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ABSTRACT

This paper explores details behind the phenomenal increase in global crude oil production over the last century and a half and the implications if that trend should be reversed. I document that a key feature of the growth in production has been exploitation of new geographic areas rather than application of better technology to existing sources, and suggest that the end of that era could come soon. The economic dislocations that historically followed temporary oil supply disruptions are reviewed, and the possible implications of that experience for what the transition era could look like are explored.

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1 Oil prices and the economics of resource exhaustion.

One of the most elegant theories in economics is Hotelling's (1931) characterization of the price of an exhaustible natural resource. From the perspective of overall social welfare, production today needs to be balanced against the consideration that, once consumed, the resource will be unavailable to future generations. One option for society would be to produce more of the commodity today, invest the current marginal benefits net of extraction costs in some other form of productive capital, and thereby accumulate benefits over time at the rate of interest earned on productive capital. An alternative is to save the resource so it can be used in the future. Optimal use of the resource over time calls for equating these two returns. This socially optimal plan could be implemented in a competitive equilibrium if the price of the resource net of marginal production cost rises at the rate of interest. For such a price path, the owner of the mine is just indifferent between extracting a little bit more of the resource today or leaving it in the ground to be exploited at higher profit in the future.

This theory is compelling and elegant, but very hard to reconcile with the observed behavior of prices over the first century and a half of the oil industry. Figure 1 plots the real price of crude petroleum since 1860. Oil has never been as costly as it was at the birth of the industry. Prior to Edwin Drake's first oil well in Pennsylvania in 1859, people were getting illuminants using very expensive methods.[1] The term kerosene, which we still use today to refer to a refined petroleum product, was actually a brand name used in the 1850s for a liquid manufactured from asphalt or coal, a process which was then, as it still is now, quite expensive.[2] *Derrick's Handbook* (1898) reported that Drake had no trouble selling all the oil his well could produce in 1859 at a price of $20/barrel. Given the 24-fold increase in estimates of consumer prices since 1859, that would correspond to a price in 2010 dollars a little below $500/barrel. As drillers producing the new-found "rock oil" from other wells brought more of the product to the market, the price quickly fell, averaging $9.31/barrel for 1860 (the first year shown in Figure 1). In 2010 prices, that corresponds to $232 a barrel, still far above anything seen subsequently. Even ignoring the initial half-century of the industry, the price of oil in real terms continued to drop from 1900 to 1970. And despite episodes of higher prices in the 1970s and 2000s, throughout the period from 1992-1999, the price of oil in real terms remained below the level reached in 1920.

There are two traditional explanations for why Hotelling's theory appears to be at odds with the long-run behavior of crude oil prices. The first is that although oil is in principle an exhaustible resource, in practice the supply has always been perceived to be so vast, and the date at which it will finally be exhausted has been thought to be so far into the future, that finiteness of the resource had essentially no relevance for the current price. This interpretation could be reconciled with the Hotelling solution if one hypothesizes a tiny rent accruing to owners of the resource that indeed does grow at the rate of interest, but in practice has always been sufficiently small that the observed price is practically the same as the marginal extraction cost.

A second effort to save Hotelling's theory appeals to the role of technological progress, which could lower marginal extraction costs (e.g., Slade, 1982), lead to discovery of new fields

(Dasgupta and Heal, 1979; Arrow and Chang, 1982), or allow the exploitation of resources previously thought not to be economically accessible (Pindyck, 1978). In generalizations of the Hotelling formulation, these can give rise to episodes or long periods in which the real price of oil is observed to fall, although eventually the price would begin to rise according to these models. Krautkraemer (1998) has a nice survey of theories of this type and examination of their empirical success at fitting the observed data.

Although it can sometimes be helpful to think about technological progress in broad, abstract terms, there is also much insight to be had from looking in some detail at the specific factors that allowed global oil production to increase almost without interruption over the last 150 years. For this purpose, I begin by examining some of the long-run trends in U.S. oil production.

1.1 Oil production in the United States, 1859-2010.

Certainly the technology for extracting oil from beneath the earth's surface has evolved profoundly over time. Although Drake's original well was steam-powered, some of the early drills were driven through rock by foot power, such as the spring-pole method. The workers would kick a heavy bit at the end of the rope down into the rock, and spring action from the compressed pole would lift the bit back up. After some time at this, the drill would be lifted out and a bucket lowered to bail out the debris. Of course subsequent years produced rapid advances over these first primitive efforts– better sources of power, improved casing technology, and vastly superior knowledge of where oil might be found.

Other key innovations included the adoption of rotary drilling at the turn of the century, in which circulating fluid lifted debris out of the hole, and secondary recovery methods first developed in the 1920s, in which water, air, or gas is injected into oil wells to repressurize the reservoir and allow more of the oil to be lifted to the surface.

Figure 2 plots the annual oil production levels for Pennsylvania and New York, where the industry began, from 1862 to 2010. Production increased by a factor of 10 between 1862 and 1891. However, it is a mistake to view this as the result of application of better technology to the initially exploited fields. Production from the original Oil Creek District in fact peaked in 1874 (Williamson and Daum, 1959, p. 378). The production gains instead came primarily from development of new fields, most importantly the Bradford field near the Pennsylvania-New York border, but also from Butler, Clarion, and Armstrong Counties. Nevertheless, it is unquestionably the case that better drilling techniques than used in Oil Creek were necessary in order to reach the greater depths of the Bradford formation.

One also sees quite clearly in Figure 2 the benefits of the secondary recovery methods applied in the 1920s, which succeeded in producing much additional oil from the Bradford formation and elsewhere in the state. However, it is worth noting that these methods never lifted production in Pennsylvania back to where it had been in 1891. In 2010– with the truly awesome technological advances of the century and a half since the industry began, and with the price of oil 5 times as high (in real terms) as it had been in 1891– Pennsylvania and New York produced under 4 million barrels of crude oil. That's only 12% of what had been produced in 1891– 120 years ago– and about the level that the sturdy farmers with their spring-poles were getting out of the ground back in 1868.

Although Pennsylvania was the most important source of U.S. oil production in the 19th century, the nation's oil production continued to increase even after Pennsylvanian production peaked in 1891. The reason is that later in the century, new sources of oil were also being obtained from neighboring West Virginia and Ohio (see Figure 3). Production from these two states was rising rapidly even as production from Pennsylvania and New York started to fall. Ohio production would continue to rise before peaking in 1896, and West Virginia did not peak until 1900.

These four states together accounted for 90% of U.S. production in 1896, with the peak in production from the region as a whole coming that year (see Figure 4). Overall U.S. production declined for a few years with falling supplies from Appalachia, but quickly returned to establishing new highs in 1900, thanks to growth in production from new areas in the central United States, details of which are shown in Figure 5. Note the difference in scale, with the vertical axes in Figure 5 spanning 6 times the magnitude of corresponding axes in Figure 3. Each of the regions featured in Figure 5 would eventually produce far more oil than Appalachia ever did. These areas began producing much later than Appalachia, and each peaked much later than Appalachia. The combined production of Illinois and Indiana peaked in 1940, Kansas-Nebraska in 1957, the southwest in 1960, and Wyoming in 1970.

Far more important for U.S. total production were the four states shown in Figure 6, which uses a vertical scale 2.5 times that for Figure 5. California, Oklahoma, Texas, and Louisiana account for 70% of all the oil ever produced in the United States. Production from Oklahoma reached a peak in 1927, though it was still able to produce at 80% of that level as recently as 1970 before entering a modern phase of decline that now leaves it at 25% of the 1927 production levels. Texas managed to grow its oil production until 1972, and today produces about a third of what it did then. California production continued to grow until 1985 before peaking. The graph for Louisiana (bottom panel of Figure 6) includes all the U.S. production from the Gulf of Mexico, growing production from which helped bring the state's indicated production for 2010 up to a value only 33% below its peak in 1971.

Figure 7 plots production histories for the two regions whose development began latest in U.S. history. Production from Alaska peaked in 1988. North Dakota is the only state that continues to set all-time records for production, thanks in part to use of new drilling techniques for recovering oil from shale formations. To put the new Williston Basin production in perspective, the 138 million barrels produced in North Dakota and Montana in 2010 is about half of what the state of Oklahoma produced in 1927 and a fifth of what the state of Alaska produced in 1988. However, the potential for these fields looks very promising and further significant increases from 2010 levels seems assured.

The experience for the U.S. thus admits a quite clear summary. Production from every state has followed a pattern of initial increase followed by eventual decline. The feature that nonetheless allowed the total production for the U.S. to exhibit a seemingly uninterrupted upward trend over the course of a century was the fact that new, more promising areas were always coming into production at the same time that mature fields were dying out (see Figure 8). Total U.S. production continued to grow before peaking in 1970, long after the original fields in Appalachia and the central U.S. were well into decline.

And the decline in production from both individual regions within the U.S. as well as the United States as a whole has come despite phenomenal improvements in technology over time. Production from the Gulf of Mexico has made a very important contribution to slowing the rate of decline over the most recent decade. Some of this production today is coming from wells that begin a mile below sea level and bore from there through up to a half-dozen more miles of rock– try doing that with three guys kicking a spring-pole down! The decline in U.S. production has further come despite aggressive drilling in very challenging environments and widespread adoption of secondary and now tertiary recovery methods. The rise and fall of production from individual states seems much more closely related to discoveries of new fields and their eventual depletion than to the sorts of price incentives or technological innovations on which economists are accustomed to focus.

Notwithstanding, technological improvements continue to bring significant new fields into play. The most important recent development has been horizontal rather than vertical drilling through hydrocarbon-bearing formations accompanied by injection of fluids to induce small fractures in the rock. These methods have allowed access to hydrocarbons trapped in rock whose permeability or depth prevented removal using traditional methods. The new methods have enabled phenomenal increases in supplies of natural gas as well as significant new oil production in areas such as North Dakota and Texas. Wickstrom, et. al. (2011) speculated that application of hydraulic fracturing to the Utica Shale formation in Ohio might eventually produce several billion barrels of oil, which would be more than the cumulative production from the state up to this point. If that indeed turns out to be the case, it could lead to a third peak in the graphs in Figure 3 for the Appalachian region that exceeds either of the first two, though for comparison the projected lifetime output from Utica would still only correspond to a few years of production from Texas at that state's peak.

Obviously price incentives and technological innovations matter a great deal. More oil will be brought to the surface at a price of $100 a barrel than at $10 a barrel, and more oil can be produced with the new technology than with the old. But it seems a mistake to overstate the operative elasticities. By 1960, the real price of oil had fallen to a level that was 1/3 its value in 1900. Over the same period, U.S. production of crude oil grew to become 55 times what it had been in 1900. On the other hand, the real price of oil rose 8-fold from 1970 to 2010, while U.S. production of oil fell by 43% over those same 40 years. The increase in production from 1900 to 1960 thus could in no way be attributed to the response to price incentives. Likewise, neither huge price incentives nor impressive technological improvements were sufficient to prevent the decline in production from 1970 to 2010. Further exploitation of offshore or deep shale resources may help put U.S. production back on an upward trend for the next decade, but it seems unlikely ever again to reach the levels seen in 1970.

1.2 World oil production, 1973-2010.

Despite the peak in U.S. production in 1970, world oil production was to grow to a level in 2010 that is 60% higher than it had been in 1970. The mechanics of this growth are the same as allowed total U.S. production to continue to increase long after production from the initial areas entered into decline– increases from new fields in other countries more than offset the declines from the United States. For example, the North Sea and Mexico accounted for only 1% of world production in 1970, but had grown to 13% of total world output by 1999. But production from the North Sea peaked in that year, and in 2010 is only at 54% of the peak level (see Figure 9). Cantarell, which is Mexico's main producing field, also appears to have passed peak production, with the country now at 75% of its 2004 oil production.

Production from members of the Organization of Petroleum Exporting Countries (OPEC) must be interpreted from a much different perspective. The episodes of declining production one sees in the bottom panel of Figure 10 have little to do with geological depletion but instead often reflect dramatic geopolitical events such as the OPEC embargo of 1973-74, the Iranian revolution in 1978-1979, the Iranian revolution and beginning of the Iran-Iraq War 1978-1981, and the first Persian Gulf war in 1990-91, events that will be reviewed in more detail in the following section. In addition, Saudi Arabia in particular (top panel) has often made a deliberate decision to increase or decrease production in an effort to mitigate price increases or decreases. For example, Saudi Arabia cut production to try to hold up prices during the weak oil market 1981-85 and recession of 2001, and boosted production to make up for output lost from other producing countries during the two Persian Gulf wars. However, the decline in Saudi Arabian production since 2005 would have to be attributed to different considerations from those that explain the earlier historical data. The kingdom's magnificent Ghawar field has been in production since 1951, and in recent years had accounted for perhaps 6% of total world production all by itself. There is considerable speculation that Ghawar may have peaked, though this is difficult to confirm. What we do know is that, for whatever reason, Saudi Arabia produced 600,000 fewer barrels each day in 2010 than it did in 2005, and with growing Saudi consumption of their own oil, the drop in exports from Saudi Arabia has been even more dramatic.

A mix of factors has clearly also contributed to stagnating production from other OPEC members over the last 5 years. Promising new fields in Angola have allowed that country to double its production since 2003. In Nigeria and Iraq, conflicts and unrest have held back what appears to be promising geological potential. In Venezuela and Iran, it is hard to know how much more might be produced with better functioning governments. But again, although there is a complicated mix of different factors at work in different countries, the bottom line is that the total production from OPEC has essentially been flat since 2005.

At the same time, some other countries continue to register increases in oil production (see Figure 11). China has doubled its oil production since 1982, though its three most important fields (Daqing, Shengli, and Liaohe) peaked in the mid 1990s (Kambara and Howe, 2007). Canadian oil production continues to increase as a result of the contribution of oil sands. Unfortunately, exploitation of this resource is far more costly in terms of capital and energy inputs and environmental externalities relative to conventional sources, and it is difficult to see it ever accounting for a major fraction of total world oil production. Other regions such as Brazil, central Asia, and Africa have also seen significant gains in oil production (bottom panel of Figure 11). Overall, global production of oil from all sources was essentially constant from 2005 to 2010 (see Figure 12).

