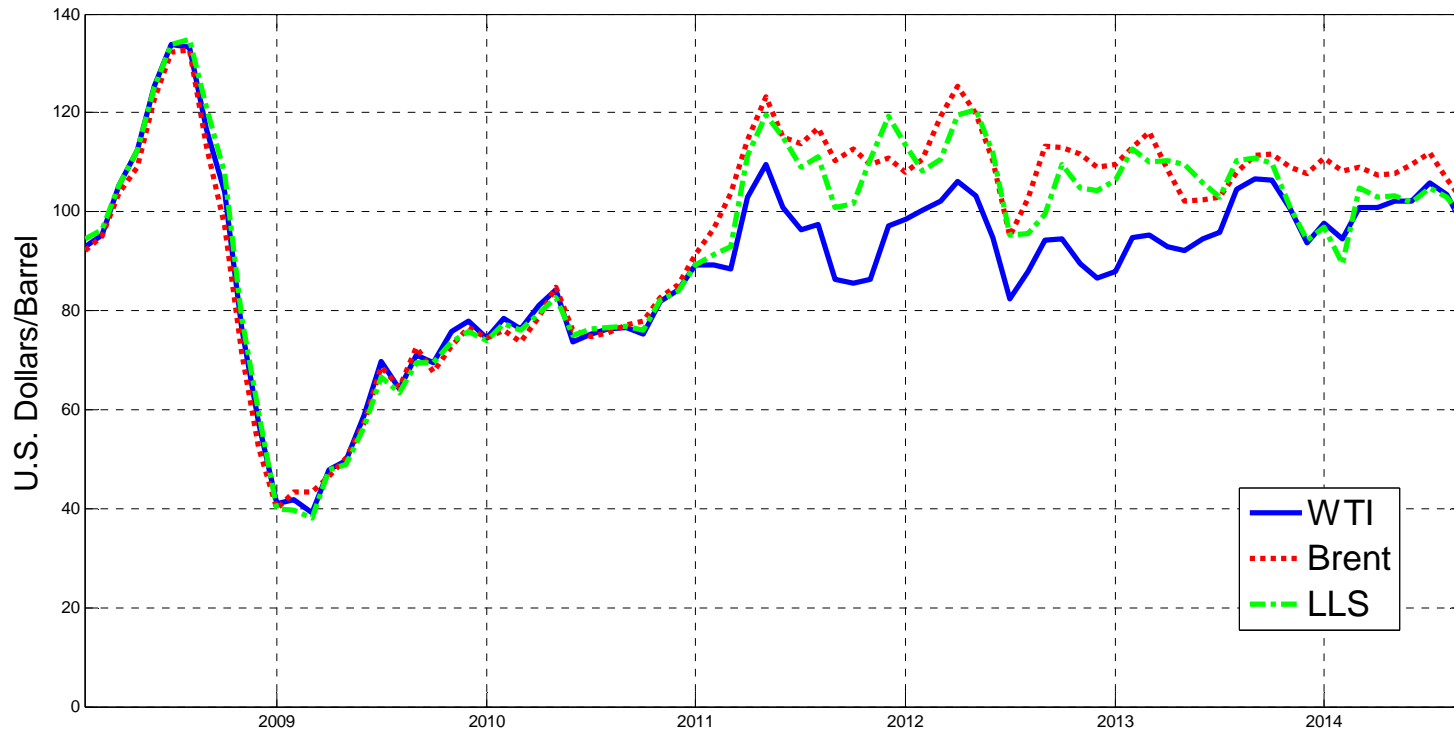
Source: U.S. Energy Information Administration, *Refinery Capacity Report*, 2012.

