ENERGY AND THE MACROECONOMY

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Contents

Summary

The role of energy in the macroeconomy is described across a range of concepts and theories encompassing current thinking in both traditional economics and more interdisciplinary efforts. Among economists, the importance of energy as an input to the macroeconomy is paramount to some, yet trivial to others. Time series and cross sectional correlations seem to validate claims that there is a strong relation between energy use and economic activity. However, closer inspection indicates that this correlation is flexible. This flexibility is associated with historical and cross sectional differences in the types of fuels consumed, the types of goods and services produced and consumed, energy prices, and technical, geographic, social, and political factors. These relations beg the question, how does energy use affect economic activity? The long run level of economic activity is determined principally by labor productivity, which is determined in part by the net supply of energy. In the short run, economic theory argues that energy affects economic activity via energy prices, an influential factor in the turning points of past business cycles. The causal order of these long- and short-run relationships has been the subject of much analysis. Clarifying the macroeconomic linkages between economic activity and energy use is critical to efforts to assess the eventual depletion of conventional supplies of crude oil and to determine

the degree to which society should mitigate carbon dioxide emissions associated with the combustion of fossil fuels.

1. Introduction

Economic growth and improvements in the material standard of living are associated with energy consumption; as economies develop and grow, both total and per capita energy consumption tends to increase. The macroeconomic relation between economic activity and energy use is the focus of this article. This exploration is organized as follows. Section 2 summarizes contrasting theories of the relationship between economic activity and energy use. The theory of energy-economy linkages is discussed relative to the role of coal in the early part of the industrial revolution.

Section 3 examines the empirical evidence for the relation between economic activity and energy use. Studies find a close correlation between economic activity and energy use both over time within nations and across nations at any give time. However, this relation is flexible. Empirical analyses of this flexibility indicate that historical and cross sectional differences in energy intensity are associated with the types of fuels consumed, the types of goods and services produced and consumed, energy prices, and technical, geographic, social, and political factors.

Section 4 describes the mechanisms by which energy use and energy prices can affect economic activity in both the long and short term. Section 5 considers the policy implications of these mechanisms in relation to the eventual depletion of conventional supplies of crude oil and the emission of carbon dioxide associated with the combustion of fossil fuels.

2. The Role of Energy in Economic Activity

Firms and households use energy services—power, heat, and lighting—along with capital equipment, labor, materials, and land to produce and consume goods and services. Traditionally, economics has argued that goods and services and these factors of production cycle between firms and households. Households own capital, labor, energy, natural resources, and land. These factors of production are purchased by firms, who use them to produce goods and services. Firms sell these goods and services to households. This cycle implies that production and consumption is powered in part by energy use. The degree to which energy is linked to production and consumption depends on the level of technology and the relative prices for the factors of production. Technology describes the combinations of factors of production that can be used to produce or consume a good or service. The combination that is used by a firm or household depends on relative prices. In market economies, sustained changes in relative prices stimulate the substitution of lower cost factors of production for higher cost factors of production within the limits of technical feasibility. Under these conditions, the link between energy use and economic activity strengthens as increases in technological know-how uncover new ways to use energy and/or the price of energy declines relative to other inputs.

More interdisciplinary descriptions of the economy-energy relation (such as those coming from the transcipline of ecological economics) argue that the circular flow of factors of production and goods and services between households and firms is a perpetual motion machine. As such, the model violates the second law of thermodynamics. This argument contends that the understanding of the economic system can be improved by studying the material and energy flows that make the traditional economic model consistent with the laws of thermodynamics. From a thermodynamic perspective, production and consumption are work processes that increase the organization state of matter. Such changes oppose the tendency towards a greater state of disorder that is dictated by the second law of thermodynamics. As such, economic activity does not occur spontaneously. Rather, energy must be used to oppose the tendency towards disorder. Accordingly, economic production and consumption are work processes that are powered by a unidirectional input of low entropy energy. This model implies that energy is the primary input to economic systems that powers the circular flow of goods, services, and factors of production between firms and households. Following this line of thinking, there is a strong link between economic activity and energy use regardless of the level of technological know-how or relative prices.

The role of energy in the economy can be illustrated by changes in coal during the early part of the industrial revolution. This example is illustrative of ends of the theoretical spectrum outlined above. Over the long term, rates of economic growth rise and fall in waves or cycles. These movements are known as long waves or long cycles, which distinguishes them from the short run fluctuations that are associated with the business cycle. Beginning with Joseph Schumpeter, economists recognized that major technical innovations, which are new products or processes that stimulate the macroeconomy and catalyze new types of economic activities, increased rates of economic growth that are associated with the advent of the next long wave. This waxing phase of the long wave can persist for several decades because new technologies diffuse slowly and new uses for the technology continue to be found over time.

Schumpeter suggested that energy-related innovations, such as the steam engine, railroads, electricity, and motorcars, triggered the growth phase of the long wave cycles from the late eighteenth century through the mid-twentieth century. Prior to this period, fuel wood was the dominant source of energy. Coal was used primarily in the regions where it was mined. However, as the production of glass and metals increased, the demand for charcoal grew beyond the level that could be provided sustainably by local forests. As a result, the demand for fuel wood and charcoal outstripped supply, and this caused the price of wood and charcoal to rise relative to coal. As the price for wood-based fuels rose relative to coal, the demand for coal increased. Coal production was able to meet expanded demand due, in part, to the invention of the steam engine. The steam engine was introduced in 1698 to power pumps that were used to de-water mines. Prior to the introduction of the steam engine, there were no mechanical means of removing water that accumulated in mines; the water was removed by human labor alone. By substituting steam power for labor, the steam engine sped up coal production and improved labor productivity.