1.3 Reconciling historical experience with the theory of exhaustible resources.

The evidence from the preceding subsections can be summarized as follows. When one looks at individual oil-producing regions, one does not see a pattern of continuing increases as a result of ongoing technological progress. Instead there has inevitably been an initial gain as key new fields were developed followed by subsequent decline. Technological progress and the incentives of higher prices can temporarily reverse that decline, as was seen for example in the impressive resurgence of Pennsylvanian production in the 1920s. In recent years these same factors have allowed U.S. production to grow rather than decline, and that trend in the U.S. may continue for some time. However, these factors have historically appeared to be distinctly secondary to the broad reality that after a certain period of exploitation, annual flow rates of production from a given area are going to start to decline. Those encouraged by the 10% increase in U.S. oil production between 2008 and 2010 should remember that the level of U.S. production in 2010 is still 25% below where it had been in 1990 (when the real price of oil was half of what it is today) and 43% below the level of 1970 (when the real price of oil was 1/8 of what it is today).

Some may argue that the peaking of production from individual areas is governed by quite different economic considerations than would apply to the final peaking of total production from all world sources combined. Certainly in an environment in which the market is pricing oil as an essentially inexhaustible resource, the pattern of peaking documented extensively above is perfectly understandable, given that so far there have always been enough new fields somewhere in the world to take the place of declining production from mature regions. One could also reason that, even if the price of oil has historically been following some kind of Hotelling path, fields with different marginal extraction costs would logically be developed at different times. Smith (2011) further noted that, according to the Hotelling model, the date at which global production peaks would be determined endogenously by the cumulative amount that could eventually be extracted and the projected time path for the demand function. His analysis suggests that the date for an eventual peak in global oil production should be determined by these economic considerations rather than the engineering mechanics that have produced the historical record for individual regions detailed above.

However, my reading of the historical evidence is as follows. (1) For much of the history of the industry, oil has been priced essentially as if it were an inexhaustible resource. (2) Although technological progress and enhanced recovery techniques can temporarily boost production flows from mature fields, it is not reasonable to view these factors as the primary determinants of annual production rates from a given field. (3) The historical source of increasing global oil production is exploitation of new geographical areas, a process whose promise at the global level is obviously limited. The combined implication of these three observations is that, at some point there will need to be a shift in how the price of oil is determined, with considerations of resource exhaustion playing a bigger role than they have historically.

A factor accelerating the date of that transition is the phenomenal growth of demand for oil from the emerging economies. Eight emerging economies– Brazil, China, Hong Kong, India, Singapore, South Korea, Taiwan, and Thailand– accounted for 43% of the increase in world petroleum consumption between 1998 and 2005 and for 135% of the increase between 2005 and 2010 (the rest of the world decreased its petroleum consumption over the latter period in response to the big increase in price). [3] And, as Hamilton (2009a) noted, one could easily imagine the growth in demand from the emerging economies continuing. One has only to compare China's one passenger vehicle per 30 residents today with the one vehicle per 1.3 residents seen in the United States, or China's 2010 annual petroleum consumption of 2.5 barrels per person with Mexico's 6.7 or the United States' 22.4. Even if the world sees phenomenal success in finding new sources of oil over the next decade, it could prove quite challenging to keep up with both depletion from mature fields and rapid growth in demand from the emerging economies, another reason to conclude that the era in which petroleum is regarded as an essentially unlimited resource has now ended.

Some might infer that the decrease in Saudi Arabian production since 2005 reflects not an inability to maintain production flows from the mature Ghawar field but instead is a deliberate response to recognition of a growing importance of the scarcity rent. For example, Hamilton (2009a) noted the following story on April 13, 2008 from Reuters news service:

> Saudi Arabia's King Abdullah said he had ordered some new oil discoveries left untapped to preserve oil wealth in the world's top exporter for future generations, the official Saudi Press Agency (SPA) reported.
>
> "I keep no secret from you that when there were some new finds, I told them, 'no, leave it in the ground, with grace from God, our children need it'," King Abdullah said in remarks made late on Saturday, SPA said.

If that is indeed the interpretation, it is curious that we would see the private optimizing choices predicted by Hotelling manifest by sovereign governments rather than the fields under control of private oil companies. In any case, it must be acknowledged that calculation of the correct Hotelling price is almost insurmountably difficult. It is hard enough for the best forecasters accurately to predict supply and demand for the coming year. But the critical calculation required by Hotelling is to evaluate the transversality condition that the resource be exhausted when the price reaches that of a backstop technology or alternatively over the infinite time horizon if no such backstop exists. That calculation is orders of magnitudes more difficult than the seemingly simpler task of just predicting next year's supply and demand.

One could argue that the combined decisions of the many participants in world oil markets can make a better determination of what the answer to the above calculation should be than can any individual, meaning that if the current price seems inconsistent with a scenario in which global oil production will soon reach a peak, then such a scenario is perhaps not the most likely outcome. But saying that the implicit judgment from the market is the best guess available is not the same thing as saying that this guess is going to prove to be correct. The historical record surely dictates that we take seriously the possibility that the world could soon reach a point from which a continuous decline in the annual flow rate of production could not be avoided, and inquire whether the transition to a pricing path consistent with that reality could prove to be a fairly jarring event. For this reason, it seems worthwhile to review the historical record on the economic response to previous episodes in which the price or supply of oil changed dramatically, to which we now turn in the next section.

2 Oil prices and economic growth.

2.1 Historical oil price shocks.

There have been a number of episodes over the last half century in which conflicts in the Middle East have led to significant disruptions in production of crude oil. These include closure of the Suez Canal following the conflict between Egypt, Israel, Britain, and France in October 1956, the oil embargo implemented by the Arab members of OPEC following the Arab-Israeli War in October 1973, the Iranian revolution beginning in November 1978, the Iran-Iraq War beginning in September of 1980, and the first Persian Gulf war beginning in August 1990. Figure 13 summarizes the consequences of these 5 events for world oil supplies. In each panel, the solid line displays the drop in production from the affected areas expressed as a percentage of total world production prior to the crisis. In each episode, there were some offsetting increases in production elsewhere in the world. The dashed lines in Figure 13 indicate the magnitude of the actual decline in total global production following each event, again expressed as a fraction of world production. Each of these 5 episodes was followed by a decrease in world oil production of 4-9%.

There have also been some other more minor supply disruptions over this period. These include the combined effects of the second Persian Gulf war and strikes in Venezuela beginning in December 2002, and the Libyan revolution in February 2011. The disruption in supply associated with either of these episodes was about 2% of total global production at the time, or less than a third the size of the average event in Figure 13.

There are other episodes since World War II when the price of oil rose abruptly in the absence of a significant physical disruption in the supply of oil. Most notable of these would be the broad upswing in the price of oil beginning in 2004, which accelerated sharply in 2007. The principal cause of this oil spike appears to have been strong demand for oil from the emerging economies confronting the stagnating global production levels documented in the previous sections (see Kilian, 2008, 2009, Hamilton, 2009b and Kilian and Hicks, 2011). Less dramatic price increases followed the economic recovery from the East Asian Crisis in 1997, dislocations associated with post World War II growth in 1947, and the Korean conflict in 1952-53. Table 1 summarizes a series of historical episodes discussed in Hamilton (forthcoming [b]). It is interesting that of the 11 episodes listed, 10 of these were followed by a recession in the United States. The recession of 1960 is the only U.S. postwar recession that was not preceded by a spike in the price of crude oil.

A large empirical literature has investigated the connection between oil prices and real economic growth. Early studies documenting a statistically significant negative correlation include Rasche and Tatom (1977, 1981) and Santini (1985). Empirical analysis of dynamic forecasting regressions found that oil price changes could help improve forecasts of U.S. real output growth (Hamilton, 1983; Burbidge and Harrison, 1984; Gisser and Goodwin, 1986). However, these specifications, which were based on linear relations between the log change in oil prices and the log of real output growth, broke down when the dramatic oil price decreases of the mid-1980s were not followed by an economic boom. On the contrary, the mid-1980s appeared to be associated with recession conditions in the oil-producing states (Hamilton and Owyang, forthcoming). Mork (1989) found a much better fit to a model that allowed for oil price decreases to have a different effect on the economy from oil price increases, though Hooker (1996) demonstrated that this modification still had trouble describing subsequent data. Other papers finding a significant connection between oil price increases and poor economic performance include Santini (1992, 1994), Rotemberg and Woodford (1996), Daniel (1997), and Carruth, Hooker and Oswald (1998).

Alternative nonlinear dynamic relations seem to have a significantly better fit to U.S. data than Mork's simple asymmetric formulation. Loungani (1986) and Davis (1987a, 1987b) found that oil price decreases could actually reduce economic growth, consistent with the claim that sectorial reallocations could be an important part of the economic transmission mechanism resulting from changes in oil prices in either direction. Ferderer

(1996), Elder and Serletis (2010), and Jo (2011) showed that an increase in oil price volatility itself tends to predict slower GDP growth, while Lee, Ni, and Ratti (1995) found that oil price increases seem to affect the economy less if they occur following an episode of high volatility. Hamilton (2003) estimated a flexible nonlinear form and found evidence for a threshold effect, in which an oil price increase that simply reverses a previous decrease seems to have little effect on the economy. Hamilton (1996), Raymond and Rich (1997), Davis and Haltiwanger (2001) and Balke, Brown and Yücel (2002) produced evidence in support of related specifications, while Carlton (2010) and Ravazzolo and Rothman (2010) reported that the Hamilton (2003) specification performed well in an out-of-sample forecasting exercise using data as it would have been available in real time. Kilian and Vigfusson (forthcoming [a]) found weaker (though still statistically significant) evidence of nonlinearity than reported by other researchers. Hamilton (forthcoming [a]) attributed their weaker evidence to use of a shorter data set and changes in specification from other researchers.

A negative effect of oil prices on real output has also been reported for a number of other countries, particularly when nonlinear functional forms have been employed. Mork, Olsen and Mysen (1994) found that oil price increases were followed by reductions in real GDP growth in 6 of the 7 OECD countries investigated, the one exception being the oil exporter Norway. Cuñado and Pérez de Gracia (2003) found a negative correlation between oil prices changes and industrial production growth rates in 13 out of 14 European economies, with a nonlinear function of oil prices making a statistically significant contribution to forecast growth rates for 11 of these. Jiménez-Rodríguez and Sánchez (2005) found a statistically significant negative nonlinear relation between oil prices and real GDP growth in the U.S., Canada, Euro area overall, and 5 out of 6 European countries, though not in Norway or Japan. Kim (forthcoming) found a nonlinear relation in a panel of 6 countries, while Engemann, Kliesen, and Owyang (forthcoming) found that oil prices helped predict economic recessions in most of the countries they investigated. Daniel, et. al. (2011) also found supporting evidence in most of the 11 countries they studied. By contrast, Rasmussen and Roitman (2011) found much less evidence for economic effects of oil shocks in an analysis of 144 countries. However, their use of this larger sample of countries required using annual rather than the monthly or quarterly data used in the other research cited above. Insofar as the effects are high frequency and cyclical, they may be less apparent in annual average data. Kilian (2009) has argued that the source of the oil price increase is also important, with increases that result from strong global demand appearing to have more benign implications for U.S. real GDP growth than oil price increases that result from shortages of supply.

Blanchard and Galí (2010) found evidence that the effects of oil shocks on the economy have decreased over time, which they attributed to the absence of other adverse shocks that had historically coincided with some big oil price movements, a falling value of the share of oil in total expenses, more flexible labor markets, and better management of monetary policy. Baumeister and Peersman (2011) also found that an oil price increase of a given size seems to have a decreasing effect over time, but noted that the declining price-elasticity of demand meant that a given physical disruption had a bigger effect on price and turned out to have a similar effect on output as in the earlier data. Ramey and Vine (2012) attributed the declining coefficients relating real GDP growth to oil prices to the fact that the oil shocks of the 1970s were accompanied by rationing, which would have magnified the economic dislocations. Ramey and Vine found that once they correct for this, the economic effects have been fairly stable over time.

2.2 Interpreting the historical evidence.

The equation below reports the regression estimates from equation (3.8) of Hamilton (2003), which is based on data from 1949:Q2 to 2001:Q3. Here y_t represents the quarterly log change in real GDP. The specification implies that oil prices do not matter unless they make a new high relative to values seen over the previous 3 years. If oil prices make a new high, $o_t^{\#}$ is the amount by which the log of the producer price index at the end of quarter t exceeds its maximum over the preceding 3 years, whereas $o_t^{\#}$ is zero if they do not. Standard errors appear in parentheses, and both y_t and $o_t^{\#}$ have been multiplied by 100 to express as percentage rates:

$$\begin{aligned} y_t = {} & \underset{(0.13)}{0.98} + \underset{(0.07)}{0.22} y_{t-1} + \underset{(0.07)}{0.10} y_{t-2} - \underset{(0.07)}{0.08} y_{t-3} - \underset{(0.07)}{0.15} y_{t-4} \\ & - \underset{(0.014)}{0.024} o_{t-1}^{\#} - \underset{(0.014)}{0.021} o_{t-2}^{\#} - \underset{(0.014)}{0.018} o_{t-3}^{\#} - \underset{(0.014)}{0.042} o_{t-4}^{\#}. \end{aligned} \tag{1}$$

Two aspects of this relation are puzzling from the perspective of economic theory. First, the effects of an oil price increase take some time to show up in real GDP, with the biggest drop in GDP growth appearing a full year after the price of oil first increases. Second, the size of the estimated effect is quite large. If the price of oil exceeds its 3-year high by 10%, the relation predicts that real GDP growth would be 0.42% slower (at a quarterly rate) 4 quarters later, with a modest additional decline coming from the dynamic implications of $o^{\#}_{t-4}$ for y_{t-1}, y_{t-2}, and y_{t-3}.