Figure 6. World Oil Shipping Routes



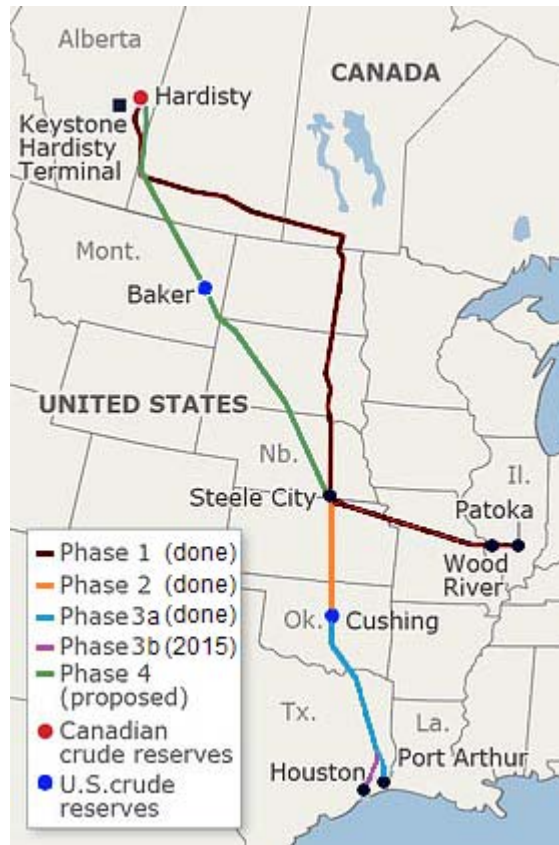
Source: U.S. Energy Information Administration.

Figure 7: Monthly Spot Price of Crude Oil, 2008.1- 2014.8



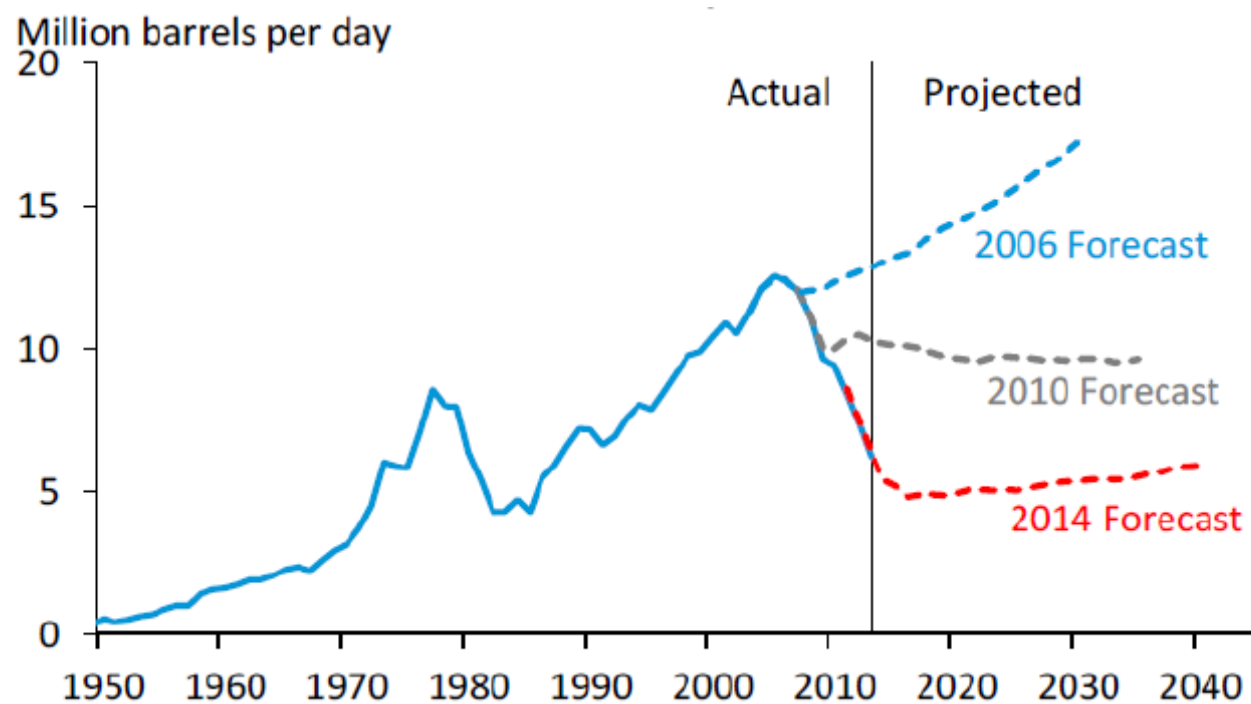
Source: Based on EIA data. LLS stands for Louisiana Light Sweet.

