Energy and Economic Development: An Assessment of the State of Knowledge

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Abstract

Energy development is an integral part of enhanced economic development. The fact that expanded provision and use of energy services is strongly associated with economic development leaves open how important energy is as a causal factor in economic development, however; and energy development competes with other opportunities for scarce capital and opportunities for policy and institutional reform. In this paper we first give a brief conceptual discussion that seeks to identify the channels through which increased availability of energy services might be a key to stimulating economic development along different stages of the development process. We then examine some empirical work to see what evidence it might provide regarding possible channels of influence. The evidence underscores the importance of energy development *in concert with* other forms of development. More work is needed to better understand the magnitude of energy's importance for economic development.

Key Words: energy. economic development. productivity. poverty alleviation.

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Michael Toman with Barbora Jemelkova*

Introduction

Energy development, interpreted broadly to mean increased provision and use of energy services, is an integral part of enhanced economic development. Advanced industrialized societies use more energy per unit of economic output and far more energy per capita than poorer societies, especially those still in a pre-industrial state. Energy use per unit of output does seem to decline over time in the more advanced stages of industrialization, reflecting the adoption of increasingly more efficient technologies for energy production and utilization as well as changes in the composition of economic activity (see, e.g., Nakicenovic 1996). And energy intensity in today's developing countries probably peaks sooner and at a lower level along the development path than was the case during the industrialization of the developed world. But even with trends toward greater energy efficiency and other dampening factors, total energy use and energy use per capita continue to grow in the advanced industrialized countries, and even more rapid growth can be expected in the developing countries as their incomes advance.

The fact that expanded provision and use of energy services is strongly associated with economic development leaves open how important energy is as a causal factor in economic development. Development involves a number of other steps besides those associated with energy, notably including the evolution of education and labor markets, financial institutions to support capital investment, modernization of agriculture, and provision of infrastructure for water, sanitation, and communications. This is not just an academic question; energy development competes with other development opportunities in the allocation of scarce capital and in the allocation of scarce opportunities for policy and institutional reform.

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The landmark research by Sam Schurr and colleagues remains one of the best and most convincing examples of the potential for positive synergy between energy development and broader economic development for industrial societies (see Schurr 1984 for a summary). Schurr argued that apart from changes in the composition of economic activity toward less energy-intensive goods and services, and an increase in the thermal conversion efficiency of energy in the economy, observed productivity increases for nonenergy production factors partly resulted from increased use of more flexible energy forms (liquid fuels and especially electricity), through which "the discovery, development, and use of new processes, new equipment, new systems of production, and new industrial locations" was enhanced (Schurr 1984, 415). A critical element of Schurr's argument is that changes in the *quality* of energy services drive broader economic productivity, apart from the physical availability of energy per se. These arguments are further developed in a subsequent part of this paper.

In large part, however, the literature on energy and development—including the literature relevant to lower-income countries—focuses on how energy demand is driven by economic development (see, e.g., Barnes and Floor 1996) and on how energy services can be improved for developing countries (Dunkerley et al. 1981; OTA 1991, 1992; Barnes and Floor 1996; ESMAP 2000). Less is found in the literature on the importance at the margin of energy advance versus growth in other inputs as an agent of economic development. To partly paraphrase a venerable RFF book title (Darmstadter et al. 1979), the literature has given much consideration to how developing societies use energy, and less to how energy-using societies develop.

In this paper we begin with a brief conceptual discussion that seeks to identify the channels through which increased availability of energy services might be a key for stimulating economic development along different stages of the development process. A fundamental tenet of economic theory is that short of some hypothetical saturation point, an increment to any factor of production implies a *ceteris paribus* increase in output. More is always more. Therefore, our theoretical discussion seeks to highlight ways in which the contribution of increased energy availability might somehow *disproportionately* stimulate development. This discussion is motivated partly by recent developments in the theory of endogenous economic growth with increasing returns (Barro and Sala-i-Martin 1995), though that literature has said little about energy per se.

After laying out some conceptual ideas, we then examine some empirical work to see what evidence it might provide regarding possible channels of influence. We do find some illustrations of a disproportionate role for energy. However, that evidence also underscores the importance of energy development *in concert with* other forms of development. Moreover, the amount of relevant literature we found was fairly limited, and in many cases it was difficult to separate out various influences in the study to see how energy might be exerting a disproportionate role. This underscores our conclusion that although much is known about how the productivity of energy provision and use might be augmented at the micro level, more work is needed to understand the magnitude of its importance for economic development at an economy-wide level. As is always the case with development questions, institutional puzzles loom large in this query.

