Modeling Energy-Efficiency Program Effort and Administrative Expenditures

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ABSTRACT

Questions are being raised about the adequacy of policy and technology representation in conventional energy and economic models. Most conventional models rely on a highly stylized and limited characterization of technology. In these models, any desired changes in energy demand are driven only by pure price mechanisms such as Btu taxes or carbon charges. In this paper, however, we explore the existence of market and organizational imperfections that also affect energy demand. We then examine how cost-effective program expenditures might prompt desirable increases in energy efficiency. Finally, we show how such program expenditures and the resulting changes in energy efficiency might be more properly represented in models of the industrial sector.

Introduction

Questions are being raised about the adequacy of policy and technology representation in conventional energy and economic models (Worrell et al 2003, Sanstad et al 2003, and Laitner et al 2003). Most conventional models rely on a highly stylized but a limited characterization of technology that require large price increases to reduce energy demand and their associated externalities. These various pricing mechanisms include gasoline taxes, Btu taxes, or some form of a carbon charge.

There are several reasons for the dislike of high energy prices including their effects on international competitiveness, inflation, and income transfers and distribution within society. But in this paper we explore yet another reason to look beyond the pure price mechanism: the existence of market and organizational imperfections that affect the current level of energy demand, and the cost (or gains) to society and individual companies of increasing energy efficiency through cost-effective program expenditures.

In making incremental energy-efficiency investments within an industrial plant, some decision-maker within the firm will typically compare the capital cost to save a unit of energy with the discounted present value of purchasing the energy. The key, however, is: (1) knowing about and having confidence in cost-effective technologies, and (2) the discount rate that the decision-maker uses to evaluate any potential investment.

High marginal cost-of-capital, relevant to incremental investments, will lower investments in energy efficiency below the level that would maximize the economy's Gross Domestic Product (GDP) growth (Hanson & Laitner 2000). Further, with pervasive principal-agent problems in firms, the agent (or decision-maker) responsible for initiating the energy-efficiency investment may be risk averse and apply a discount rate that is higher than even the marginal cost-of-capital — even though it would have been in the interest of the firm's shareholders (the principal) to make the investment. Policies and programs that build on the many market and organizational imperfections can target specific approaches to increase energy-efficiency investments. If shown to be cost-effective, such programs would, in turn, increase the value of a firm, but would also increase the value of production in the economy. Besides contributing to a small but positive increase in GDP, other social benefits of energy-efficiency investments include increased energy security, reduced pollution, attendant improvements associated with adopting advanced technologies, and less greenhouse gas emissions.

This paper is intended to illustrate how insights from industrial investment decisions and cost-effective energy efficiency programs can be represented in the analysis and modeling of the industrial sector. We use algorithms within Argonne's AMIGA modeling system to illustrate this perspective (AMIGA model documentation report is available from the first author). The problem addressed here is separated into two distinct parts: (1) the appropriate representation of the technology choice set in large energy models of the U.S. or other economies, and (2) the decision of where on the choice set to operate a manufacturing facility. Different market segments for decision-making imply a distribution of choices spread over each choice set. Energy efficiency programs and policies can be targeted at the different market segments. The importance of disaggregating types of capital stocks in the analysis is also emphasized.

Technology Structure and Decision Framework

The technological structure of a typical industrial production process is shown in Figure 1. This conceptual diagram is interpreted in this section and its usefulness as an analytical model is presented. Earlier work on similar industrial energy use modeling was done by Ross (1993).

Energy Efficiency Investments

Figure 1 shows various energy-using subsystems assembled into a total system which transforms material and/or semi-finished goods into output products. Typical subsystems include:

- Lighting,
- Electrical drives for machining, conveyers, refrigeration, and other electrical systems using motors, compressors, and/or pumps,
- Heating, Ventilation, and Air Conditioning (HVAC),
- Boilers and steam systems,
- Furnaces and process heat systems,
- Combined heat and power systems,
- Sensor and control systems,
- Information systems, and
- Transport of materials and goods within the facility.

In new industrial facilities, all systems are open to be designed. In existing facilities in a given period, investment is limited to replacements, capacity expansion, and upgrading and modernizing. Each year a relatively small portion of industrial capacity is retrofitted, replaced, or added to expand capacity.