Figure 8: The Keystone Pipeline



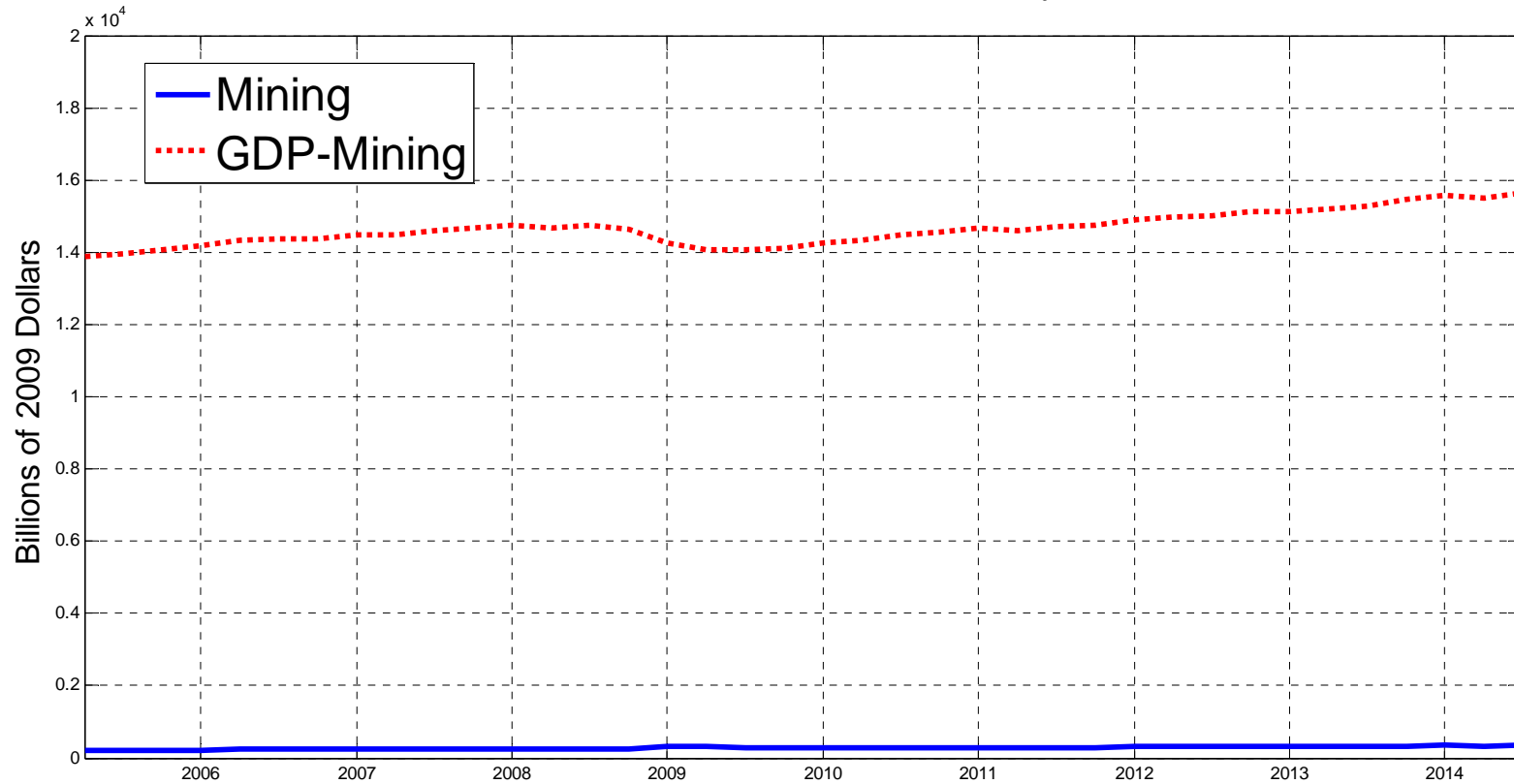
Source: TransCanada

Figure 9. EIA Projections of U/S. Petroleum Net Imports, 1950-2040



Source: Executive Office of the President of the United States, May 2014

Figure 10. Real Value Added by U.S. Private Industry in the Mining Sector and Real Value Added in the Remainder of the U.S. Economy, 2005Q1-2014Q2



Source: All data from the FRED database at the Federal Reserve Bank of St. Louis. The plot shows real value added by U.S. private industries in mining and U.S. real GDP adjusted for real value added by U.S. private industries in mining. The approximate share of mining in U.S. real GDP is 2.7% at the end of the sample. Mining is defined to include not only all conventional and unconventional oil and natural gas extraction, but also mining for coal, metals and minerals.

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