To understand why effects of this magnitude are puzzling,[4] suppose we thought of the level of real GDP (Y) as depending on capital K, labor N, and energy E according to the production function,

$$Y = F(K, N, E).$$

Profit maximization suggests that the marginal product of energy should equal its relative price, denoted P_E/P:

$$\frac{\partial F}{\partial E} = P_E/P.$$

Multiplying the above equation by E/F implies that the elasticity of output with respect to energy use should be given by γ, the dollar value of expenditures on energy as a fraction of GDP:

$$\frac{\partial \ln F}{\partial \ln E} = \frac{P_E E}{PY} = \gamma. \tag{2}$$

Suppose we thought that wages adjust instantaneously to maintain full employment and that changes in investment take much longer than a few quarters to make a significant difference for the capital stock. Then neither K nor N would respond to a change in the real price of energy, and

$$\begin{aligned} \frac{\partial \ln Y}{\partial \ln P_E/P} &= \frac{\partial \ln F}{\partial \ln E} \frac{\partial \ln E}{\partial \ln P_E/P} \\ &= \gamma\theta \end{aligned} \tag{3}$$

for θ the price-elasticity of energy demand.

The energy expenditure share is a small number– the value of crude oil consumed by the United States in 2010 corresponds to less than 4% of total GDP. Moreover, the short-run price elasticity of demand θ is also very small (Dahl, 1993). Hence it seems that any significant observed response to historical oil price increases could not be attributed to the direct effects of decreased energy use on productivity, but instead would have to arise from forces that lead to underemployment of labor and underutilization of capital. Such effects are likely to operate from changes in the composition of demand rather than the physical process of production itself.[5] Unlike the above mechanism based on aggregate supply effects, the demand effects could be most significant when the price-elasticity of demand is low.

For example, suppose that the demand for energy is completely inelastic in the short run, so that consumers try to purchase the same physical quantity E of energy despite the energy price increase. Then nominal saving or spending on other goods or services must decline by $E\Delta P_E$ when the price of energy goes up. Letting C denote real consumption spending and P_C the price of consumption goods,

$$\frac{\partial \ln C}{\partial \ln(P_E/P_C)} = \frac{P_E E}{P_C C} = \gamma_C$$

for γ_C the energy expenditure share in total consumption. Again, for the aggregate economy γ_C is a modest number. Currently about 6% of total U.S. consumer spending is devoted to energy goods and services[6], though for the lower 60% of U.S. households by income, the share is closer to 10% (Carroll, 2011). And although the increased spending on energy represents income for someone else, it can take a considerable amount of time for oil company profits to be translated into higher dividends for shareholders or increased investment expenditures.

Recycling the receipts of oil exporting countries on increased spending on U.S.-produced goods and services can take even longer. These delays may be quite important in determining the overall level of spending that governs short-run business cycle dynamics.

Edelstein and Kilian (2009) conducted an extensive investigation of U.S. monthly spending patterns over 1970 to 2006, looking at bivariate autoregressions of measures of consumption spending on their own lags and on lags of energy prices. They scaled the energy price measure so that a one unit increase would correspond to a 1% drop in total consumption spending if consumers were to try to maintain real energy purchases at their original levels. Figure 14 reproduces some of their key results. The top panel shows that, as expected, an increase in energy prices is followed by a decrease in overall real consumption spending. However, the same two puzzles mentioned in connection with (1) occur again here. First, although consumers' spending power first fell at date 0 on the graph, the decline in consumption spending is not immediate but continues to increase in size up to a year after the initial shock. Second, although the initial shock corresponded to an event that might have forced a consumer to cut total spending by 1%, after 12 months, we see total spending down 2.2%.

The details of Edelstein's and Kilian's other analysis suggest some explanations for both the dynamics and the apparent multiplier effects. The second panel in Figure 14 looks at one particular component of consumption spending, namely spending on motor vehicles and parts. Here the decline is essentially immediate, and quite large relative to normal expenditures on this particular category. The drop in demand for domestically manufactured motor vehicles could lead to idled capital and labor as a result of traditional Keynesian frictions in adjusting wages and prices, and could be an explanation for both the multiplier and the dynamics observed in the data. Hamilton (1988) showed that multiplier effects could also arise in a strictly neoclassical model with perfectly flexible wages and prices. In that model, the technological costs associated with trying to reallocate specialized labor or capital could result in a temporary period of unemployment as laid-off workers wait for demand for their sector to resume. Bresnahan and Ramey (1993), Hamilton (2009b), and Ramey and Vine (2012) demonstrated the economic importance of shifts in motor vehicle demand in the recessions that followed several historical oil shocks.

Another feature of the consumer response to an energy price increase uncovered by Edelstein and Kilian is a sharp and immediate drop in consumer sentiment (see the bottom panel of Figure 14). Again, this could produce changes in spending patterns whose consequences accumulate over time through Keynesian and other multiplier effects.

Bohi (1989) was among the early doubters of the thesis that oil prices were an important contributing factor in postwar recessions, noting that the industries in which one sees the biggest response were not those for which energy represented the biggest component of total costs. However, subsequent analyses allowing for nonlinearities found effects for industries for which energy costs were important both for their own production as well as for the demand for their goods (Lee and Ni, 2002; Herrera, Lagalo and Wada, 2010).

Bernanke, Gertler and Watson (1997) suggested that another mechanism by which oil price increases might have affected aggregate demand is through a contractionary response of monetary policy. They presented simulations suggesting that , if the Federal Reserve had kept interest rates from rising subsequent to historical oil shocks, most of the output decline could have been avoided. However, Hamilton and Herrera (2004) demonstrated that this conclusion resulted from the authors' assumption that the effects of oil price shocks could be captured by 7 monthly lags of oil prices, a specification that left out the biggest effects found by earlier researchers. When the Bernanke, et. al. analysis is reproduced using 12 lags instead of 7, the conclusion from their exercise would be that even quite extraordinarily expansionary monetary policy could not have eliminated the contractionary effects of an oil price shock.

Hamilton (2009b) noted that what happened in the early stages of the 2007-2009 recession was quite consistent with the pattern observed in the recessions that followed earlier oil shocks. Spending on the larger domestically manufactured light vehicles plunged even as sales of smaller imported cars went up. Had it not been for the lost production from the domestic auto sector, U.S. real GDP would have grown 1.2% during the first year of the recession. Historical regressions based on energy prices would have predicted much of the falling consumer sentiment and slower consumer spending during the first year of the downturn. Figure 15 updates and extends a calculation from Hamilton (2009b), in which the specific parameter values from the historically estimated regression (1) were used in a dynamic simulation to predict what would have happened to real GDP over the period 2007:Q4 to 2009:Q3 based solely on the changes in oil prices. The pattern and much of the magnitude of the initial downturn are consistent with the historical experience.

Of course, there is no question that the financial crisis in the fall of 2008 was a much more significant event in turning what had been a modest slowdown up to that point into what is now being referred to as the Great Recession. Even so, Hamilton (2009b) noted that the magnitude of the problems with mortgage delinquencies could only have been aggravated by the weaker economy, and suggested that the oil price spike of 2007-2008 should be counted as an important factor contributing to the early stages of that recession as well as a number of earlier episodes.

2.3 Implications for future economic growth and climate change.

The increases in world petroleum production over the first 150 years of the industry have been quite impressive. But given the details behind that growth, it would be prudent to acknowledge the possibility that world production could soon peak or enter a period of rocky plateau. If we should enter such an era, what does the observed economic response to past historical oil supply disruptions and price increases suggest could be in store for the economy?

The above analysis suggests that historically the biggest economic effects have come from cyclical factors that led to underutilization of labor and capital and drove output below the level that would be associated with full employment. If we are asking about the character of an alternative long-run growth path, most economists would be more comfortable assuming that the economy would operate close to potential along the adjustment path. For purposes of that question, the relatively small value for the energy expenditure share γ in equation

(2) would seem to suggest a modest elasticity of total output with respect to energy use and relatively minor effects.

One detail worth noting, however, is that historically the energy share has changed dramatically over time. Figure 16 plots the consumption expenditure share γ_C since 1959. Precisely because demand is very price-inelastic in the short run, when the real price of oil doubles, the share nearly does as well. The relatively low share in the late 1990s and early 2000s, to which Blanchard and Galí (2010) attributed part of the apparent reduced sensitivity of the economy to oil shocks, basically disappeared with the subsequent price increases. If a peaking of global production does result in further big increases in the price of oil, it is quite possible that the expenditure share would increase significantly from where it is now, in which case even a frictionless neoclassical model would conclude that the economic consequences of reduced energy use would have to be significant.

In addition to the response of supply to these price increases discussed in Section 1, another key parameter is the long-run price-elasticity of demand. Here one might take comfort from the observation that, given time, the adjustments of demand to the oil price increases of the 1970s were significant. For example, U.S. petroleum consumption declined 17% between 1978 and 1985 at the same time that U.S. real GDP increased by 21%. However, Dargay and Gately (2010) attributed much of this conservation to one-time effects, such as switching away from using oil for electricity generation and space heating, that would be difficult to repeat on an ongoing basis. Knittel (forthcoming) was more optimistic, noting that there has been ongoing technological improvement in engine and automobile design over time, with most of this historically being devoted to making cars larger and more powerful rather than more fuel-efficient. If the latter were to become everyone's priority, significant reductions in oil consumption might come from this source.

Knowing what the future will bring in terms of adaptation of both the supply and demand for petroleum is inherently difficult. However, it is not nearly as hard to summarize the past. Coping with a final peak in world oil production could look pretty similar to what we observed as the economy adapted to the production plateau encountered over 2005-2009. That experience appeared to have much in common with previous historical episodes that resulted from temporary geopolitical conflict, being associated with significant declines in employment and output. If the future decades look like the last 5 years, we are in for a rough time.

Most economists view the economic growth of the last century and a half as being fueled by ongoing technological progress. Without question, that progress has been most impressive. But there may also have been an important component of luck in terms of finding and exploiting a resource that was extremely valuable and useful but ultimately finite and exhaustible. It is not clear how easy it will be to adapt to the end of that era of good fortune.

Let me close with a few observations on the implications for climate change. Clearly reduced consumption of petroleum by itself would mean lower greenhouse gas emissions. Moreover, since GDP growth has historically been the single biggest factor influencing the growth of emissions (Hamilton and Turton, 2002), the prospects for potentially rocky economic growth explored above would be another factor slowing growth of emissions. But the key question in terms of climate impact is what we might do instead, since many of the alternative sources of transportation fuel have a significantly bigger carbon footprint than those we relied on in the past. For example, creating a barrel of synthetic crude from surface-mined Canadian oil sands may emit twice as much carbon dioxide equivalents as are associated with producing a barrel of conventional crude, while in-situ processing of oil sands could produce three times as much (Charpentier, Bergerson and MacLean, 2009). This is not quite as alarming as it sounds, since greenhouse gas emissions associated with production of the crude itself are still dwarfed by those released when the gasoline is combusted in the end-use vehicle. The median study surveyed by Charpentier, Bergerson and MacLean (2009) concluded that on a well-to-wheel basis, vehicles driven by gasoline produced from surface-mined oil sands would emit 17% more grams of carbon dioxide equivalent per kilometer driven compared to gasoline from conventional petroleum. Enhanced oil recovery and conversion of natural gas to liquid fuels are also associated with higher greenhouse gas emissions per kilometer driven than conventional petroleum, though these increases are more modest than those for oil sands. On the other hand, creating liquid fuels from coal or oil shale could increase well-to-wheel emissions by up to a factor of two (Brandt and Farrell, 2007).

In any case, if the question is whether the world should decrease combustion of gasoline produced from conventional petroleum sources, we may not have any choice.

Notes

[1]See Fouquet and Pearson (2006, 2012) on the history of the cost of illumination.

[2]See for example Williamson and Daum (1959, pp. 44-48).

[3]Data source: Total petroleum consumption, EIA (http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=5&aid=2&cid=regions&syid=1980&eyid=2010&unit=TBPD)

[4]The discussion in this paragraph is adapted from Hamilton (forthcoming [a]).

[5]Other neoclassical models explore the possibility of asymmetric or multiplier effects arising through utilization of capital (Finn, 2000) or putty-clay capital (Atkeson and Kehoe, 1999). Related general equilibrium investigations include Kim and Loungani (1992) and Leduc and Sill (2004).

[6]See BEA Table 2.3.5.u (http://www.bea.gov/national/nipaweb/nipa_underlying/SelectTable.asp).

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Table 1. Summary of significant postwar events.

Gasoline shortages	**Crude oil price increase**	**Crude oil or gasoline price controls**	**Key factors**	**Business cycle peak**
Nov 47- Dec 47	Nov 47-Jan 48 (37%)	no (threatened)	strong demand, supply constraints	Nov 48
May 52	Jun 53 (10%)	yes	strike, controls lifted	Jul 53
Nov 56-Dec 56 (Europe)	Jan 57-Feb 57 (9%)	yes (Europe)	Suez Crisis	Aug 57
none	none	no	---	Apr 60
none	Feb 69 (7%) Nov 70 (8%)	no	strike, strong demand, supply constraints	Dec 69
Jun 73 Dec 73- Mar 74	Apr 73-Sep 73 (16%) Nov 73-Feb 74 (51%)	yes	strong demand, supply constraints, OAPEC embargo	Nov 73
May 79-Jul 79	May 79-Jan 80 (57%)	yes	Iranian revolution	Jan 80
none	Nov 80-Feb 81 (45%)	yes	Iran-Iraq War, controls lifted	Jul 81
none	Aug 90-Oct 90 (93%)	no	Gulf War I	Jul 90
none	Dec 99-Nov 00 (38%)	no	strong demand	Mar 01
none	Nov 02-Mar 03 (28%)	no	Venezuela unrest, Gulf War II	none
none	Feb 07-Jun 08 (145%)	no	strong demand, stagnant supply	Dec 07

Source: Hamilton (forthcoming [b]).

