Box 1. The "energy revolution", innovation, and the nature of substitution

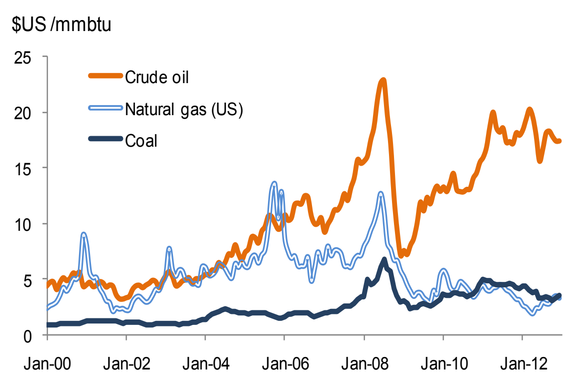
Large, sustained price changes alter relative input prices and induce innovation (Hicks 1932). The post-2004 crude oil price increases did just that in both natural gas and oil exploration and extraction through new technologies such as horizontal drilling and hydraulic fracturing. Because of these technologies, the United States increased its natural gas production by almost 30 percent during 2005-12. Similarly, U.S. crude oil production increased by 1.3 mb/d over the past four years. To put this additional oil supply into perspective, consider that global biofuel production in terms of crude oil energy equivalent was 1.2 mb/d in 2011.

The sharp increase in natural gas supplies not only put downward pressure on prices, but also induced substitution of coal by natural gas in various energy intensive industries, notably in electricity generation and petrochemicals. Natural gas, which traded just 7 percent below oil in 2000-04 in energy-equivalent terms, averaged 82 percent lower in 2011-12 and has been trading close to parity with coal (figure box 1.1). On the other hand, growing U.S. oil supplies, coupled with weak demand, caused WTI to be traded at 20 percent below Brent, the international marker (figure box 1.2). The discount is expected to persist until 2015, when new pipelines and reversal of existing pipelines will move oil supplies from the Midwestern United States to the Gulf Coast.

Yet, the shift from crude oil to other types of energy, notably electricity and natural gas, with potential use by the transportation industry (which globally accounts for more than half of crude oil consumption) has been very slow. Such slow response reflects the different physical properties of various types of fuel, namely density (the amount of energy stored in a unit of mass) and scalability (how easily the energy conversion process can be scaled up). The energy densities of the fuels relevant to the transportation industry are 37 MJ/liter for crude oil, 1 MJ/kg for electricity, and 0.036 MJ/liter for natural gas (in its natural state). Compressed natural gas (GNG), used by bus fleets in large cities, is about 10 MJ/liter, while the density of liquefied natural gas (LNG) is 24 MJ/liter. Energy density is measured in megajoules (MJ) per kilogram or liter. For comparison, note that one MJ of energy can light one 100-watt bulb for about three hours.

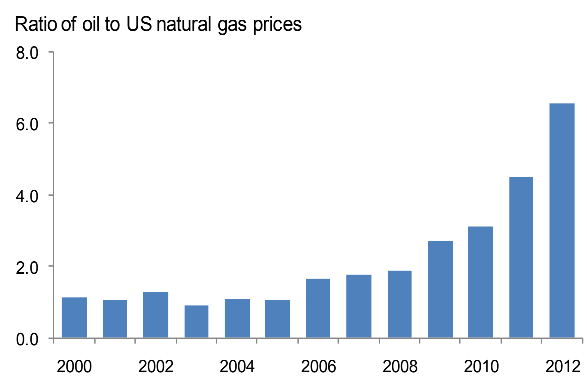
To gauge the importance of energy density associated with various fuels and technologies consider the following illustrative example. If a truck with a net weight capacity of 40,000 pounds were to be powered by lithium-sulphur batteries (currently used by electric-powered vehicles) for a 500-mile range, the batteries would occupy almost 85 percent of the truck's net capacity, leaving only 6,000 pounds of commercial space. That is, an energy conversion process that works at a small scale (a passenger car) does not work at larger scales (in a truck, an airplane, or an ocean-liner). Similarly, to increase the energy density of natural gas, it must be liquefied, which involves cooling it to about -62°C at a LNG terminal, transporting it in specially designed ships under near atmospheric pressure but under cooling, and then off loading at destination, gasified and re-injected into the natural gas pipe network. This is a technically demanding process adding considerable costs at delivery. Contrary to natural gas, crude oil products have convenient distribution networks and refueling stations that can be reached by cars virtually everywhere in the world. Thus, in order for the transport industry to substitute crude oil by natural gas at a scale large enough to reduce oil prices, innovations must take place such that the distribution and refueling costs of natural gas become comparable to those of crude oil, which explains why the transport industry is slow to utilize natural gas.

Box figure 1.1 Energy prices



Source: World Bank.

Box figure 1.2 Oil to natural gas price ratio



Source: World Bank.