Energy and Development: Conceptual Linkages

The linkages among energy, other inputs, and economic activity clearly change significantly as an economy moves through different stages of development. Barnes and Floor (1996) describe this phenomenon as an energy ladder, though it is recognized by these authors and others that the ladder concept does not imply a monotonic transition from one type of energy to another. At the lowest levels of income and social development, energy tends to come from harvested or scavenged biological sources (wood, dung, sunshine for drying) and human effort (also biologically powered). More processed biofuels (charcoal), animal power, and some commercial fossil energy become more prominent in the intermediate stages. Commercial fossil fuels and ultimately electricity become predominant in the most advanced stages of industrialization and development. Again, energy resources of different levels of development may be used concurrently at any given stage of economic development: electric lighting may be used concurrently with biomass cooking fires. Changes in relative opportunity costs as well as incomes can move households and other energy users up and down the ladder for different energy-related services.

Despite the substantial differences in energy forms and economic activities across different stages of development, some common elements can be seen. Energy provision or acquisition is a costly activity requiring a variety of inputs, whether that cost is denominated in terms of household labor allocated to biomass gathering or expenditures for commercial fuels and the inputs needed to provide them. Energy utilization also does not occur in a vacuum but depends on the opportunity costs of other inputs, notably various types of capital goods (be they cookstoves or electricity grids). Finally, the literature makes clear that observed patterns of energy production and utilization reflect a great deal of subtle optimizing behavior, given the constraints faced by the economic actors (Barnes and Floor 1996; OTA 1991, 1992). Those constraints can impede better outcomes, however; and much of the work to date on energy development has concerned how lower-cost and more effective energy services can be delivered by alleviating or working around financing and informational barriers as well as regulatory distortions.

Recognizing that the details of energy-development relationships differ considerably along the different stages of development, we can use a very simple model of an economy to discuss in general conceptual terms the possible ways in which increased energy availability might be especially important to economic development. Let us suppose that

(1) $Y = F(K_Y, H_Y, E)$

(2) $E = E(K_E, H_E)$

(3) $H = G(K_H, L)$

In (1), Y represents output of final goods and services, and (K_Y, H_Y) represent the application of physical capital and human capital services to the production of final goods and services, along with another intermediate good, *E,* which we interpret as energy services. Energy services in turn are produced through the application of other physical and human capital services, (K_E, H_E) in (2). Clearly, the provision of energy services depends on many other factors as well, notably the availability of the resource base itself, but for simplicity we suppress those arguments of the production relationship here. Finally, human capital in the economy ($H = H_Y + H_E$) is the product of raw labor services/time and the application of other capital services (including the human capital services of teachers and others; this is clearly a static simplification of a more complex dynamic process).

Obviously, this simple setup omits many important elements, including the dependence of final output on other intermediate goods and the coproduction of environmental residuals with valued economic outputs. Moreover, for simplicity we have ignored the fact that both human and physical capital inputs may be specialized to different sectors (thus requiring, for example, separate production functions for the different flows of human capital services).

A standard assumption from economic growth theory is that the production functions *F, E,* and *G* are homogeneous of degree one: if all inputs are increased by some percentage, outputs grow at the same percentage. It would then follow from this assumption that if raw labor and capital services flowing into all production sectors (including human capital) all increase by *x*%, then final output will increase by *x*% as well. On the other hand, if inputs to energy services were increased by *x*% while labor and capital services in final output and human capital provision were maintained, then final output would rise but by less than *x*% because of the law of diminishing marginal productivity of a single input (in this case, energy services). The resulting increase in economic activity could be substantial if the supply of energy services were constrained and their marginal value product was correspondingly high, but this would be identifiable directly from data on the potential contribution of energy services to productivity, without reference to broader energy-economy linkages.

To see how increased energy availability somehow might make a disproportionate contribution to expanded economic activity, we must explore different ways in which the economic system might experience some form of increasing returns related to energy services. This could occur either in the provision of energy services or in their utilization, as discussed in the subsections that follow. Before turning to specific possibilities, we illustrate the argument pictorially in Figure 1, which is taken from ESMAP (2002a).

In the diagram, we show two schedules for the marginal value product of lighting services—lumens in providing various household benefits (longer reading time, easier reading, more security, and the like). The schedule MVP_0 represents the situation at a lower level of income, which we assume is also associated with use of lower-quality and higher-per-lumen-cost kerosene lighting. At this lower level of income, the introduction of lower-per-lumen-cost electric lighting will raise total lighting used and generate an economic welfare increase measured by Area abcd (the fall in cost of inframarginal lighting usage) plus Area bce (the consumer surplus from increased lighting utilization).

The schedule MVP_1 represents the marginal value product of lighting services at a higher income level induced by an increase in energy service availability—perhaps as a result of improved education capacity or ability to shift household tasks to evening hours and devote time during the day to paying work. Along this higher schedule, the additional (multiplier) benefits of lighting are reflected in additional benefits from baseline consumption (Area eghi) as well as in benefits from a further induced increase in usage (Area efg).