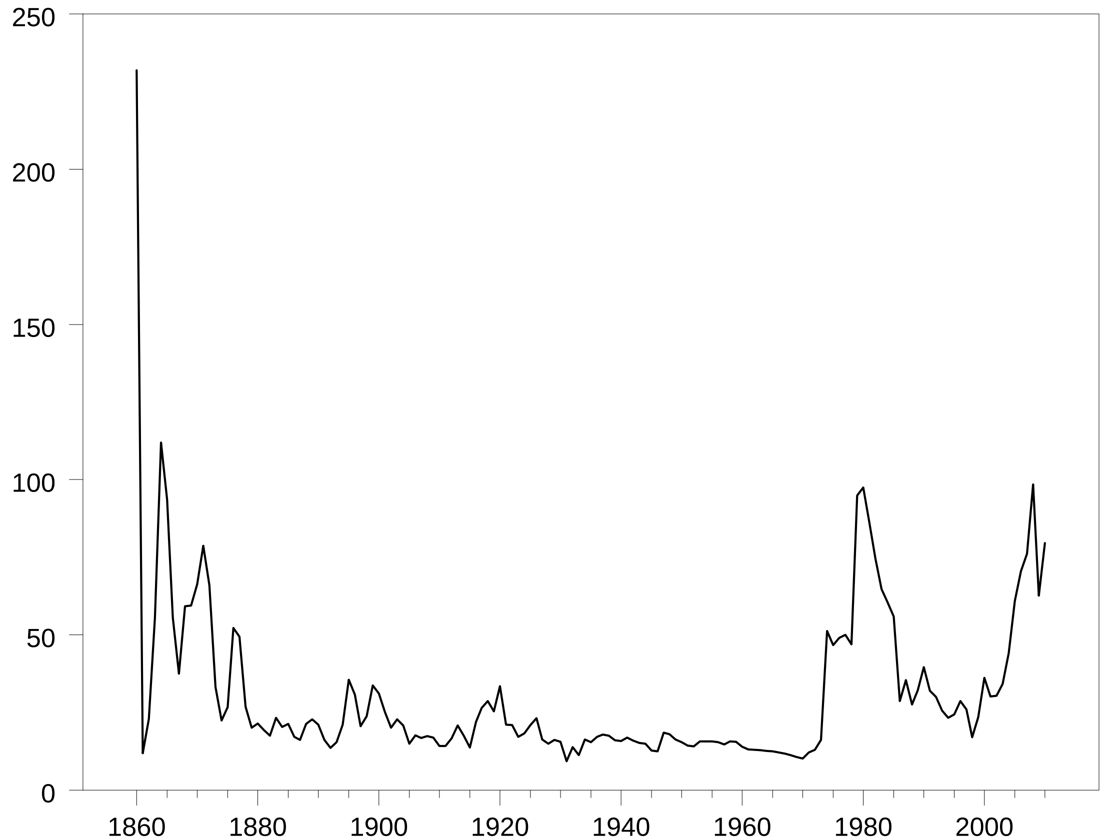

Figure 1. Price of oil in 2010 dollars per barrel, 1860-2010. Data source: 1861-2010 from BP, *Statistical Review of World Energy 2010*; 1860 from Jenkins (1985, Table 18) (which appears to be the original source for the early values of the BP series) and *Historical Statistics of the United States,* Table E 135-166, Consumer Prices Indexes (BLS), All Items, 1800 to 1970.

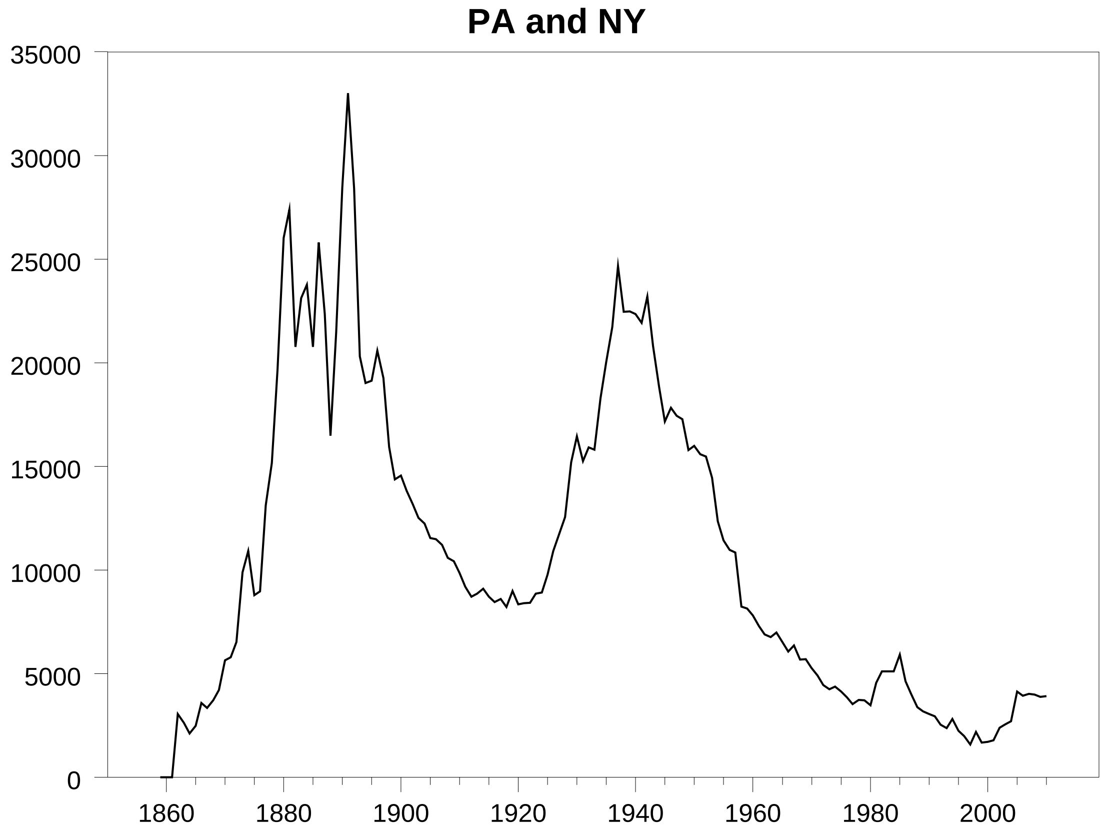

Figure 2. Annual crude oil production (in thousands of barrels per year) from the states of Pennsylvania and New York combined. Data sources: see Appendix.

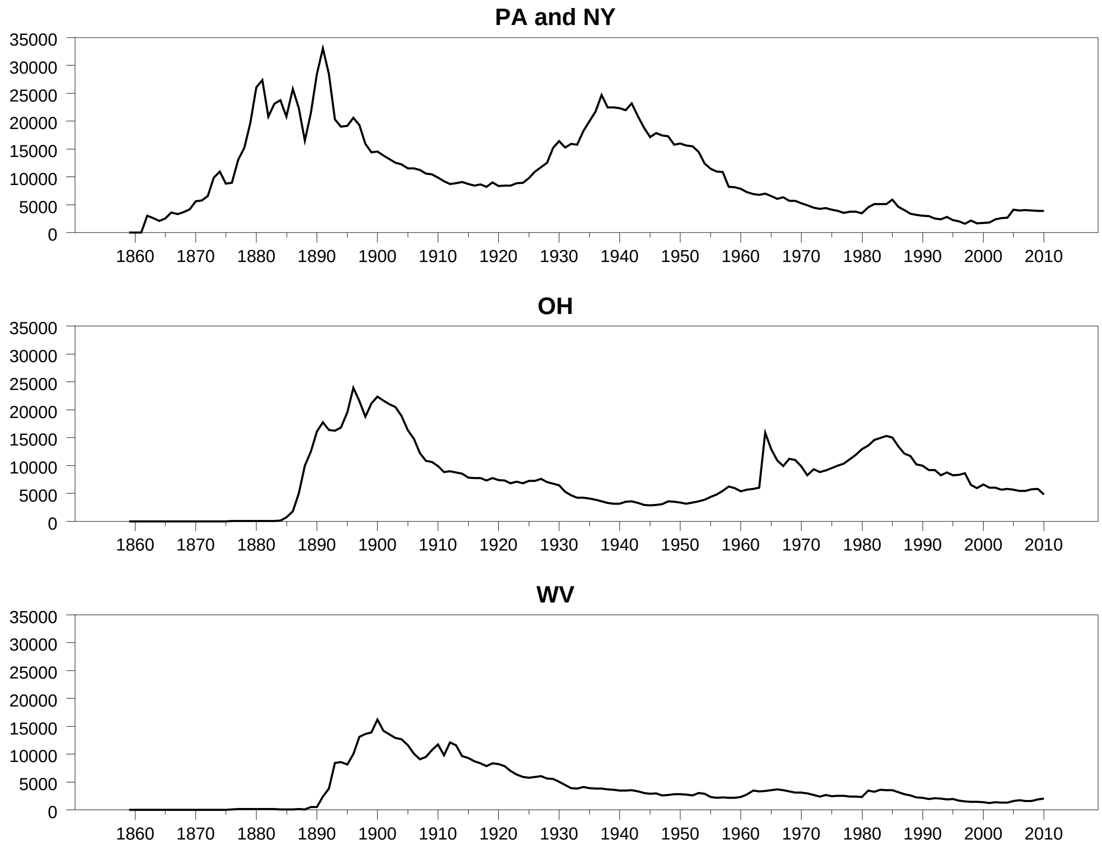

Figure 3. Annual crude oil production (in thousands of barrels per year) from the states of Pennsylvania and New York combined (top panel), Ohio (middle panel), and West Virginia (bottom panel).

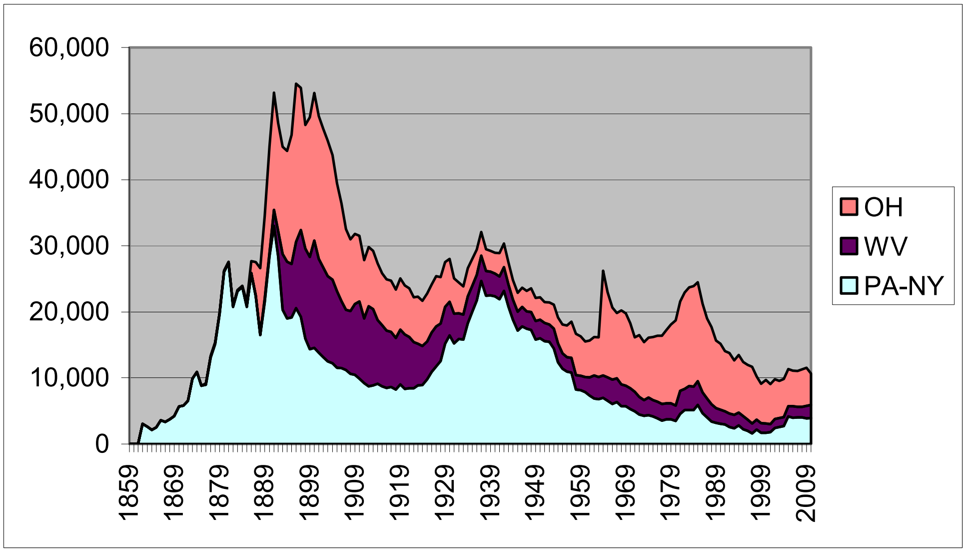

Figure 4. Combined annual crude oil production (in thousands of barrels per year) from the states of Pennsylvania, New York, West Virginia, and Ohio.

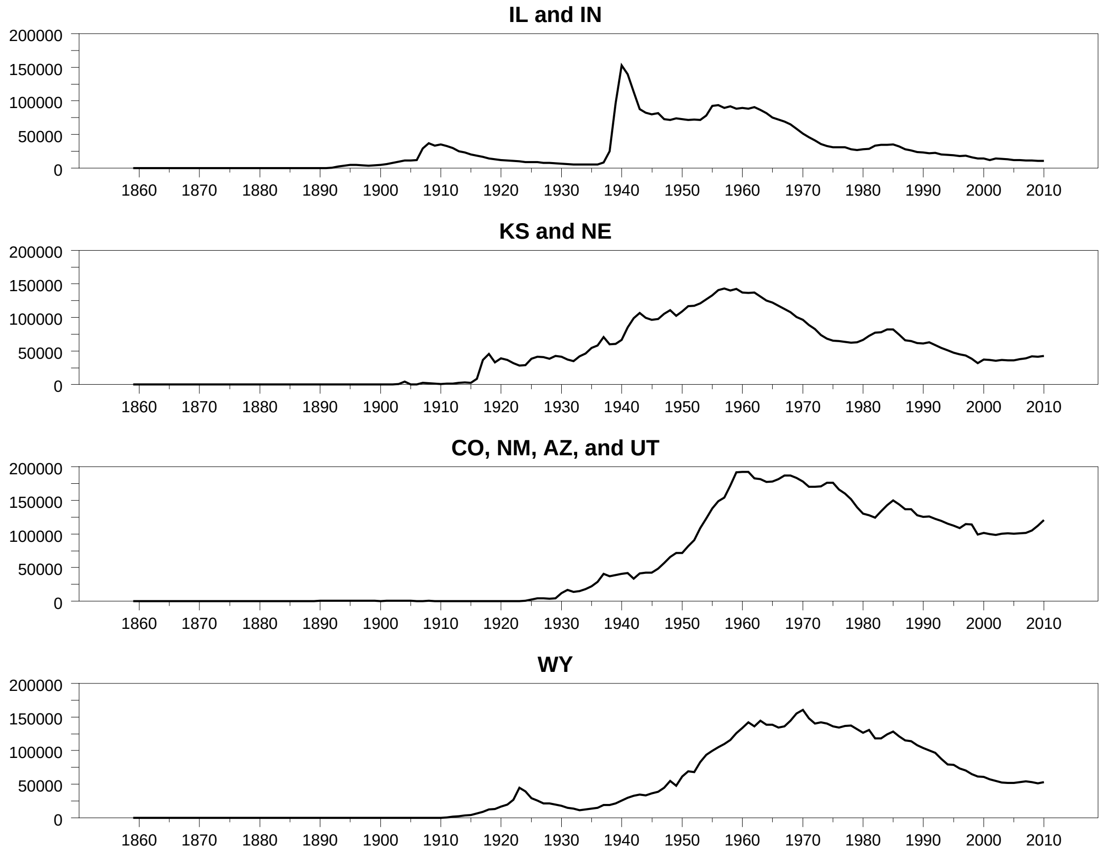

Figure 5. Annual crude oil production (in thousands of barrels per year) from assorted groups of states in the central United States.