Figure 1. The Structure of Industrial Production Capital, Labor, and Energy-Related Subsystems

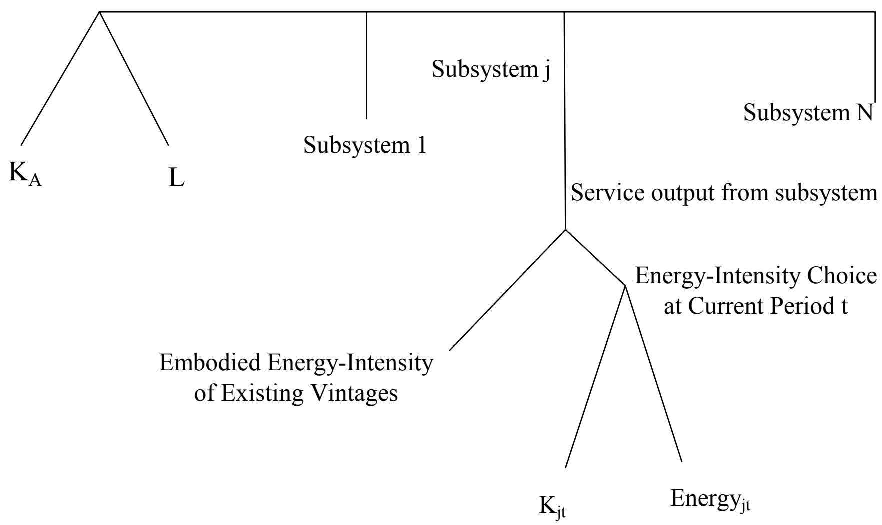


Figure 1 highlights these decisions for a hypothetical energy subsystem *j*. This might be a refrigeration system, a motor drive system, or a combined heat and power system. The total service output from the subsystem will be the sum of the services provided by existing capital and by any new investment. The energy-intensity and other characteristics of existing equipment are generally fixed (although there may be some opportunity for retrofit improvements and operational improvements, which is discussed later). The energy-intensity of the new equipment is a choice problem for the firm (Steinmeyer 1998). This is denoted by the decision node in Figure 1, showing capital investment, K_{jt}, and energy use, E_{jt}, in period *t*, where energy use is evaluated at expected operating conditions. If we denote the expected service output from this new investment of vintage *t* to be S_{jt}, then the embodied energy-intensity will be $E_{jt},/ S_{jt}$.

The decision node represents the opportunity to incrementally increase initial investment in order to reduce the flow of energy consumption over the operational life of the equipment. In terms of economic theory, we can think of a production function with a service output and with factors K_{jt} and E_{jt}.

The function relating subsystem investment to energy flow for a given service output is called the isoquant. As shown in figure 2, the isoquant represents the range of technological options available at a given time. Of course, technological progress in future time periods will shift the isoquant curve down and to the left to reflect performance improvements and cost reductions; hence all variables are subscripted with the vintage *t*. This technological change reflects learning from experience with energy efficient technologies or penetration of more efficient products into the market for firms to select.

The isoquant is a reduced form representation of the technology options facing a specific firm or industry sector for a specific energy use. It is a useful analytical structure because it separates technology options from differences in decision criteria. Note that the slope of the isoquant gives the incremental investment necessary to reduce annual energy consumption by one unit. In many cases individual technologies can be identified along an isoquant.

Decision criteria will depend on factors internal and external to the firm. The firm's debt-equity ratio, corporate bond rating, and share price will affect the firm's cost-of-capital. Capital budgeting and decision authority channels within the firm will also affect decisions (more on these factors later). Different firms could be distributed along an isoquant because they apply different decision criteria. Recognizing the range of decision criteria allows well-designed policy and programs to influence energy-efficiency investments for industrial equipment.