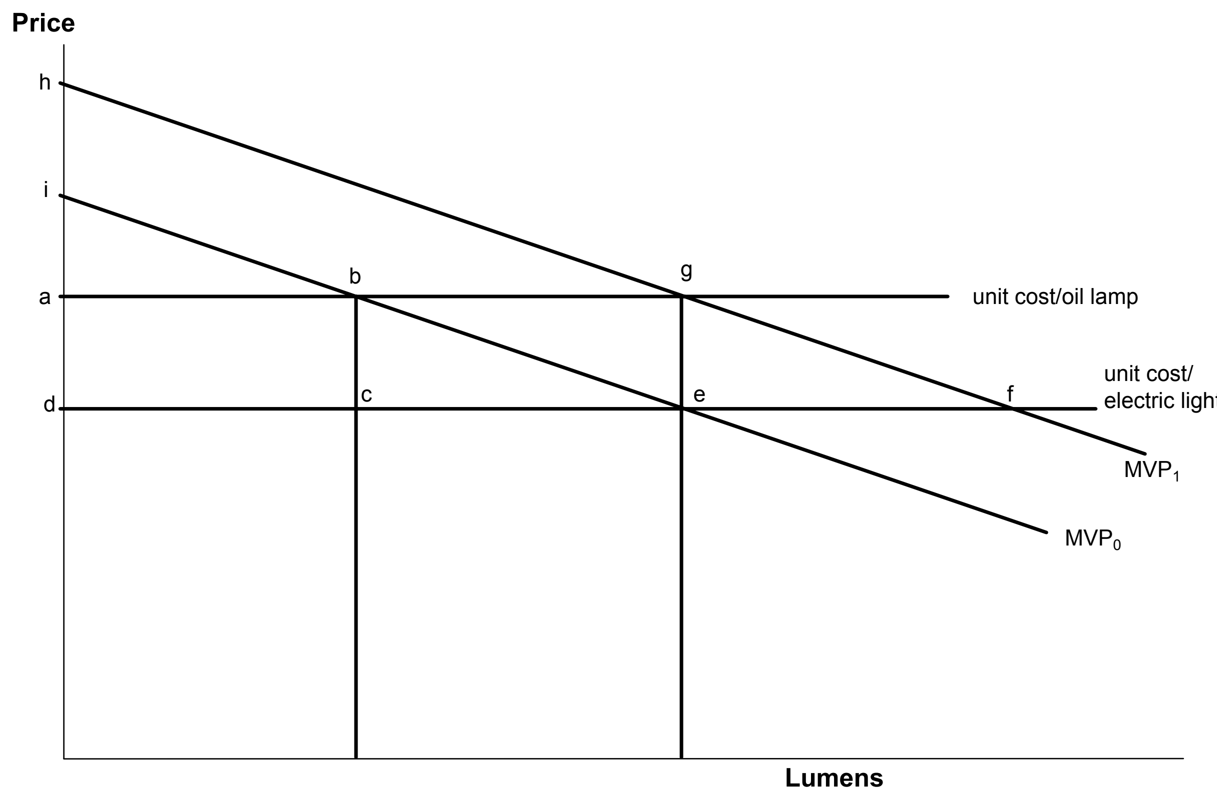

Figure 1. Illustration of multiplier economic effects from increased energy services utilization.

Source: Adapted from ESMAP (2002a).

Provision of Energy Services

Consider first the provision of energy services in (2) above. Suppose that an increase of *x*% in inputs resulted in an energy services output of more than *x*%. Then by expanding inputs economy-wide by *x*%, economy-wide output could grow by more than *x*% because of the "extra" expansion experienced in intermediate energy inputs. It follows that final output could be increased in this case even if the scale of energy inputs were expanded at the expense of other factors in final output. Given increasing returns in the provision of *E*, factor requirements per unit of energy services output decline with scale; so reallocation of other factors to a larger scale of energy services provision could increase final output.

Increasing returns in energy services provision would take different forms at different stages of development. Industrial-scale production and distribution of various forms of modern energy (grid electricity, refined petroleum products) are known to exhibit increasing technological returns to scale. As modern energy systems develop, they require investments in large infrastructure, such as transmission systems, that show declining unit costs over a wide range of scale and utilization. Moreover, the transformation of primary energy into deliverable energy (electricity generation, petroleum refining) also exhibits returns to scale, though the magnitude of increasing returns, at least in electricity generation, has probably fallen over time with technical advances (Joskow and Schmalensee 1983; Nakicenovic 1996; Brennan et al. 1996).