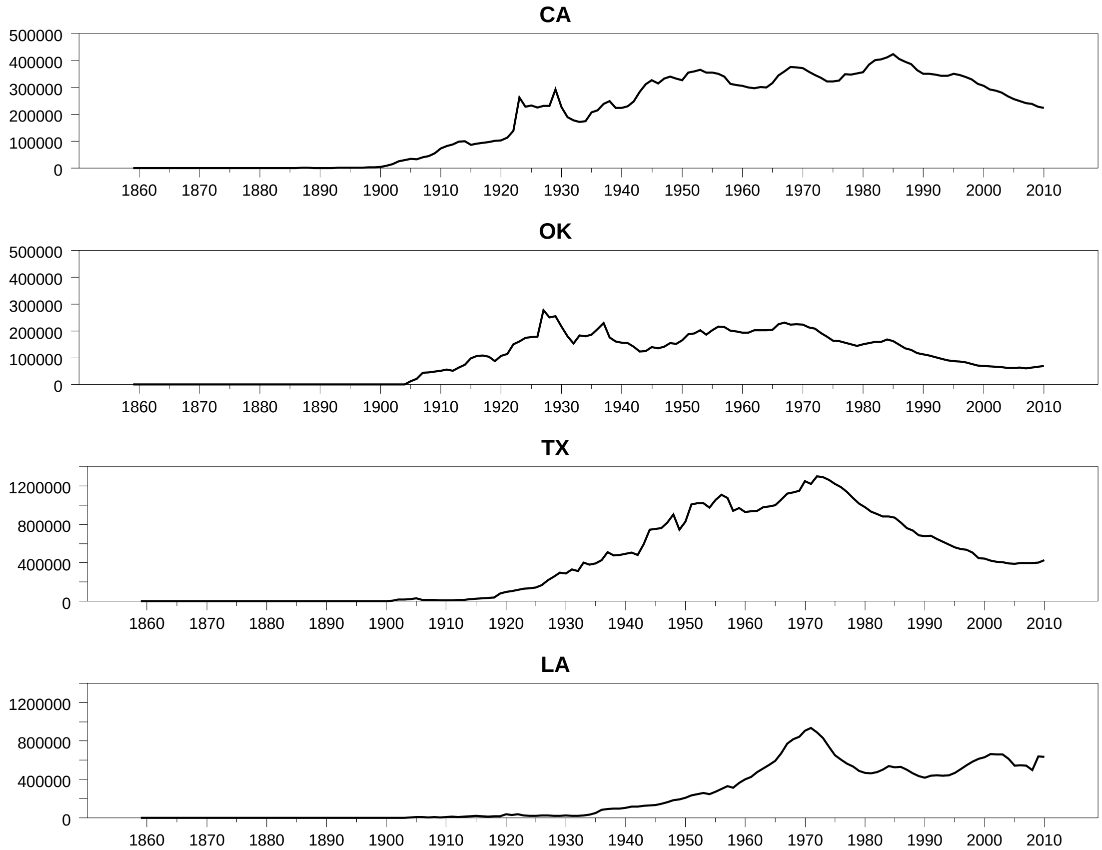

Figure 6. Annual crude oil production (in thousands of barrels per year) from 4 leading producing states. California includes offshore and Louisiana includes all Gulf of Mexico U.S. production.

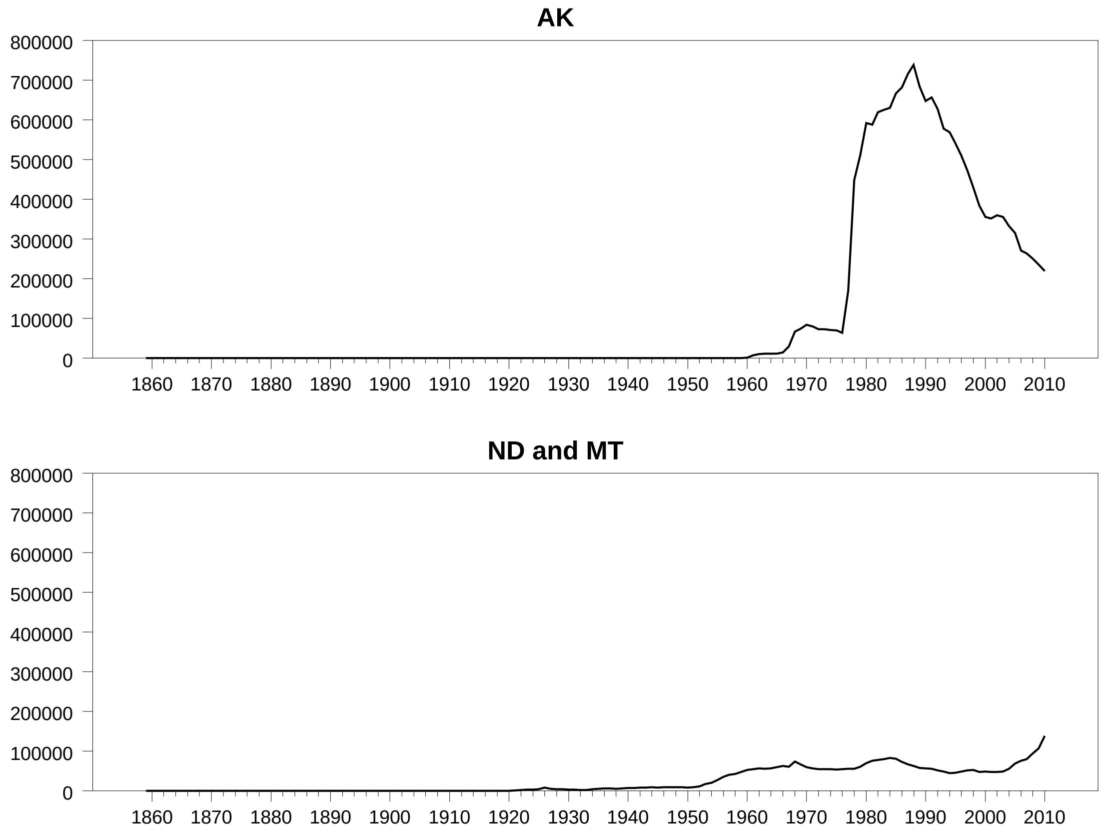

Figure 7. Annual crude oil production (in thousands of barrels per year) from Alaska (including offshore), North Dakota, and Montana.

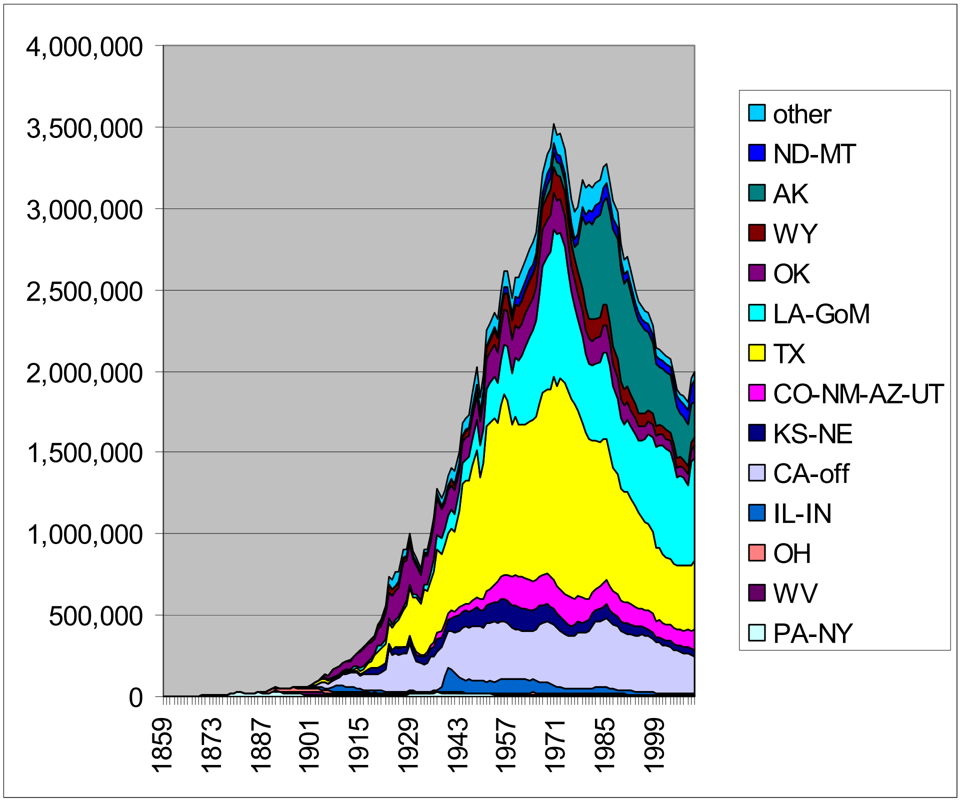

Figure 8. Annual crude oil production (in thousands of barrels per year) from entire United States, with contributions from individual regions as indicated.

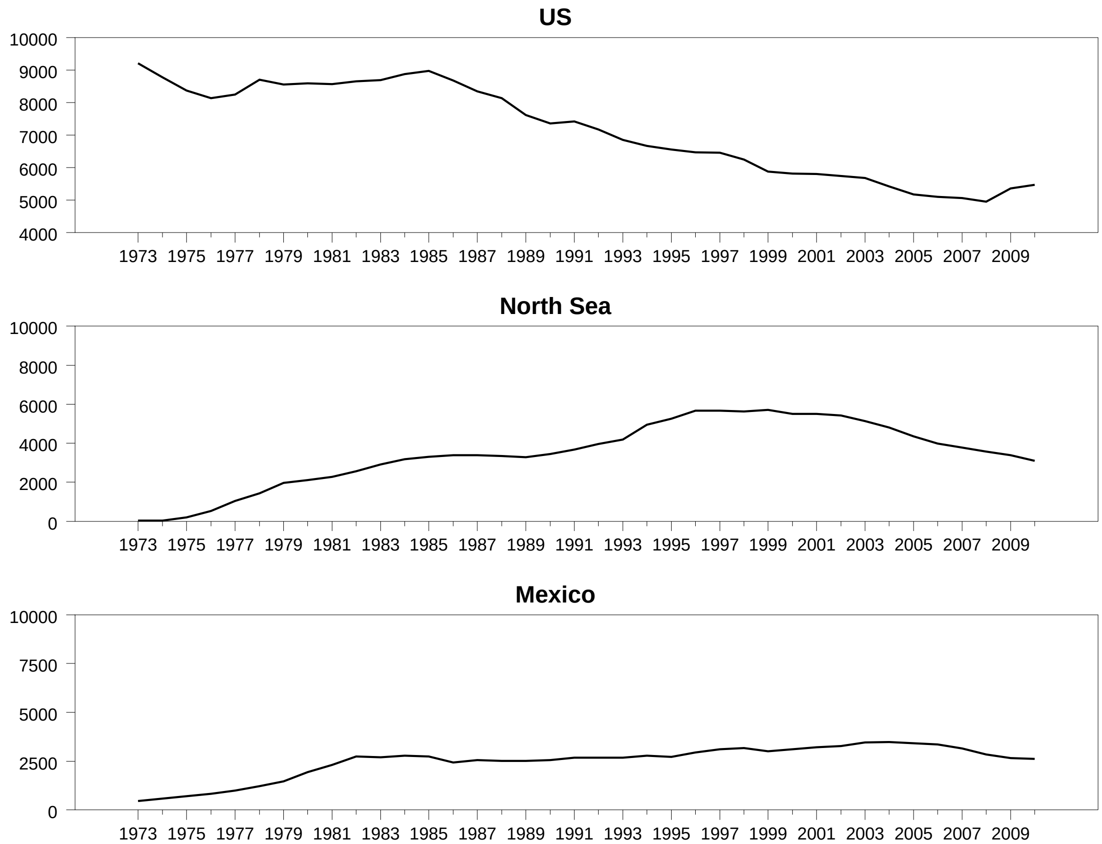

Figure 9. Annual crude oil production, thousand barrels per day, for United States, combined output of Norway and United Kingdom, and Mexico, 1973-2010. Data source: *Monthly Energy Review,* Sept. 2011, Table 11.1b (http://205.254.135.24/totalenergy/data/monthly/query/mer_data.asp?table=T11.01B).

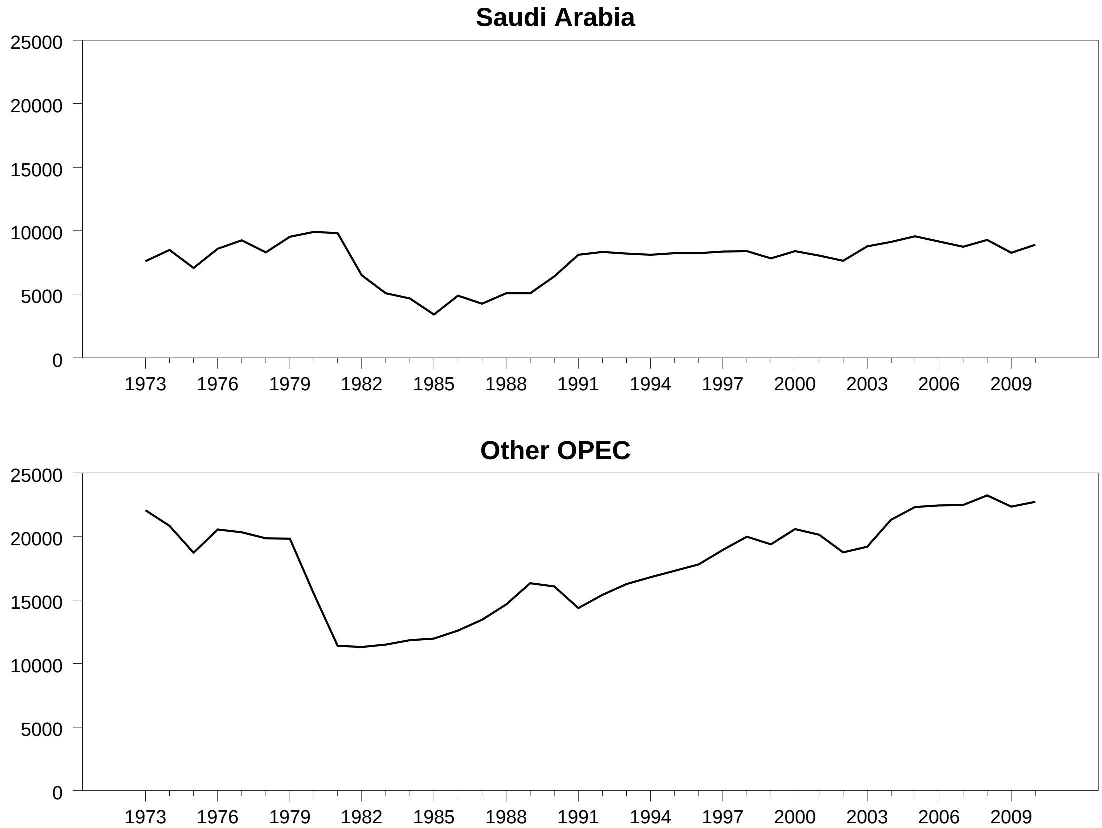

Figure 10. Annual crude oil production, thousand barrels per day, for Saudi Arabia and the rest of OPEC. Data source: *Monthly Energy Review,* Sept. 2011, Table 11.1a (http://205.254.135.24/totalenergy/data/monthly/query/mer_data.asp?table=T11.01A).