In analyzing and modeling industrial production systems and program effectiveness, a unit-isoquant is frequently used. By unit-isoquant we mean an isoquant normalized to unit service output, that is, $S_{jt}=1$. This assumption is equivalent to assuming that the production process is constant returns to scale, or what economists call *linear homogeneous*. This assumption is probably sufficiently accurate for most broad situations in which energy-efficiency is analyzed, and this assumption is commonly used in economic models of industry production and energy use. One can think of constant returns to scale as the case where each system or subsystem is ideally sized for new investments and these systems are added as modules. The slope of the isoquant is negative and captures the tradeoff between investing in energy-efficient equipment versus purchasing energy. Mathematically, the slope of the isoquant is given by

$$\left.\frac{dK}{dE}\right|_{\bar{S}} = -F_E^{'} / F_K^{'}$$

where output $\bar{S}$ is held fixed and the underlying production function is denoted by

$$S_{jt} = F_{jt}(K_{jt}, E_{jt}).$$

The decision criterion is that dollars should be invested in energy-efficient equipment as long as the capital cost of saving one unit of energy is less than the discounted present value of purchasing one unit of energy over the life of the equipment. The discounted present value formula is the inverse of the capital recovery factor (CRF), which we will denote by *r*. For a uniform series of annual energy flows, *r* is given by the formula

$$r = \frac{\varphi(1+\varphi)^n}{(1+\varphi)^n - 1}$$

which approaches φ for long-life equipment. The φ is the hurdle rate that the firm uses for incremental investments and includes the firm's marginal cost-of-capital and organizational barriers to optimal investment allocations within the firm. A high value for *r* implies that only energy-efficiency investments with a short payback will be undertaken. The energy-efficient investment decision is then determined by the condition

$$\left.\frac{dK}{dE}\right|_{\bar{S}} = -P_E / r$$

which is the point on the isoquant at which its slope and the factor price ratio are equal, i.e., the tangent point. The resulting choices for the factor intensities are denoted by *. The unit cost of the service is then given by

$$P_S = P_E\left(\frac{E}{S}\right)^* + r\left(\frac{K}{S}\right)^* .$$

Modern computer simulation models (e.g., the AMIGA modeling system) can use a virtually unlimited number of separate isoquants to represent different industrial subsystems, variations in technology by firm or location, and technical progress. The production steps represented by isoquants can also be combined into hierarchies providing more detail internal to an industrial process. Internal shadow prices for each step in the hierarchy are calculated as unit costs. Based on the decision criteria applied, factor ratios can be calculated at each step in the production hierarchy. The most common functional form used for representing the production function and its associated isoquants is the Constant Elasticity of Substitution (CES) production function (Kemfert 1998; Varian 1992).

The CES Production Function

The CES production function is a functional form that can be used to build up much of the subsystems of major industrial processes. It can be transformed in various ways to model an industrial process and technical change. The CES production function for some subsystem *j* is given by

$$S = A((K/\alpha)^{-\rho} + (E/\beta)^{-\rho})^{-1/\rho}$$

where *A* is a shift or productivity parameter, α and β are related to cost shares, and ρ captures the elasticity of substitution between factors *K* and *E*, given by

$$\sigma = \frac{1}{1+\rho} .$$

As a function of the factor price ratio and output *S*, we can write the energy and capital factor demands as follows:

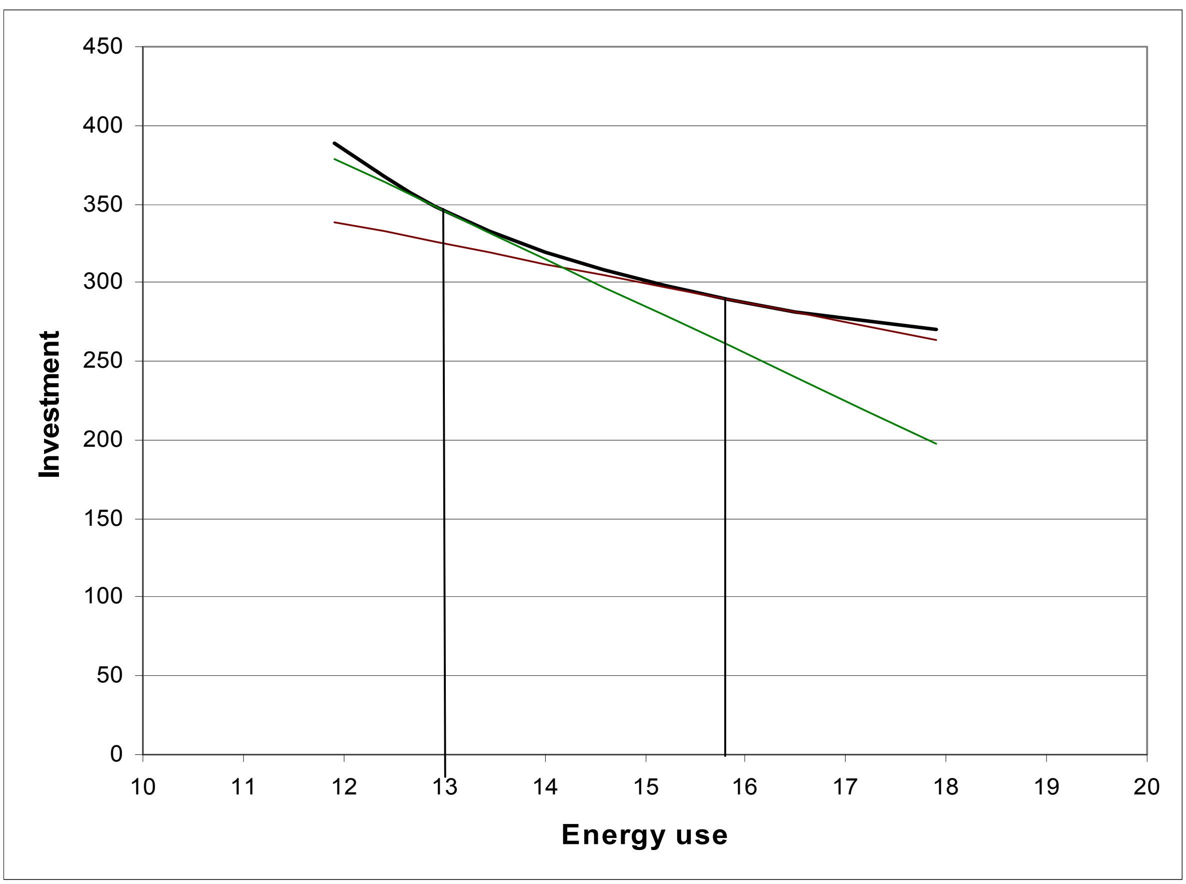
$$D = \alpha^{1-\sigma} + \beta^{1-\sigma}\left(\frac{P_E}{r}\right)^{1-\sigma}$$

$$K^* = \alpha^{1-\sigma} D^{1/\rho} S / A$$

$$E^* = \beta^{1-\sigma} \left(\frac{P_E}{r} \right)^{-\sigma} D^{1/\rho} S / A$$

An isoquant based on the CES production function with an elasticity of substitution equal to 0.7 is shown in Figure 2 for a representative replacement natural gas industrial process. This Figure shows the effects of a combined energy price increase from \$4 to \$6 and a voluntary industrial program in which the firm's management is able to change the decision criterion for energy-efficient investments from a 30% hurdle rate to 15%. The figure also shows the tangent lines with slopes equal to the factor price ratios. The tangent point determines the selected factors. Annual energy use decreases from 15.8 MBtu to 13.1 MBtu. Up-front investment increases from \$290 to \$342. So an incremental investment of \$52 earns a 2.7 MBtu savings per year for the 10-year life of the equipment. Valuing the savings at \$6/MBtu, the annual savings are \$16.2 for a payback period of 3.2 years. Of course, these results can be different for different industries and processes.

Figure 2. Tangent Points on the Isoquant for Two Different Factor Price Ratios



CES shifts in capital. Consider how the CES function can be shifted up or down to represent, say, an industrial refrigeration subsystem. The parameters in the CES function, including σ, can be used to define the slope and curvature of the energy-efficiency technology opportunity set as represented by the isoquant. Then the total capital needed to build the refrigeration system, at a given amount of energy efficiency, would be the height on the K-axis. This will represent total first cost expenditures on the system and are part of the firm's investment outlays. Note that the CES isoquants can be shifted in the vertical direction by a constant to calibrate to total subsystem capital expenditures with the slope of the isoquant remaining unchanged by this vertical shift.

Implications for macroeconomic impacts. Measuring the amount of capital embodied in a given subsystem can have important implications for energy price impacts and energy and climate policy impacts. If factor prices change enough, some older, existing systems can be shut down (i.e., early economic retirement). Then the resulting services that had been produced from the retired facility will have to be replaced with new spending that can crowd out a small increment of GDP growth.