Different kinds of increasing returns in lower-scale energy provision also seem to exist and may be quite important to the earlier stages of development. The energy development literature is replete with discussions of how subsistence energy systems involve large investments of household labor time, notably the time of women and children, in gathering poor-quality fuels (OTA 1991, 1992). An increase not just in the raw provision of energy per se but in scale—including changes in the types of energy services offered and the organization of markets to allow for greater specialization of effort—seems likely to lower considerably the effective cost of the energy services delivered.

There might be a substantial threshold effect in the achievement of these economies. Unless a considerable fraction of households were above some minimum effective income level, it might not be possible to achieve the required specialization of functions at a scale and cost of energy services that could be afforded. On the other hand, raising income across such a threshold might be greatly facilitated by a reduction in the effective cost of energy services.

Utilization of Energy Services

Let us now turn to the possibility of various types of increasing returns in the utilization of energy services. One simple but ultimately somewhat unsatisfying way to capture this would be to posit that the marginal product of energy in final output, (1) above, is increasing in the utilization of energy services at least over some range of energy use. Then output growth can be disproportionate to input growth. However, this setup provides no insights as to how this might occur.

A potentially more fruitful approach is to modify (1) as follows:

$$(4)\, Y = F(A_K * K_Y, A_H * H_Y, E)$$

where the A_K and A_H are "factor augmentation" terms—multipliers that indicate how the effective flows of these inputs can be enhanced by other factors. In traditional economic growth with exogenous technical change, these terms are exogenous time trends. In endogenous growth theory, the terms can be thought of as by-products of deliberate economic activity. The endogenous growth literature has emphasized factor augmentation through research and development, education, and the provision of public goods. However, it is also possible that increased energy use has multiplier effects on the productivity of other factors. If this is the case, then when the supply of energy services is increased, there is not just more energy to be used with each skilled worker or machine; the productivity with which every unit of energy is used also rises. If all inputs to final production are increased in some proportion, final output would grow in greater proportion because of the multiplier effect on nonenergy inputs.

Equation (4) emphasizes an increased quantity of energy services use as a source of multiplier effects. As already noted, the work of Schurr and others emphasizes increased quality (e.g., flexibility) of energy services—especially electricity—as well as quantity. To encompass this aspect, we can modify the theoretical framework developed above as follows:

$$(5)\, Y = F(K_Y, H_Y, E_l, E_n)$$

$$(6)\, E_i = E_i(K_{Ei}, H_{Ei}), i = l, n$$

Here E_l and E_n can be thought of as higher- and lower-quality forms of energy, respectively, with differing capabilities to contribute to the productivity of other factors in the production of final output. If higher-quality energy is more costly to provide (in particular, requires more capital expenditure) but offers higher overall factor productivity, then society can make a trade-off between the two energy forms that favors more advanced but more productive energy forms as development progresses; the result, measured in terms of productivity per unit of energy input (e.g., BTUs), will be greater overall productivity as a consequence of the energy advance. This kind of approach has been followed by Jorgenson (1984), whose work is discussed below. In principle it can be combined with the factor augmentation framework in (4).

There are several ways in which increased availability or quality of energy could augment the productivity and thus the effective supply of physical and/or human capital services. The transmission mechanisms are likely to differ across the stages of development. We have already noted that for more advanced industrialized or industrializing countries, increased energy availability and flexibility can facilitate the use of more modern machinery and techniques that expand the effective capital-labor ratio as well as increase the productivity of workers. Whereas supply-side energy changes in less advanced countries economize on household labor, here energy availability can augment the productivity of industrial labor in the formal and informal sectors.

Increased energy service reliability is another important component of quality, again especially for electricity. Estimates for developed countries of the cost of electricity supply interruption per lost megawatt-hour are several orders of magnitude larger than the cost of baseload or peak electricity supply costs (OTA 1990). We have not attempted in this paper to probe the potential size of these costs for developing countries.[1] Our conjecture is that the direct costs are lower per disruption because disruptions (interruptions or large voltage fluctuations) are so much more common in many developing countries that users are better adapted. But this means in turn that a significant amount of capital can be tied up in providing energy service redundancy (backup generators) that could be otherwise and more productively deployed if the effective supply of electricity were enhanced through increased reliability.

For less advanced developing countries, factor productivity enhancement effects necessarily operate more through labor inputs. One possibility is through the development and use of human capital. Energy availability for cheaper and better lighting (in concert with the appropriate physical capital) can increase the productivity of education inputs generally and lead to a multiplier effect in human capital provision, as well as extend the length of the workday.