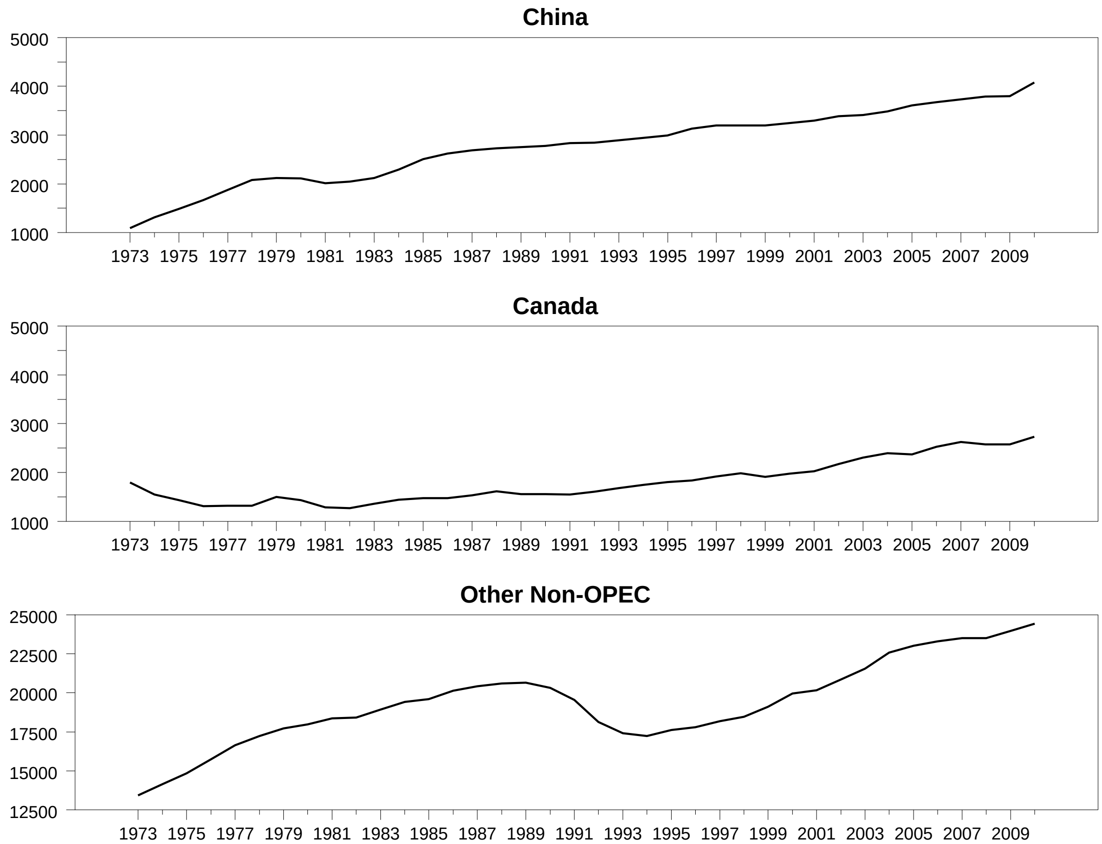

Figure 11. Annual crude oil production, thousand barrels per day. Top two panels: China and Canada. Bottom panel combines all non-OPEC countries other than those in Figure 10 or top two panels. Data source: *Monthly Energy Review,* Sept. 2011, Table 11.1b (http://205.254.135.24/totalenergy/data/monthly/query/mer_data.asp?table=T11.01B).

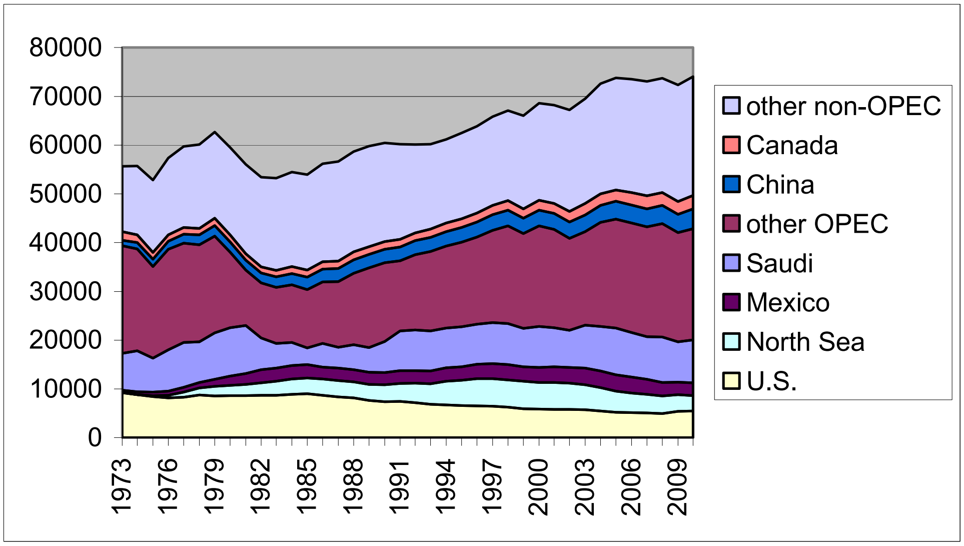

Figure 12. Annual crude oil production (in thousands of barrels per day) from entire world, with contributions from individual regions as indicated. Data sources described in notes to Figures 9-11.

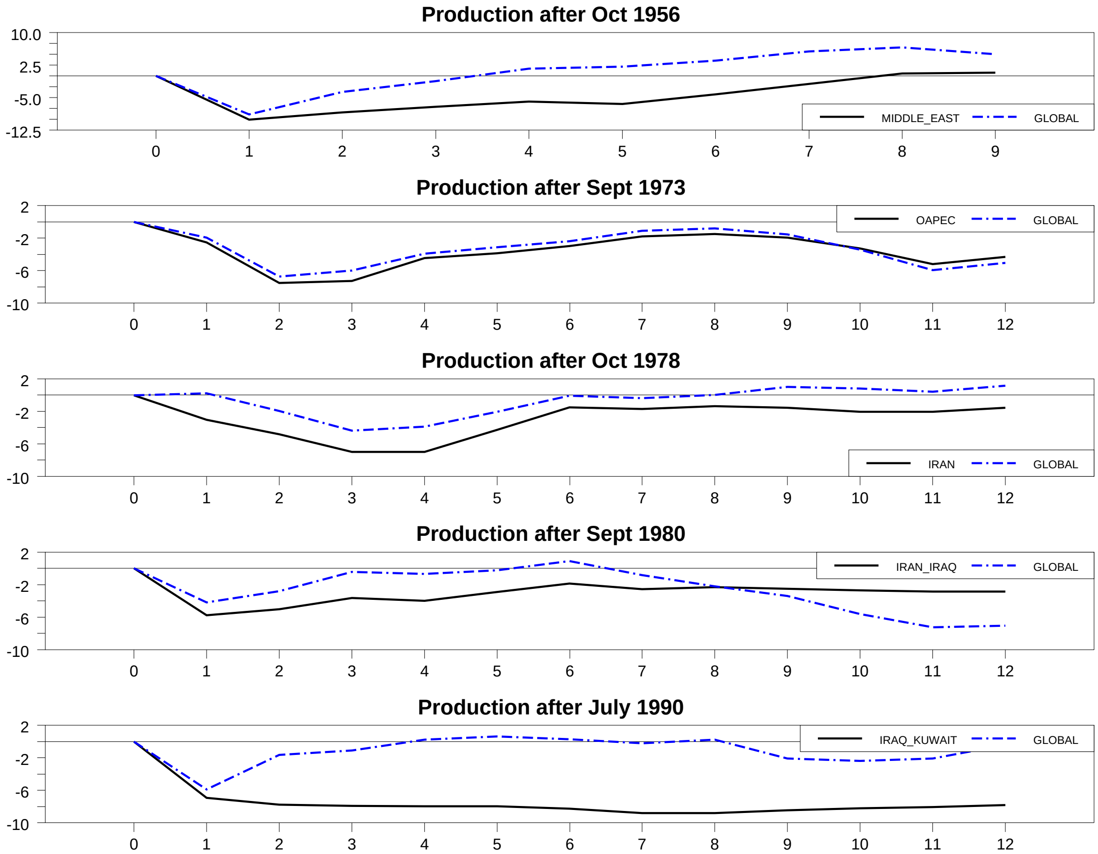

Figure 13. *First panel:* Oil production after the Suez Crisis. Dashed line: change in monthly global crude oil production from October 1956 as a percentage of October 1956 levels. Solid line: change in monthly Middle East oil production from October 1956 as a percentage of global levels in October 1956. *Second panel:* Oil production after the 1973 Arab-Israeli War. Dashed line: change in monthly global crude oil production from September 1973 as a percentage of September 1973 levels. Solid line: change in monthly oil production of Arab members of OPEC from September 1973 as a percentage of global levels in September 1973. Horizontal axis: number of months from September 1973. *Third panel:* Oil production after the 1978 Iranian revolution. Dashed line: change in monthly global crude oil production from October 1978 as a percentage of October 1978 levels. Solid line: change in monthly Iranian oil production from October 1978 as a percentage of global levels in October 1978. *Fourth panel:* Oil production after the Iran-Iraq War. Dashed line: change in monthly global crude oil production from September 1980 as a percentage of September 1980 levels. Solid line: change in monthly oil production of Iran and Iraq from September 1980 as a percentage of global levels in September 1980. *Fifth panel:* Oil production after the first Persian Gulf War. Dashed line: change in monthly global crude oil production from August 1990 as a percentage of August 1990 levels. Solid line: change in monthly oil production of Iraq and Kuwait from August 1990 as a percentage of global levels in August 1990. Horizontal axis: number of months from August 1990. Source: Adapted from Figures 6, 10, 12, 13, and 15 in Hamilton (forthcoming [b]).

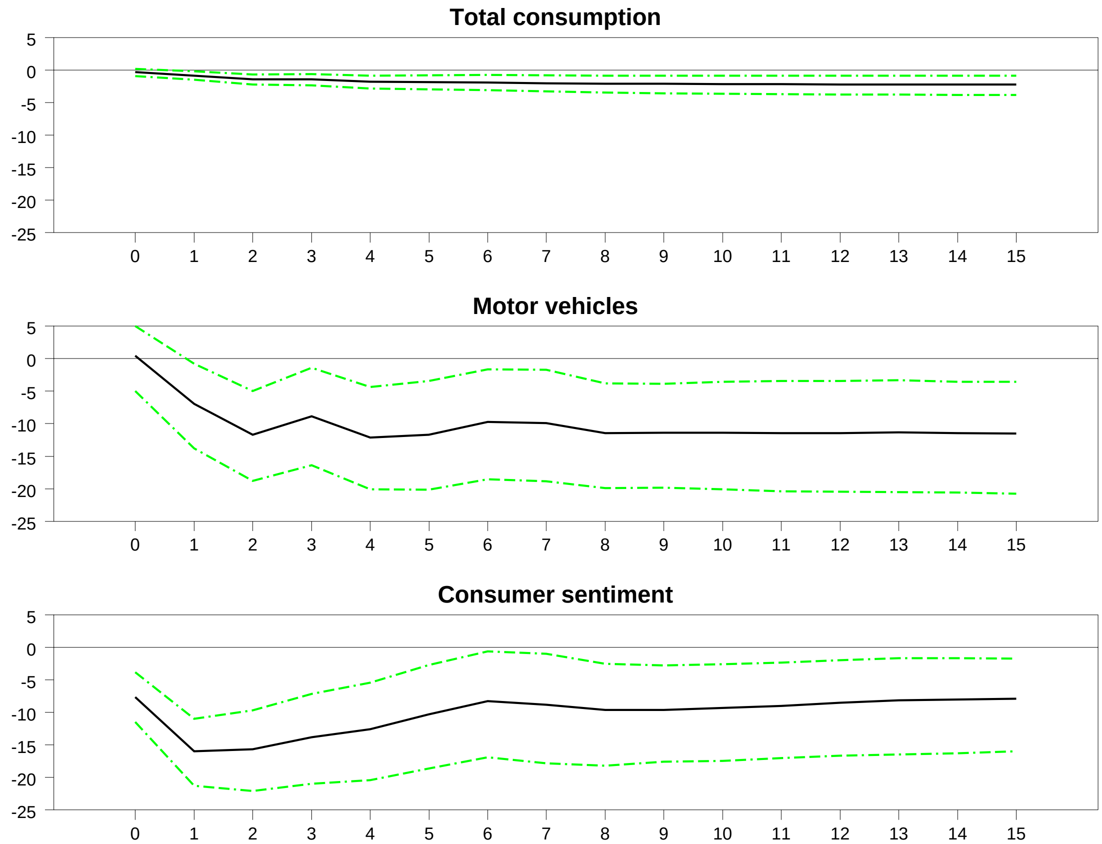

Figure 14. Top panel: impulse-response function showing percentage change in total real consumption spending *k* months following an energy price increase that would have reduced spending power by 1%. Second panel: percentage change in real spending on motor vehicles. Bottom panel: change in consumer sentiment (measured in percentage points). Dashed lines indicate 95% confidence intervals. Source: adapted from Edelstein and Kilian (2009) and Hamilton (2009b).