Representing Technological Change

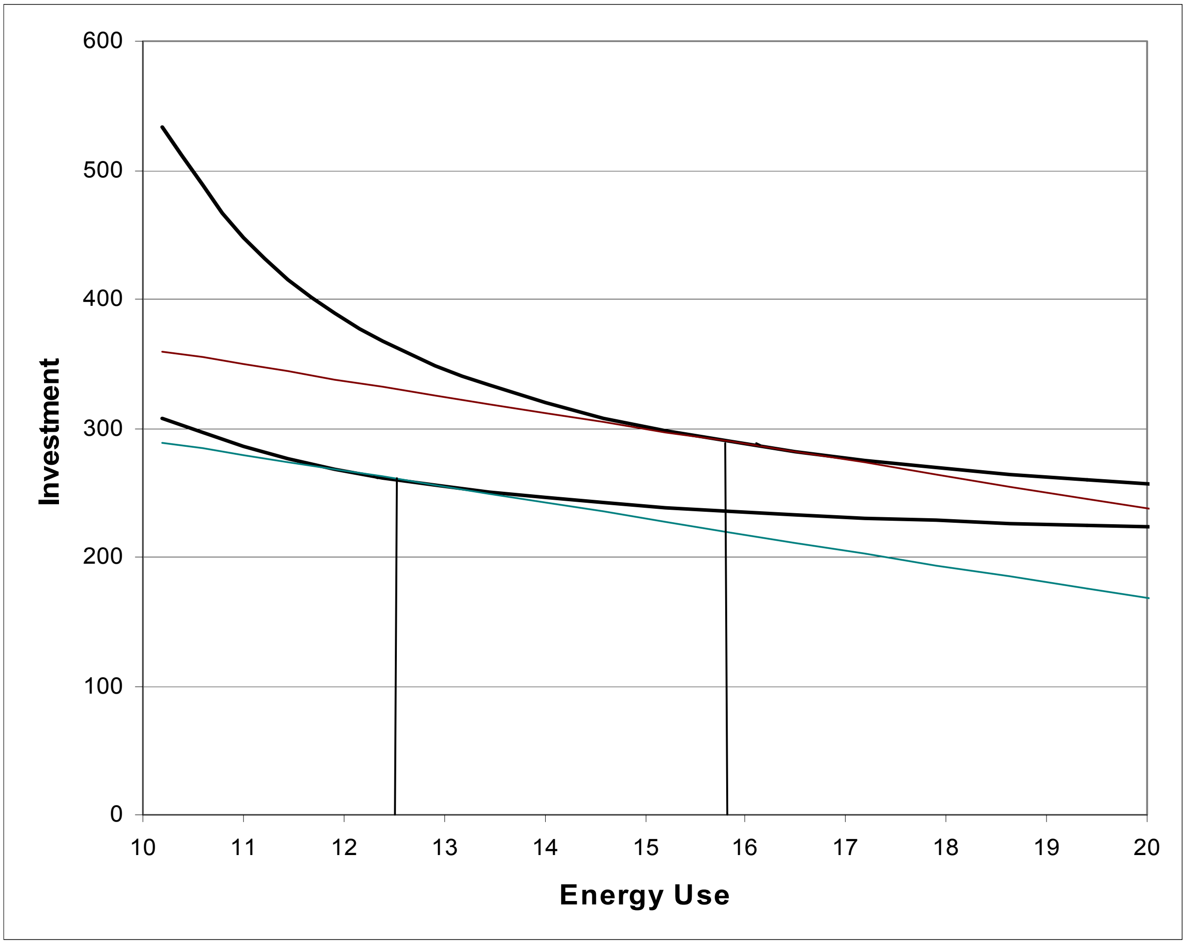
Technical change is driven by a number of factors including

- Learning from experience with energy-efficient investments;
- R&D directed at energy-efficient technologies;
- Introduction of new products that either save energy or lower costs (or both), thereby shifting the isoquant down at the high-cost end.

Energy Star is a program designed to bring more efficient products into the marketplace. As a result of penetration of Energy Star products, the customer will face a new, more-desirable (i.e., shifted down) isoquant when choosing energy-efficient investments. Technical change can be captured in new isoquant slopes through recalibrating the underlying production function using a larger elasticity of substitution.