Increased availability of different kinds of energy services also can directly or indirectly improve the health and therefore the productivity of workers. Increased availability of cleaner, modern energy forms can improve indoor air quality (see, e.g., Ezzati and Kammen 2002; Ezzati et al. 2002). It can also help promote access to safer drinking water (e.g., in deeper wells). By facilitating refrigeration, greater energy availability can reduce food-borne illness and improve the storage of medicines. By lowering costs of food production, it can make it easier for subsistence households to meet and go beyond basic dietary requirements. To capture these effects, the A_H term could be thought of as a reduced-form summary of a more complex set of production relationships for the provision of household health services in which energy availability figures prominently. The scope of the model in (1)–(3) above can be broadened to include pollution by-products.

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[1] A recent ESMAP report from the World Bank (ESMAP 2002b) provides an example from India indicating that many farmers using irrigation pay about twice the subsidized cost of electricity to use diesel for their pump sets; the authors suggest that this reflects the desire to avoid the high costs of unreliable electricity supply (since if irrigation capacity cannot be used at critical times, the results for crop yields can be disastrous).

Finally, for countries at various stages of development, greater energy availability may interact positively with the availability of other infrastructure services. Investments in a road network that lower transportation costs and thereby increase the geographic size, scale, and efficiency of markets are the more valuable if energy is more readily available for fueling transport. The same is true for electricity availability to power more modern telecommunications and information infrastructure.

Channels for Increasing Returns

To summarize, our discussion so far suggests several possible channels through which increased energy availability could disproportionately affect economic development:

- reallocation of household time (especially by women) from energy provision to improved education and income generation and greater specialization of economic functions;
- economies of scale in more industrial-type energy provision;
- greater flexibility in time allocation through the day and evening;
- enhanced productivity of education efforts;
- with more flexible and reliable as well as plentiful energy, greater ability to use a more efficient capital stock and take advantage of new technologies;
- lower transportation and communication costs: greater market size and access, more access to information (the combined result of energy and other infrastructure); and
- health-related benefits: reduced smoke exposure, clean water, and refrigeration (yielding direct benefits and higher productivity).

This discussion of how increased energy availability may promote different stages of development also underscores the need to think about more than energy development in isolation. Even if we frame the issue fairly narrowly, capital equipment (more modern stoves, refrigerators, lighting, motors, boilers, as well as marketing and delivery systems for modern fuels like liquefied petroleum gas, LPG) and increased knowledge are required to expand energy use and increase the productivity of household and industrial labor. Attempts to expand energy availability will accomplish little if bottlenecks to such investments are not overcome.

It is necessary also to consider what happens to the labor services saved through an increase in the scale and technical sophistication of energy service provision. One option could be the expansion of other household production activities, such as animal husbandry and microenterprise. The size of such benefits depends on, among other things, the status of women in the society.

A less direct but important potential link is through the lowering of households' opportunity cost of education, especially for children. If the reduced need for raw labor input in (2) above is accompanied by an increase in labor input to human capital provision in (3), then the economy can experience a multiplied effect of the increasing returns from provision of energy services. But in practice, this requires investment in the capacity for increased education, not just the freeing up of household labor time from drudgework.

Similar observations can be made about the development of social institutions that permit effective use and enjoyment of the increasing returns. If energy markets are poorly established or organized because of weak property rights, for example, then the potential benefits of economies of scale in service provision may not be realized. This would apply to the creation of both additional biomass plantations and additional high-tension electricity transmission capacity. Thus, although increasing returns in the provision of energy services may offer the *potential* for a disproportionate effect of energy development on overall development, the fuller realization of this potential requires other economic and social development interventions as well.

Finally, whatever disproportionate effects increased energy availability may have in facilitating development on the supply side of the economy, it is important not to lose track of direct demand-side benefits as well. Quality of life improvements stemming from better health, less drudgery, more leisure, greater communication opportunities, and increased social status all have direct positive effects on the well-being of various household members, in addition to whatever effects might be enjoyed through increasing the production possibilities of the economy.

Empirical Illustrations of Energy-Development Linkages

One could explore the questions addressed above using macroeconomic data on income or production, energy utilization, capital investment, human knowledge acquisition, and other factors. That is, one could examine across countries and perhaps across time how gross domestic product (GDP) per capita changes with energy availability per capita. The literature on energy development contains a number of examples of the reverse relationship—that is, how energy usage is strongly driven by economic development, as indicated by per capita income. Although this relationship clearly is valid, the discussion highlights the difficulty in sorting out complex interactions between energy and development with simple macroeconomic relationships. In particular, drawing conclusions about the *process* of development from the *cross-section* experiences of disparate countries can be risky. As already noted, the time profiles of energy and GDP growth for today's developing countries do appear to be quantitatively, if not qualitatively, different from the past experiences of today's industrialized countries.