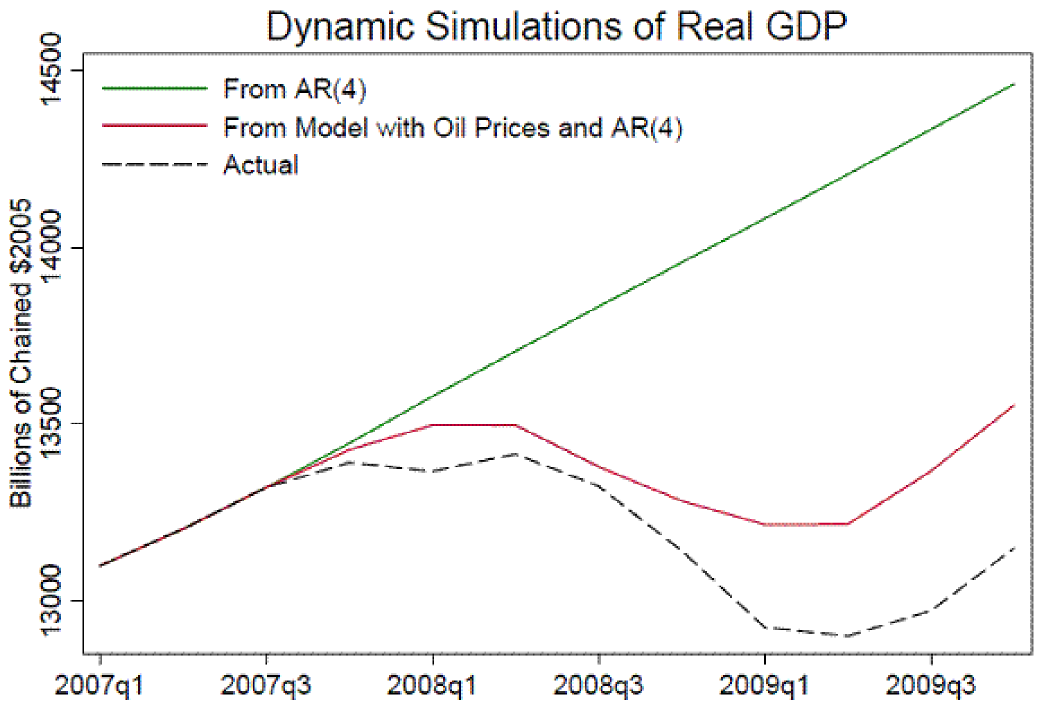

Figure 15. Dashed line: actual value for real GDP. Green line: dynamic forecast (1- to 5-quarters ahead) based on coefficients of univariate AR(4) estimated 1949:Q2 to 2001:Q3 and applied to GDP data through 2007:Q3. Red line: dynamic conditional forecast (1- to 5-quarters ahead) based on coefficients reported in equation (3.8) in Hamilton (2003) using GDP data through 2007:Q3 and conditioning on the ex-post realizations of the net oil price increase measure $o_{t+s}^{\#}$ for $t + s$ = 2007:Q4 through 2009:Q3. Source: Foote and Little (2011).

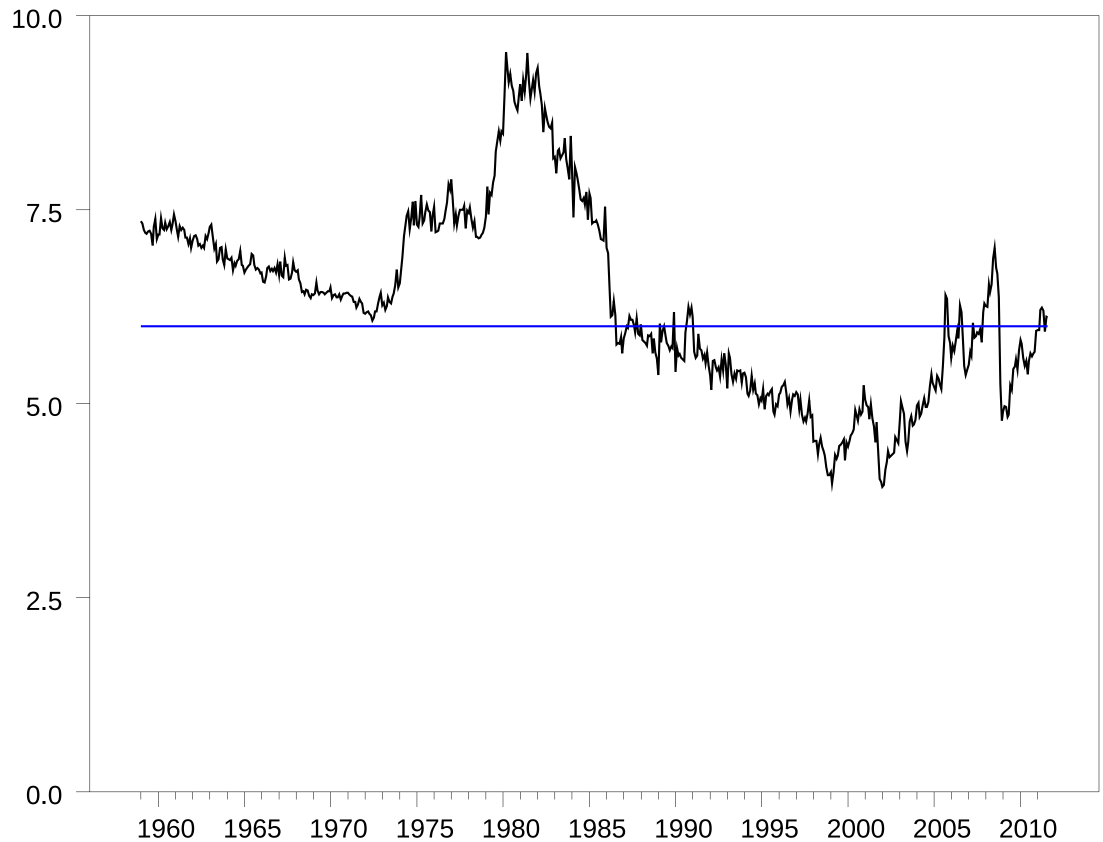

Figure 16. Energy expenditures as a fraction of total U.S. consumption spending. Calculated as 100 times nominal monthly consumption expenditures on energy goods and services divided by total personal consumption expenditures, 1959:M1 to 2011:M8. Horizontal line drawn at 6%. Data source: BEA Table 2.3.5U (http://www.bea.gov/national/nipaweb/nipa_underlying/SelectTable.asp).

Data Appendix

State-level production data (in thousands of barrels per year) were assembled from the following sources: *Derrick's Handbook* (1898, p. 805); *Minerals Yearbook*, U.S. Department of Interior, various issues (1937, 1940, 1944, and 1948); *Basic Petroleum Data Book*, American Petroleum Institute, 1992; and Energy Information Administration online data set (http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm). Numbers for Kansas for 1905 and 1906 include Oklahoma. The *Basic Petroleum Data Book* appears to allocate some Gulf of Mexico production to Texas but most to Louisiana. The EIA series (which has been used here for data from 1981 onward) does not allocate Federal offshore Gulf of Mexico to specific states, and has been attributed entirely to Louisiana in the table below.

Year	US total	PA-NY	WV	OH	IL-IN	CA	KS-NE	CO-NM-AZ-UT	TX	LA	OK	WY	AK	ND-MT	Other
1862	3,056	3,056	0	0	0	0	0	0	0	0	0	0	0	0	0
1863	2,631	2,631	0	0	0	0	0	0	0	0	0	0	0	0	0
1864	2,116	2,116	0	0	0	0	0	0	0	0	0	0	0	0	0
1865	2,498	2,498	0	0	0	0	0	0	0	0	0	0	0	0	0
1866	3,598	3,598	0	0	0	0	0	0	0	0	0	0	0	0	0
1867	3,347	3,347	0	0	0	0	0	0	0	0	0	0	0	0	0
1868	3,716	3,716	0	0	0	0	0	0	0	0	0	0	0	0	0
1869	4,215	4,215	0	0	0	0	0	0	0	0	0	0	0	0	0
1870	5,659	5,659	0	0	0	0	0	0	0	0	0	0	0	0	0
1871	5,795	5,795	0	0	0	0	0	0	0	0	0	0	0	0	0
1872	6,539	6,539	0	0	0	0	0	0	0	0	0	0	0	0	0
1873	9,894	9,894	0	0	0	0	0	0	0	0	0	0	0	0	0
1874	10,927	10,927	0	0	0	0	0	0	0	0	0	0	0	0	0
1875	8,788	8,788	0	0	0	0	0	0	0	0	0	0	0	0	0
1876	9,133	8,969	120	32	0	12	0	0	0	0	0	0	0	0	0
1877	13,350	13,135	172	30	0	13	0	0	0	0	0	0	0	0	0
1878	15,396	15,163	180	38	0	15	0	0	0	0	0	0	0	0	0
1879	19,914	19,685	180	29	0	20	0	0	0	0	0	0	0	0	0
1880	26,286	26,028	179	39	0	40	0	0	0	0	0	0	0	0	0
1881	27,662	27,377	151	34	0	100	0	0	0	0	0	0	0	0	0
1882	21,073	20,776	128	40	0	129	0	0	0	0	0	0	0	0	0
1883	23,449	23,128	126	47	0	143	0	0	0	0	0	0	0	0	5
1884	24,218	23,772	90	90	0	262	0	0	0	0	0	0	0	0	4
1885	21,859	20,776	91	662	0	325	0	0	0	0	0	0	0	0	5
1886	28,065	25,798	102	1,783	0	377	0	0	0	0	0	0	0	0	5
1887	28,283	22,356	145	5,023	0	678	0	76	0	0	0	0	0	0	5
1888	27,612	16,489	119	10,011	0	690	0	298	0	0	0	0	0	0	5
1889	35,163	21,487	544	12,472	34	303	1	317	0	0	0	0	0	0	5
1890	45,824	28,458	493	16,125	65	307	1	369	0	0	0	0	0	0	6
1891	54,293	33,009	2,406	17,740	138	324	1	666	0	0	0	0	0	0	9
1892	50,515	28,422	3,810	16,363	699	385	5	824	0	0	0	0	0	0	7
1893	48,431	20,315	8,446	16,249	2,336	470	18	594	0	0	0	0	0	0	3
1894	49,344	19,020	8,577	16,792	3,689	706	40	516	0	0	0	2	0	0	2
1895	52,892	19,144	8,120	19,545	4,386	1,209	44	438	0	0	0	4	0	0	2
1896	60,960	20,584	10,020	23,941	4,681	1,253	114	361	1	0	0	3	0	0	2
1897	60,476	19,262	13,090	21,561	4,123	1,903	81	385	66	0	1	4	0	0	0
1898	55,367	15,948	13,618	18,739	3,731	2,257	72	444	546	0	0	6	0	0	6
1899	57,071	14,375	13,911	21,142	3,848	2,642	70	390	669	0	0	6	0	0	18
1900	63,621	14,559	16,196	22,363	4,874	4,325	75	317	836	0	6	6	0	0	64
1901	69,389	13,832	14,177	21,648	5,757	8,787	179	461	4,394	0	10	5	0	0	139
1902	88,767	13,184	13,513	21,014	7,481	13,984	332	397	18,084	549	37	6	0	0	186
1903	100,461	12,518	12,900	20,480	9,186	24,382	932	484	17,956	918	139	9	0	0	557
1904	117,081	12,239	12,645	18,877	11,339	29,649	4,251	501	22,241	2,959	1,367	12	0	0	1,001
1905	134,717	11,555	11,578	16,347	11,145	33,428	0	376	28,136	8,910	12,014	8	0	0	1,220
1906	126,494	11,500	10,121	14,788	12,071	33,099	0	328	12,568	9,077	21,718	7	0	0	1,217
1907	166,095	11,212	9,095	12,207	29,410	39,748	2,410	332	12,323	5,000	43,524	9	0	0	825
1908	178,527	10,584	9,523	10,859	36,969	44,855	1,801	380	11,207	5,789	45,799	18	0	0	743