Figure 3 illustrates the changed isoquant resulting from increasing the elasticity of substitution from 0.7 to 0.75 (with an appropriate recalibration of the alpha and beta parameters.) The upper isoquant in Figure 3 is the same isoquant show in Figure 2. The upper tangent point is also the same, based on a $4 industrial gas price and a 30% hurdle rate. We think of the second lower isoquant as representing a future period. The shift one isoquant to the other is due to some form of technical progress, such as the availability of a new generation of Energy Star rated equipment. The new tangent point, for illustration, continues to be based on the same energy price and hurdle rate. Such a technical change would result in energy use decreasing from 15.8 MBtu to 12.5 MBtu per year. Hence, the new, more elastic isoquant presents more opportunities to save energy at lower cost.

Figure 3. Technical Change In Period 2 Leads to More Energy Saving at Lower Cost



The Total Production System: Planned Labor and Assembly Capital

Figure 1 shows the services from various energy using subsystems integrated into the total production process by combining with labor and another kind of capital that we will refer to as *assembly* capital stock, K_A, because it is used to assemble the subsystem functions into an integrated manufacturing facility. At the overall system level, there is a further opportunity to increase energy-efficiency by substituting labor and assembly capital for the more energy-intensive subsystem steps. Essentially, the overall system can be designed to allow efficient use of energy-intensive subsystem services. For example, perhaps the overall system could be designed with fewer motors, not just efficient motors.

Since the assembly capital is of strategic importance for the firm (at least as a whole it is not an incremental investment), a different decision criterion applies to that capital investment (Ross 1986). A quite high marginal cost-of-capital applied to incremental investment decisions may be replaced with a much lower average cost-of-capital for strategic investments.

System Operation and Labor Training

In the above description, the focus has been on investment decisions. However, once investments are made, management and workers operate the facility to produce valued goods and services. Hence, operational choices are made *ex post* of the investments that configure the facility. (In the economics literature, this is the distinction between long run decisions and short run decisions.) Operational decisions respond to business cycles and other load fluctuations and to outages and maintenance schedules. Empirically there appears to be a high rate of return associated with training workers to more efficiently run industrial subsystems and building HVAC systems achieving desired services at lower energy usage (Delta Institute 2000, Madan 2002).

Market and Organizational Imperfections

Of course, no markets or organizations are perfect and imperfections exist to varying degrees. However, if these imperfections have significant effects in a large share of firms, then there is a case to be made that targeted policies and programs could achieve economic gains from improved allocation of resources. More specifically, if the imperfections have particularly significant effects on energy consumption, and energy has large associated negative externalities such as security, pollution, and climate change, it is worth devoting attention to the question of whether expanded technology policies and programs would be a good idea. In this section we focus on two of the most pervasive of the market imperfections that affect energy demand. An issue not developed here is the underinvestment in technology R&D due to risks in the appropriation of the returns from potential projects.

High Marginal Cost-of-Capital

Not all firms are constrained by high debt-equity ratios. And most firms have relatively low risk of bankruptcy. Many firms have adequate access to capital at competitive market rates so that the marginal cost-of-capital is close to the average for the firm. It is the marginal cost-of-capital that is relevant to undertaking discretionary investments. But still a significant share of firms face very high financing costs, if they were to increase capital spending. Further, this problem is pervasive and dramatic in magnitude in the U.S. energy-intensive industries that face stiff international competition and are hard pressed to raise capital. In some energy-intensive industries, the marginal cost-of-capital probably exceeds a 40% annual rate (U.S.GAO 1998). So these firms probably have remaining opportunities to save significant amounts of energy with investments with high social returns.

Organizational Principal-Agent Problems

It is well known in the business economics literature, including industrial organization and corporate finance literature (Jensen & Meckling 1976; Myers 1977), that managers at all levels throughout a firm have incentives that are only partially in alignment with maximizing value for owners of the firm. Steinmeyer (1998) has written about this wedge from the viewpoint of upside and downside risks faced by capital budgeting finance people, project managers trying to control costs on major capital spending projects, and plant mangers with some discretion about how to spend limited maintenance budgets. The empirical evidence from people who have worked inside firms (or observed them) is that one's taking initiative to save future energy bills gets little reward but exposes the person to organizational risks. So the rate of return on energy efficiency projects must be higher than expected (compared to the situation expressed by theoretical economists that marginal products of capital are equated everywhere). Changes in organizational values, incentives, and functioning can potentially make the owners of the firm, as well as society, better off.