A better approach in principle would be the development and empirical implementation of sectorally detailed general equilibrium modeling for developing countries, along the lines suggested by the simple framework in (1)–(3) above. General equilibrium considerations are increasingly being incorporated into development economics analysis (see, e.g., Lopez 1994, 1998). To our knowledge, however, use of these models remains relatively uncommon; and what uses have been made of them usually focus on other parts of the economy than energy. A partial exception to this statement is the usage of international general equilibrium models for examining energy and climate change policies (see Weyant and Hill 1999). But these models tend to be highly stylized representations of the economies in question; indeed, they often replicate the structures of the developed economies, including assumptions about returns to scale, and differ only in specific parameter values. This approach does not provide the right platform for assessing the questions of interest in this paper.

A third option is to develop more microeconomically oriented case studies that help illuminate the questions. Here a small empirical literature does exist. As already noted, much of the energy and development literature concentrates on the microeconomics and policy issues of the energy side—the potential for expanding energy supplies and reducing their costs, and the policy measures that might be needed to accomplish this. Less, apparently, has been done to assess the broader economic consequences of such energy sector accomplishments.

To illustrate, the 1994 *World Development Report* (World Bank 1994) discusses at length the importance of infrastructure provision to economic development, a perspective buttressed by both theoretical considerations in endogenous growth theory and some research on rates of return in infrastructure investment. However, the statistical associations between energy infrastructure and economic growth that are displayed do not address the extent to which the investments pushed the growth or vice versa; and the literature cited in the volume on rates of return on infrastructure investment is concerned with multiple forms of infrastructure investment or investment in specific nonenergy infrastructure.

The two excellent studies by the Office of Technology Assessment mentioned previously provide valuable information on the potential importance of energy progress for economic progress (OTA 1991, 1992). In particular, they cite figures on how much household labor time is invested in subsistence energy provision, and how energy-inefficient human hand labor is relative to even simple machines powered by external energy sources. These kinds of figures strengthen the conviction that energy progress is a key to economic progress, especially at the earlier stages of development. However, the OTA reports do not supply figures on the economic value of such energy advances; their main emphasis, as in much of the other energy and development literature, is the technical options for improved provision of energy services and policies to encourage that outcome.

Energy and Industrial Progress

Schurr (1982, 1984) begins his argument on the potential for positive synergy between energy development and broader economic development for industrial societies by noting some apparent paradoxes in income, energy, and productivity statistics for the United States. From roughly the end of World War I to the first oil shock in the 1973, the U.S. economy experienced both substantial increases in overall productivity and a drop in energy intensity; moreover, the drop in energy intensity occurred during a period of stagnant or falling energy prices. This combination of circumstances seems paradoxical because one would expect a productivity increase to be stimulated in part by substitution of machines and energy services for labor, and because energy intensity should not be falling (other things equal, at least) under the conditions observed for energy prices.

Part of the explanation for the figures is to be found in changes in the composition of economic activity toward less energy-intensive goods and services, and an increase in the thermal conversion efficiency of energy in the economy. But Schurr argues that this is only part of the story. Energy use rose relative to labor and capital but not relative to output. The energy intensity of output fell because of technical advances throughout the economy that accelerated output growth.

The last and most critical part of Schurr's hypothesis is that the productivity increase for other factors was in turn partly the result of the changing energy picture in the U.S. economy. Because of increased use of more flexible energy forms (liquid fuels and especially electricity), "the discovery, development, and use of new processes, new equipment, new systems of production, and new industrial locations" were enhanced (Schurr 1984, 415). Even though energy use rose relative to energy and capital, the effect of increased use of flexible energy forms through greater productivity of other factors was large enough that energy intensity of output fell. Schurr provides a more detailed illustration of the argument in the context of the electrification of U.S. manufacturing and broader productivity benefits provided by electric motors.[2]

Schurr (1982) also adds a few remarks concerning the relevant trends after 1973. During this time, higher energy prices stimulated great increases in energy efficiency and therefore in measures of energy productivity (these trends later abated somewhat after the drops in energy prices experienced from the mid-1980s). At the same time, overall economic productivity stagnated or even declined. Schurr suggests that despite the need for further exploration of the many relevant interconnections linking energy and the economy, the possibility of reduced overall productivity as a consequence of higher energy costs must be considered.

Jorgenson (1981, 1984) addresses both the pre-1973 and the post-1973 energy-economy links through more formal econometric analysis of 35 U.S. sectors. Jorgenson uses a translogarithmic dual function approach that emphasizes relationships among factor prices, factor shares, and the overall technology level of a sector as represented by a time proxy. A five-input model is used: capital, labor, electricity, nonelectrical energy, and materials. By dividing energy in this way, Jorgenson seeks to isolate the special role that electrification may have played in industrial productivity advance.