The steam engine improved over time and steam power gradually spread to the manufacturing and transportation sectors of the economy. These changes also increased the demand for coal. One of the most important uses of the steam engine was its use to power trains. Railroads, which began to be built in the 1830s, influenced energy use and the economy in three ways. Rail and car construction required large amounts of iron and steel. Metal industries had by this time switched their production processes from wood fuel to coal, in the form of coke. Thus rail construction spurred demand for coal products indirectly. Rail operations required coal for fuel and were therefore a direct source of new demand. Finally, the rail system facilitated the geographic expansion of markets for coal and manufactured goods.

The interdependence between energy use and technical innovations and the self-reinforcing effects of these changes are readily apparent: the steam engine was developed to aid the production of coal and was itself a source of demand for coal. The availability of inexpensive coal stimulated the development of new applications for steam power in manufacturing and transportation sectors. Thus coal availability fueled the development of new sources of demand for coal and, ultimately, the rapid economic growth and structural change of the industrial revolution in the United Kingdom economy.

3. The Macroeconomic Relation between Economic Activity and Energy Use: Empirical Analyses

Consistent with the role of coal in the industrial revolution, empirical analyses demonstrate a strong correlation between economic activity and energy use, both over time within nations and across nations at any point in time. Within individual nations, increases in economic activity, as measured by Gross National Product (GNP) or Gross Domestic Product (GDP) usually are linked with increases in energy use. For example, total energy use in the US increased by a factor of about ten between 1890 and 1999 while real GDP also increased by about a factor of ten. A similar correlation is present in international comparisons of energy use and economic activity. Nations with a high material standard of living, as measured by per capita GDP or GNP, consume large quantities of energy relative to poorer nations. For example, in 1990 US per capita GDP was about ten times greater than in Egypt. In that same year, per capita energy consumption in the US was about eleven times greater than in Egypt.

Despite this evidence of strong correlation between energy use and economic activity, both can grow at very different rates and a given material standard can be supported by different levels of energy use. In the US, real GDP more than doubled between 1973 and 1999. During the same period, energy consumption increased only by about 20 percent. Similarly, citizens of the US and the UK enjoy similar material standards of living--but per capita energy use in the US is considerably larger than per capita energy use in the UK. This variation implies that the potential to decouple economic activity from energy is consistent with arguments about the importance of technical change and relative prices.

This section describes the correlations between economic activity and energy use and the factors that may disrupt a simple one-to-one correlation between economic activity and energy use.

3.1. Energy Intensity

The degree to which economic activity and energy use can be decoupled often is measured by energy intensity. Energy intensity is the ratio of energy use divided by economic activity. For the macroeconomy, energy intensity is the ratio of national energy use divided by economic output over a one-year period. Calculating national energy intensities requires aggregating energy flows from different fuels and economic output from different sectors. The standard methods aggregate energy use according to their heat content and aggregate economic activity using the accounting methods that underlie the calculation of real gross national product (GNP) or gross domestic product (GDP).

The ratio of total energy use to macroeconomic activity – the so-called energy-GDP ratio – is the starting point for many empirical analyses of the role of energy in the macroeconomy. In most developed nations, the energy-GDP ratio peaked before World War I and fell during much of the twentieth century. In the US, the energy-GDP ratio declined by about 66 percent between 1929 and 1999. Similarly, the energy-GDP ratio for many industrial nations is less than the ratio for many industrializing nations. For instance, in 1990 the energy-GDP ratio in Norway was 50 percent lower than the energy-GDP ratio in China. These historical and cross sectional differences appear to support a common economic perspective that technical change and changes in relative prices can decouple the link between economic activity and energy use.

Some analysts use macroeconomic energy intensity to measure the energy efficiency of an economy. They argue that a small energy intensity indicates a high level of energy efficiency. According to this interpretation, the energy efficiency of the US economy increased between 1929 and 1999, and the Norwegian economy is more energy efficient than the Chinese economy. However, using the energy-GDP ratio to measure macroeconomic energy efficiency is misleading. From a physical perspective, an increase in energy efficiency implies that one economy does the same tasks using less energy from the same fuels. As described below, historical and cross sectional differences in the energy-GDP ratio are largely associated with changes in the types of fuels used and the types of goods and services produced and consumed. These differences are lost when energy flows, goods, and services are aggregated to calculate energy intensity. To understand fully the degree to which economic activity can be decoupled from energy use, section 3.2 examines the factors that influence energy intensity.

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Biographical Sketches

Robert Kaufmann is an Associate Professor in the Department of Geography and Center for Energy and Environmental Studies at Boston University, Boston, MA. He received his Ph.D. in Energy Management & Policy from the University of Pennsylvania in 1988, an MA in Economics from the University of New Hampshire in 1984, and a BS in Biology (with a Concentration in Ecology & Systematics) from Cornell University in 1979. His research focuses on three areas: world oil markets, global climate change, and ecological economics. In each area, his research seeks to make progress by integrating theory and techniques developed in the social and natural sciences. Progress is defined by the ability to understand the issue at hand and the ability to develop effective policy. These results are described in three books and more than forty research papers in journals such as *Nature, Science, The American Journal of Agricultural Economics,* and *The Energy Journal*. These efforts have won prizes from the National Wildlife Federation and the International Association of Energy Economists.

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