1909	183,171	10,434	10,745	10,633	33,194	55,472	1,264	311	9,534	3,060	47,859	20	0	0	645
1910	209,557	9,849	11,753	9,916	35,303	73,011	1,128	240	8,899	6,841	52,029	115	0	0	473
1911	220,449	9,201	9,796	8,817	33,012	81,134	1,279	227	9,526	10,721	56,069	187	0	0	480
1912	222,935	8,712	12,129	8,969	29,572	87,269	1,593	206	11,735	9,263	51,427	1,572	0	0	488
1913	248,446	8,865	11,567	8,781	24,850	97,788	2,375	189	15,010	12,499	63,579	2,407	0	0	536
1914	265,763	9,109	9,680	8,536	23,256	99,775	3,104	223	20,068	14,309	73,632	3,560	0	0	511
1915	281,104	8,726	9,265	7,825	19,918	86,592	2,823	208	24,943	18,192	97,915	4,246	0	0	451
1916	300,767	8,467	8,731	7,744	18,483	90,952	8,738	197	27,645	15,248	107,072	6,234	0	45	1,211
1917	335,316	8,613	8,379	7,751	16,537	93,878	36,536	121	32,413	11,392	107,508	8,978	0	100	3,110
1918	355,928	8,217	7,867	7,285	14,244	97,532	45,451	143	38,750	16,043	103,347	12,596	0	69	4,384
1919	378,367	8,988	8,327	7,736	12,932	101,183	33,048	121	79,366	17,188	86,911	13,172	0	90	9,305
1920	442,929	8,344	8,249	7,400	11,719	103,377	39,005	111	96,868	35,714	106,206	16,831	0	340	8,765
1921	472,183	8,406	7,822	7,335	11,201	112,600	36,456	108	106,166	27,103	114,634	19,333	0	1,509	19,510
1922	557,530	8,425	7,021	6,781	10,470	138,468	31,766	97	118,684	35,376	149,571	26,715	0	2,449	21,707
1923	732,407	8,859	6,358	7,085	9,750	262,876	28,250	86	131,023	24,919	160,929	44,785	0	2,782	44,705
1924	713,940	8,926	5,920	6,811	9,016	228,933	28,836	543	134,522	21,124	173,538	39,498	0	2,815	53,458
1925	763,743	9,792	5,763	7,212	8,692	232,492	38,357	2,286	144,648	20,272	176,768	29,173	0	4,091	84,197
1926	770,874	10,917	5,946	7,272	8,568	224,673	41,498	4,434	166,916	23,201	179,195	25,776	0	7,727	64,751
1927	901,129	11,768	6,023	7,593	7,846	231,196	41,069	4,057	217,389	22,818	277,775	21,307	0	5,058	47,230
1928	901,474	12,559	5,661	7,015	7,514	231,811	38,596	3,717	257,320	21,847	249,857	21,461	0	4,015	40,101
1929	1,007,323	15,197	5,574	6,743	7,300	292,534	42,813	4,188	296,876	20,554	255,004	19,314	0	3,980	37,246
1930	898,011	16,450	5,071	6,486	6,730	227,329	41,638	11,845	290,457	23,272	216,486	17,868	0	3,349	31,030
1931	851,081	15,255	4,472	5,327	5,879	188,830	37,018	16,772	332,437	21,804	180,574	14,834	0	2,830	25,049
1932	785,159	15,920	3,876	4,644	5,479	178,128	34,848	13,591	312,478	21,807	153,244	13,418	0	2,457	25,269
1933	905,656	15,805	3,815	4,235	4,981	172,010	41,976	15,035	402,609	25,168	182,251	11,227	0	2,273	24,271
1934	908,065	18,282	4,095	4,234	5,317	174,305	46,482	18,003	381,516	32,869	180,107	12,556	0	3,603	26,696
1935	996,596	20,046	3,902	4,082	5,099	207,832	54,843	22,043	392,666	50,330	185,288	13,755	0	4,603	32,107
1936	1,099,687	21,733	3,847	3,847	5,297	214,773	58,317	28,873	427,411	80,491	206,555	14,582	0	5,868	28,093
1937	1,279,160	24,667	3,845	3,559	8,343	238,521	70,761	40,459	510,318	90,924	228,839	19,166	0	5,805	33,953
1938	1,214,355	22,471	3,684	3,298	25,070	249,749	60,064	37,171	475,850	95,208	174,994	19,022	0	4,946	42,828
1939	1,264,962	22,480	3,580	3,156	96,623	224,354	60,703	39,041	483,528	93,646	159,913	21,454	0	5,960	50,524
1940	1,353,214	22,352	3,444	3,159	152,625	223,881	66,415	40,755	493,209	103,584	156,164	25,711	0	6,728	55,187
1941	1,402,228	21,935	3,433	3,510	139,804	230,263	85,140	41,719	505,572	115,908	154,702	29,878	0	7,526	62,838
1942	1,386,645	23,200	3,574	3,543	113,134	248,326	98,873	33,743	483,097	115,785	140,690	32,812	0	8,074	81,794
1943	1,505,613	20,816	3,349	3,322	87,543	284,188	106,813	41,216	594,343	123,592	123,152	34,253	0	7,916	75,110
1944	1,677,904	18,815	3,070	2,937	82,531	311,793	99,179	42,638	746,699	129,645	124,616	33,356	0	8,647	73,978
1945	1,713,665	17,163	2,879	2,838	79,962	326,482	96,720	42,387	754,710	131,051	139,299	36,219	0	8,420	75,535
1946	1,733,909	17,829	2,929	2,908	82,023	314,713	97,511	48,670	760,215	143,669	134,794	38,977	0	8,825	80,846
1947	1,856,987	17,452	2,617	3,108	72,554	333,132	105,361	56,628	820,210	160,128	141,019	44,772	0	8,742	91,264
1948	2,020,185	17,288	2,692	3,600	71,782	340,074	111,123	65,847	903,498	181,458	154,455	55,032	0	9,382	103,954
1949	1,841,940	15,799	2,839	3,483	74,197	332,942	102,198	71,869	744,834	190,826	151,660	47,890	0	9,118	94,285
1950	1,973,574	16,002	2,808	3,383	72,727	327,607	109,133	71,898	829,874	208,965	164,599	61,631	0	8,109	96,838
1951	2,247,711	15,599	2,757	3,140	71,343	354,561	117,080	81,847	1,010,270	232,281	186,869	68,929	0	8,983	94,052
1952	2,289,836	15,475	2,602	3,350	72,126	359,450	117,467	90,799	1,022,139	243,929	190,435	68,074	0	11,155	92,835
1953	2,357,082	14,449	3,038	3,610	71,849	365,085	120,910	108,650	1,019,164	256,632	202,570	82,618	0	17,103	91,404
1954	2,314,988	12,364	2,902	3,880	78,002	355,865	127,100	122,931	974,275	246,558	185,851	93,533	0	20,220	91,507
1955	2,484,428	11,435	2,320	4,353	92,411	354,812	132,872	137,838	1,053,297	271,010	202,817	99,483	0	26,797	94,983
1956	2,617,283	10,978	2,179	4,785	93,859	350,754	140,408	148,875	1,107,808	299,421	215,862	104,830	0	35,255	102,269
1957	2,616,901	10,856	2,215	5,478	89,745	339,646	143,200	154,108	1,073,867	329,896	214,661	109,584	0	40,431	103,214

1958	2,448,987	8,235	2,186	6,260	92,139	313,672	140,315	172,074	940,166	313,891	200,699	115,572	0	42,216	101,562
1959	2,574,600	8,140	2,184	5,978	88,281	308,946	142,424	192,116	971,978	362,666	198,090	126,050	187	47,681	119,879
1960	2,574,933	7,822	2,300	5,405	89,395	305,352	137,278	192,516	927,479	400,832	192,913	133,910	559	52,232	126,940
1961	2,621,758	7,301	2,760	5,639	88,318	299,609	136,610	192,503	939,191	424,962	193,081	141,937	6,327	54,558	128,962
1962	2,676,189	6,891	3,470	5,835	90,873	296,590	136,970	182,873	943,328	477,153	202,732	135,847	10,259	56,829	126,539
1963	2,752,723	6,762	3,350	6,039	86,698	300,908	130,953	181,727	977,835	515,057	201,962	144,407	10,740	55,900	130,385
1964	2,786,822	6,987	3,370	15,859	81,451	300,009	125,365	177,257	989,525	549,698	202,524	138,752	11,059	56,378	128,588
1965	2,848,514	6,554	3,530	12,908	75,189	316,428	121,949	178,072	1,000,749	594,853	203,441	138,314	11,128	59,128	126,271
1966	3,027,762	6,072	3,674	10,899	72,278	345,295	117,588	181,889	1,057,706	674,318	224,839	134,470	14,358	62,506	121,870
1967	3,215,742	6,359	3,561	9,924	69,223	359,219	112,573	187,021	1,119,962	774,527	230,749	136,312	29,126	60,274	116,912
1968	3,329,042	5,692	3,312	11,204	65,083	375,496	107,688	187,361	1,133,380	817,426	223,623	144,250	66,204	73,500	114,823
1969	3,371,751	5,704	3,104	10,972	58,565	375,291	100,822	183,249	1,151,775	844,603	224,729	154,945	73,953	66,657	117,382
1970	3,517,450	5,287	3,124	9,864	51,234	372,191	96,304	178,061	1,249,697	906,907	223,574	160,345	83,616	59,877	117,369
1971	3,453,914	4,924	2,969	8,286	45,742	358,484	88,594	170,669	1,222,926	935,243	213,313	148,114	79,494	56,252	118,904
1972	3,455,369	4,459	2,677	9,358	41,004	347,022	82,449	170,103	1,301,686	891,827	207,633	140,011	72,893	54,528	129,719
1973	3,360,903	4,249	2,385	8,796	35,981	336,075	73,467	171,036	1,294,671	831,524	191,204	141,914	72,323	54,855	142,423
1974	3,202,585	4,374	2,665	9,088	32,472	323,003	68,302	176,306	1,262,126	737,324	177,785	139,997	70,603	54,251	144,289
1975	3,056,779	4,139	2,479	9,578	30,699	322,199	65,226	176,088	1,221,929	650,840	163,123	135,943	69,834	53,296	151,406
1976	2,976,180	3,876	2,519	9,994	30,902	326,021	64,896	165,945	1,189,523	606,501	161,426	134,149	63,398	54,539	162,491
1977	3,009,265	3,539	2,518	10,359	30,922	349,609	63,464	160,223	1,137,880	562,905	156,382	136,472	169,201	55,953	169,838
1978	3,178,216	3,739	2,382	11,154	28,051	347,181	62,448	151,948	1,074,050	532,740	150,456	137,385	448,620	55,279	172,783
1979	3,121,310	3,729	2,406	11,953	26,508	352,268	63,063	140,173	1,018,094	489,687	143,642	131,890	511,335	60,871	165,691
1980	3,146,365	3,475	2,336	12,928	27,680	356,923	66,391	130,510	977,436	469,141	150,140	126,362	591,646	69,921	161,476
1981	3,128,624	4,570	3,473	13,551	28,811	384,958	72,481	128,088	932,350	462,097	154,056	130,563	587,337	76,237	150,052
1982	3,156,715	5,116	3,227	14,571	33,273	401,572	77,397	124,344	908,217	475,474	158,621	118,300	618,910	78,192	139,501
1983	3,170,999	5,113	3,628	14,971	34,521	404,688	77,974	133,990	882,911	499,334	158,604	118,303	625,527	79,915	131,520
1984	3,249,696	5,124	3,524	15,271	34,394	412,020	82,181	143,085	883,174	536,868	168,385	124,269	630,401	82,413	128,587
1985	3,274,553	5,922	3,555	14,988	35,433	423,877	82,350	149,743	869,218	527,852	162,739	128,514	666,233	80,625	123,504
1986	3,168,252	4,636	3,145	13,442	32,004	406,665	74,132	144,354	819,595	532,119	149,105	121,337	681,310	72,700	113,708
1987	3,047,378	4,012	2,835	12,153	27,718	395,698	65,975	137,049	760,962	500,544	134,378	115,267	715,955	66,410	108,422
1988	2,979,126	3,396	2,621	11,711	26,141	386,014	64,802	136,718	735,495	464,466	128,874	113,985	738,143	62,681	104,079
1989	2,778,771	3,196	2,243	10,215	23,689	364,250	61,715	127,921	688,169	432,222	117,493	107,715	683,979	57,700	98,264
1990	2,684,679	3,056	2,143	10,008	22,954	350,899	61,317	125,428	678,478	417,386	112,273	103,856	647,309	56,527	93,045
1991	2,707,043	2,958	1,963	9,156	22,082	351,016	62,760	126,377	682,616	438,825	108,094	99,928	656,349	55,470	89,449
1992	2,624,631	2,541	2,068	9,197	22,319	348,040	59,087	122,573	650,623	443,984	101,807	96,810	627,322	51,376	86,884
1993	2,499,044	2,371	2,048	8,282	20,167	343,729	54,493	119,714	619,090	439,791	96,625	87,667	577,495	48,363	79,209
1994	2,431,483	2,817	1,918	8,758	19,640	343,569	50,948	115,185	590,735	440,306	90,973	79,528	568,951	44,103	74,052
1995	2,394,268	2,243	1,948	8,258	18,968	350,686	47,560	112,544	559,646	467,203	87,490	78,884	541,654	45,865	71,319
1996	2,366,021	2,001	1,680	8,305	18,098	346,828	45,330	108,917	543,342	505,795	85,379	73,365	509,999	48,236	68,746
1997	2,354,832	1,597	1,509	8,593	18,545	339,307	43,172	114,850	536,584	546,302	83,364	70,176	472,949	51,358	66,526
1998	2,281,921	2,197	1,471	6,541	15,940	329,860	38,715	113,969	504,662	582,608	77,578	64,782	428,850	52,045	62,703
1999	2,146,726	1,677	1,471	5,970	14,029	312,719	31,709	99,164	449,233	614,072	70,556	61,126	383,199	47,819	53,982
2000	2,130,720	1,710	1,400	6,575	14,304	306,124	37,420	101,374	443,397	628,675	69,976	60,726	355,199	48,147	55,693
2001	2,117,521	1,786	1,226	6,051	12,114	291,766	36,864	99,832	424,297	665,095	68,531	57,433	351,411	47,611	53,504
2002	2,097,121	2,398	1,382	6,004	14,013	287,793	35,500	98,514	411,985	661,287	66,642	54,717	359,335	47,848	49,703
2003	2,073,454	2,569	1,334	5,647	13,561	280,000	36,699	100,382	405,801	659,242	65,356	52,407	355,582	48,726	46,148
2004	1,983,300	2,708	1,339	5,785	12,739	267,260	36,365	101,014	392,867	615,311	62,502	51,619	332,465	55,878	45,448
2005	1,890,105	4,144	1,563	5,652	11,934	256,848	36,236	100,184	387,680	543,259	62,142	51,626	315,420	68,515	44,902
2006	1,862,259	3,945	1,749	5,422	12,054	249,562	37,964	101,173	397,220	547,876	62,841	52,904	270,486	76,173	42,890

2007	1,848,452	4,033	1,574	5,455	11,336	241,378	38,824	101,631	396,894	542,763	60,952	54,130	263,595	79,887	46,000
2008	1,811,819	3,997	1,593	5,715	11,281	238,691	41,976	105,507	398,014	494,708	64,065	52,943	249,874	94,321	49,134
2009	1,956,597	3,880	1,864	5,834	10,903	228,994	41,703	112,443	403,797	638,004	67,018	51,333	235,500	107,428	47,896
2010	1,998,138	3,923	1,992	4,785	10,901	223,501	42,672	120,583	426,700	633,639	69,513	53,133	218,762	138,341	49,693