A crucial concept introduced by Jorgenson is the extent to which productivity growth is *electricity-using*. Electricity-using productivity growth is observed when technical progress increases the share of total value added accounted for by electricity (growth is electricity-saving if the share drops). Similar definitions can be applied to the other factors (e.g., labor-saving productivity growth implies a drop in the value share of labor as technology improves).

The concept of electricity-using productivity growth is important because it expresses not just the way that an input's value share evolves with changes in technology, but also the dependence of productivity growth on input prices. Specifically, if productivity growth is electricity-using, then a decrease in the price of electricity will raise the rate of productivity growth, other things equal. Again, similar relationships apply for other factors (e.g., with capital-using productivity growth, an increase in the cost of capital would dampen productivity growth). Thus the concept of electricity-using (or electricity-saving) productivity growth provides a unifying framework for interpreting both historical evidence on changes in patterns of electricity

[2] Other examples are provided by Rosenberg (1983), as well as in other papers in that volume.

and other energy use in manufacturing as technology has advanced, and evidence on the ways that energy and other input prices can affect productivity (as discussed in Schurr 1982, 1984, and Rosenberg 1983).

Table 1 below reproduces some of Jorgenson's central econometric findings using data from 1958 through 1979. As Jorgenson notes, one finding is that for 23 of the 35 sectors studied, and 15 of the 21 manufacturing sectors, technical progress tended to be electricity-using over the period, highlighting an apparent connection between electrification and broader economic progress. As Jorgenson also points out, however, in 19 of these sectors technical progress was also nonelectric-energy-using. Moreover, there were more sectors (28 versus 23, and 19 versus 15 manufacturing) in which nonelectric-energy-using progress was observed compared with electricity-using progress. This suggests a more complicated picture than is explained by electrification alone.

Some sectors that show significant nonelectric-energy-using technical progress are those in which one would expect multiplier effects from greater use of more flexible fluid energy forms, such as agriculture and transport. In other cases, nonelectric-energy-using technical change would be expected given the sheer importance of nonelectric energy inputs, such as chemicals, crude oil and gas production, refining, and gas and electric utilities. Some of these sectors also are electricity-using, but others are electricity-saving.

The pattern of sectors that are capital-using and capital-saving also paints a mosaic. Many of the sectors that are electricity-using and nonelectric-energy-using involve light industries, consumer goods, more technical intermediate products, and services. Some of these sectors also are capital-using (implying that technical progress was primarily economizing on labor and/or materials), but others were capital-saving. Chemicals and primary metals production were capital-saving; refining and various mining activities were capital-using. Taken as a whole, the results do indicate important connections between patterns of energy use and productivity changes, but they also indicate a number of other influences at work.

Jorgenson takes up the point raised by Schurr that higher energy prices since 1973 would be an important part of the observed productivity slowdown. Since 32 of 35 sectors studied are energy-using (electricity, nonelectrical, or both), the fact that energy-using sectors would have lower productivity growth in the face of higher energy prices would seem to underscore the point. It is worth pointing out, however, that most of the sample period considered by Jorgenson involved steady or declining energy prices, and prices were distorted in the United States during the 1973–1979 period by oil and gas price controls (not to mention a regulatory lag in the adjustment of electricity rates to rising fuel costs). In any event, six years of data is a short period from which to draw conclusions about longer-term productivity consequences of factor price changes.

Table 1. Patterns of factor share biases with technical change in Jorgenson (1984).

	Electricity-using	*Electricity-saving*
Nonelectric-using	*Capital-using:* tobacco textiles apparel lumber, wood printing, publishing fabricated metals motor vehicles transport electrical machinery *Capital-saving:* food paper rubber leather instruments gas utilities finance, insurance, real estate transport equipment communications electric utilities	*Capital-using:* nonmetallic mining miscellaneous manufacturing government activities agriculture crude petroleum and natural gas refining *Capital-saving:* chemicals stone, clay, glass machinery
Nonelectric-saving	*Capital-using*: metal mining services construction *Capital-saving*: primary metals	*Capital-using*: coal mining trade *Capital-saving*: furniture

Subsequent macroeconomic research has tended to confirm the conclusion that energy price shocks have disproportionate adverse consequences for the economy (for a recent review, see Brown and Yücel 2002). However, the emphasis in much of that work has been on the various adjustment costs experienced by markets in the face of abrupt price changes, as opposed to longer-term productivity effects. The transmission mechanisms for these adjustment costs and their magnitudes are still under debate.[3] From the standpoint of the theme of this paper, we can likewise conclude that patterns of energy use do seem to have some important broader productivity implications, but more work is needed to determine their importance vis-à-vis other influences and to understand the interactions between energy and nonenergy influences.