Supply of Energy-Efficiency Improvements

The problem on the demand-side to fully invest in energy-efficient technology creates less demand for these energy-efficient products and hence less incentive for manufactures of energy-intensive products to improve efficiencies through technical advances or even simple known measures. So programs such as Energy Star attempt to reach out to manufactures of energy-intensive products and provide incentives for improvements. This technical advance shifts down the isoquant, as shown in Figure 3.

Policies and Programs

In this section we highlight a few of the major energy efficiency policies and programs. We also offer a simple benefit-cost test to evaluate public sector spending.

Third-party Financing and Energy Service Companies

Third party financing can help overcome high marginal costs-of-capital within a firm as well as help overcome internal organizational barriers. CHP investments are mostly third-party financed. A manufacturing firm could contract with an energy service company that would purchase energy efficient equipment. This would also overcome the firm's high marginal cost-of-capital. The energy service company could also invest in training operating engineers to improve energy efficiency of production.

Energy Star

This joint U.S.EPA and DOE program focuses on persuading manufactures of electric products, and some other energy using products, to install controls and other measures to conserve energy in the use of the equipment. The documented benefits of the Energy Star program have impressive (U.S. Environmental Protection Agency 2002).

Minimum Efficiency Standards for Select Equipment

Minimum efficiency standards can help change the most inefficient decisions. At the same time these standards take the least efficient products "off the self" in distribution outlets and hence allow more self space for more efficient products. This can assist in market transformation.

Labor Training Programs

The City of Chicago and the Local Operating Engineers Union have been offering training courses in the operation of energy-intensive equipment and processes. The payoff from this training has been high. (Delta Institute 2000). Certification of trained workers is recognized. Similarly the U.S.DOE has emphasized the importance of human capital development in operating manufacturing facilities efficiently (Madan 2002).

Industry Voluntary Programs

Working with management on a voluntary basis to set goals, create incentives, and communicate corporate values can be a fruitful approach. Also, industrial assessment programs run by university engineering departments have been helpful, but tend to lack the resources to engage in in-depth recommendations. The focus there has been on simple measures with short paybacks.

Administrative Policy and Program Expenditures in the Clean Energy Futures Study

In Appendix E.1 of the Clean Energy Futures (CEF) Study, Oak Ridge National Laboratory reviewed the historic administrative costs associated with energy efficiency policies and programs. On average they found administrative costs of about $0.60 per MBtu saved of primary energy. (To convert electric energy savings into primary energy savings the CEF report recommends multiplying the $0.60 per MBtu by 2.9.) However, Appendix E.1 notes that historically there has been a great deal of difference in administrative costs among types of programs. For Energy Star, they estimate a cost only $0.10 per MBtu, a number consistent with recent EPA estimates (U.S. Environmental Protection Agency 2002). Equipment standards may require considerably less administrative effort and cost than out-reach programs such as voluntary industrial energy-efficiency programs.

A Benefit-Cost Test

Here we offer a simple benefit-cost test for evaluating public expenditures on energy efficiency programs. The test only includes economic benefits of improving efficiency and excludes important other benefits such as reduced greenhouse gas emissions. The program passes the test if the resulting social surplus is positive. We define social surplus as

$$SocialSurplus = P_E - r^* \, dK \text{ - } AdminCost$$

where *dK* is the investment required to save one unit of energy (i.e., the slope of the isoquant), *r** is the social discount rate, and *AdminCost* is the program expenditure needed to encourage the investment. The program administrative cost is estimated to be in the range of $0.10 to $0.60 per MBtu.

The Modeling Context

A dynamic simulation model, such as the AMIGA model, can extend the analysis of the effects of energy price changes and energy-efficiency policy and program effects. The model represents capital stock turnover, replacement demand and the need for new capacity additions. This capital demand drives investment expenditures on a yearly basis. Estimates of incremental government administrative expenditures by program type can be added to overall government spending. In general equilibrium (using, in this case, the assumption of full employment of all capital, labor, and energy resources), the evolution of sector outputs, consumption, and GDP growth can be computed by the model.

Conclusions

Modeling the impacts of technology policies and programs depends on having models of the industrial sector that recognize key distinctions. It is important to disaggregate key capital stocks, even though all capital is commonly assumed to be homogenous in the economics literature. Market and organizational imperfections and associated decision criteria can impact the penetration of different technologies in different ways. The potential to simultaneously save energy in the industrial sector, increase profitability, and increase output in the economy could be realized from well-designed, targeted technology policies.

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