Rural Household Energy Use

A World Bank study of the economic and social benefits of rural electrification in the Philippines (ESMAP 2002a) seeks to capture a variety of direct and indirect benefits through detailed survey-based research and a theoretically solid analytical framework similar to Figure 1 above. The basic findings of the study are reproduced in Table 2. As the authors carefully note, the various categories of benefits overlap and simply adding them up involves double counting. Still, the magnitudes indicate the potential for significant multiplier effects relative to the more direct benefits.

The first two categories of benefits—lower cost and expanded use of lighting, and lower cost and expanded use of radio and TV—are relatively easy to define as direct increases in household consumer surplus from rural electrification. The fourth item, time savings for household chores, also could be considered a direct benefit, though such time savings also reduce the opportunity cost of education and home business activity, and the survey analysis notes but does not evaluate this connection. The other two items in the table illustrate how improved energy access can spill over to enhance economic productivity. Although the figures are hard to compare, it does appear that these broader benefits are the same order of magnitude as the direct household benefits—not a trivial consideration in the overall social evaluation of energy services augmentation.

[3] One significant finding from this literature is the apparent asymmetry of the economic response: downward price shocks seem to be much less favorable than comparable upward shocks are adverse.

Table 2. Typical rural household benefits from electrification in the Philippines.

Benefit category	*Value (US$)*	*Unit (per month)*
Less expensive and expanded use of lighting	36.75	household
Less expensive and expanded use of radio and TV	19.60	household
Improved returns on education and wage income	37.07	wage earner
Time savings for household chores	24.50	household
Improved home business productivity	34.00 (current), 75.00 (new)	business

Source: ESMAP (2002a).

A (broadly) methodologically similar draft study by Barnes et al. (2002) concerns rural electrification in India. The authors consider benefits associated with improved lighting, ability to irrigate with electric pump sets, and complementary returns to education. Although the study does not provide the same summary comparison as shown for the Philippines in Table 2, it further confirms the observation that broader benefits from education are very much in evidence.

The lighting benefits, expressed in terms of percentage increases over the consumer surplus derived from inferior kerosene lighting, are enormous. The benefits from improving farm income through pump irrigation also are quite significant: depending on farm size and other factors, income increases by roughly 50% or more. The education benefits are more indirect but no less important. The availability of electricity appears to markedly accelerate the rate at which household income rises with years of schooling. This can then be translated into substantial increases in the potential for increased farm and nonfarm income when improved education is coupled with electricity availability.

Yet another recent study examines the importance of various infrastructure services (water, electricity, sanitation, telephone) for poverty alleviation and social development in Peru (World Bank 1999). The findings of this work suggest first that electricity appears to be the most important service among those considered for improving household welfare. Both electrification and sanitation interact positively with education—that is, education is more productive the greater the availability of either of these services. Finally, access to two or more infrastructure services appears to have greater-than-proportional impacts on household income, so there appear to be some economies of scope in infrastructure service provision.

Concluding Remarks

The existing literature on energy and development does show that energy development is an important component of broader development. In this paper we have attempted to pull together some of the ways in which energy might exert a significant influence on the development process. The influence may be especially important at lower levels of development, where the overall opportunity cost of less efficient energy forms and the relative payoff from use of more efficient forms seem especially high. Some empirical information does exist to substantiate this view. However, the quantitative information generally is quite limited.

More case studies along the lines of the World Bank analysis reported in ESMAP (2002a) are sorely needed to document how improved energy availability contributes in some broad multiplier way to economic development, especially at lower income levels. Where more systematic sectoral data of reasonable quality become available, econometric analysis along the lines of Jorgenson's work also can be pursued, but with underlying models that make it possible to investigate a wider range of ways in which energy could drive economic progress (including more specific factor interaction effects, as suggested by the endogenous growth literature). The ultimate practical importance of such work is not just in the documentation of benefits from improved energy availability: the analysis would also illuminate complicated choices among different strategies for improving energy availability (e.g., increased grid-based rural electrification versus more decentralized approaches; promotion of fossil or biomass-based cooking fuels).

This kind of work can deal only partly with the economy-wide implications of improved energy availability. To more fully capture these effects (e.g., impacts on rural labor markets or trade), general equilibrium research on the energy-development linkage also would need to be undertaken. However, such efforts are by no means trivial in terms of theory or data, as illustrated by Lopez's (1998) detailed work on land use and agriculture. The models need to be constructed in a way that reflects the structural and institutional realities of developing economies. Moreover, difficult causality issues need to be addressed. If one finds, for example, that within a country areas of greater economic development are associated with greater availability of higher-quality and more efficient energy, how does one separate the influence of energy on development from the influence of other factors (more fertile land, better-educated people) that could have driven development, with expanded energy availability following? This kind of difficult analysis also will be needed to deepen our understanding of energy influences on development. But until better data and modeling frameworks are available, priority should be given to the sectoral-level assessments.

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