ENERGY SHADOW VALUE AS A MARGINAL ECONOMIC MEASURE OF ENERGY EFFICIENCY: AN INTUITIVE AND THEORETICAL PERSPECTIVE

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Abstract:

This paper uses a microeconomics perspective to derive an economically meaningful energy efficiency measure. We contribute to the literature by deriving the measure based on neoclassical economic theory. Energy intensity, the most frequently used energy efficiency measure, is a technical average measure drawn from the engineering-science perspective and is not derived from microeconomic foundations, based on marginal production concepts. We address the particular problems associated with this measure and, unlike the literature, introduce the energy shadow value as an economic marginal energy efficiency measure. We describe at least two methods to model the energy index and derive energy shadow value based on a dual profit function: a quasi-fixed approach, treating energy use as quasi-fixed factor; and a directly nested mark-down and up approach, nesting the energy shadow price into the profit function; we discuss which approach is most useful and appropriate to derive an explicit energy shadow value model. We conclude that quasi-fixed approach offers more advantages when deriving a dynamic energy efficiency measure. The paper addresses fallacies of using energy intensity measure and how the shadow value indicator can be applied to address international energy efficiency comparisons and impacting factors particularly capital, technology, and environmental obligations.

Introduction

There are two choices available to society in reducing both greenhouse gas emissions and quantity of energy used: i) get more production output using less energy input,[1] i.e. improve the efficiency of energy use, or ii) invest in renewable or nuclear energy.[2] Renewable and nuclear energy resources are available but restrictions and constraints may limit potential. For example, in the former, the immediate possibilities to substitute towards renewable energy in a meaningful way are physically not available and, in the latter, the initial start up costs are substantial and there are significant political, investment, social and physical risks. Improving the efficiency of energy use appears to offer the greatest potential, at least in the short run, to reduce emissions and consumption of energy. However, to initiate a serious debate on improving energy efficiency requires an economically meaningful definition on exactly what energy efficiency means and, in particular, what does it mean to be inefficient in the use of energy. It is common in the literature to define energy efficiency in production terms as the ratio between some measure of energy output and energy input (Patterson 1996; Phylipsen et al. 1997; Lovins 2004). This definition is based on an engineering-science concept of energy efficiency. It might also be labeled 'energy productivity', since it can be considered a special case of a total factor productivity (TFP) index

[1] For society, this can be achieved by either substituting away from high energy use sectors (e.g. retail services for manufacturing services) or technological changes in the use of energy (i.e. more output with less energy input).
[2] Bio-fuels are also an alternative energy source.

defined for the energy sector (Diewert and Nakamura 2005). This concept of energy efficiency defines energy output per unit of energy input, and thus, using this definition, a higher ratio is a measure of improved energy efficiency. The inverse of this ratio is defined as 'energy intensity' (Patterson 1996); the inverse can be interpreted as the amount of energy required per unit of output. This indicator is commonly applied at a variety of aggregation levels i.e. the firm, the industrial sector or the national level; at the national level, for example, energy intensity is measured as the quantity of energy consumed per unit of real GDP. Both of these engineering definitions of energy efficiency commonly have been used as an economic measure of energy use, but such indexes are not motivated by economic theory (Schipper et al. 1993; Brookes 2000 2004)[3]. These problems and particular issues associated with energy intensity are recognized in the literature (See Schurr 1982 1985; Wilson et al. 1994; Patterson 1996; Gunn 1997; Schipper et al. 1997; Nagata 1997; Bosseboeuf et al. 1997; Freeman et al. 1997; Gunn 1997; Phylipsen et al. 1997; Birol and Okogu 1997; Brookes 1980 2000 2004;; Wing and Eckaus 2004), but nevertheless, a meaningful economic definition of energy efficiency is not well defined. Wing and Eckaus (2004) do use a cost function approach in measuring energy intensity but do not explicitly consider either energy prices or negative environmental effects of energy use and, what is more, they use an average ratio of energy intensity as an indicator of energy efficiency.

In general, an economic measure of energy efficiency must account for the benefits and costs of energy consumption at the margin; this means it must account for economic efficiency indications (Schurr 1982 1985; Schipper et al 1993; Gunn 1997; Brookes 2000 2004). It is privately efficient for a firm to consume energy until the value of the marginal product of the input is equal to its price. If a firm is in equilibrium with respect to the use of the energy input then reducing (or for that matter increasing) energy consumption is economically inefficient, although an engineering-science definition of energy efficiency would suggest the opposite. In a market economy, the consumption of energy may well be privately efficient. However, if the externality associated with energy consumption is not internalized in the decision process it will be socially inefficient. That is, the environmental cost of pollution is not accounted for in the private cost of energy and the value of the marginal product of energy use is too low relative to the total cost of energy (i.e. the price of energy and environmental costs). More than 90% of the primary commercial energy used in the world is obtained from greenhouse gas (GHG) emitting hydrocarbons (BP Statistical Review 2003); such gases have the potential to impose serious environmental costs on society. A variety of taxes and polices have been suggested to force the private sector to internalize the externality[4]. At the aggregate level a natural measure of energy efficiency can be the shadow value of energy use to society. It is common in the literature, to use the concept of shadow value to refer to marginal values measured with reference to a social objective function (See Pittman 1983; Qi et al. 1993; Färe et al. 1993; Bein and Rintoul 1999; Pearce 2003; and Ankarhem 2005). The shadow value of energy use accounts both for the marginal social benefit and cost of energy consumption. Energy efficiency in an economic sense requires that the shadow value of energy to society equals the total price of energy. If the externality of energy use is not internalized then the shadow value of energy use will be less than the total price of energy; society is economically inefficient in energy use. The externality of

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[3] For instance, (Schipper *et al*. 1993), energy efficiency is defined by energy intensity and the author associates improved technical efficiency with improved economic efficiency. Schipper places reductions in energy use on an equal footing with increase in economic efficiency. Also, see IEA/OECD; Schipper *et al*. 1997.

[4] These regulations might take a variety of forms, including short-run policies, e.g. taxation, licenses, quotas and tradable carbon permits; and long-run policies such as endogenous technological change (e.g. Smulders 2005, and Smulders and Werf 2005).

energy use (environmental cost) not included in the price of energy acts as a wedge between the shadow value and total price of energy. This study proposes the energy shadow value as an economic marginal measure of energy efficiency. The shadow value can be measured using data that are typically available at the sectoral or country level. Morrison (1988), Morrison and Schwartz (1996), and van Soest et al. (2002 2006) model energy as a quasi-fixed input in the production structure and measure the shadow value directly on estimation. On the other hand, Morrison and Macdonald (2000 2003), van Soest et al. (2002 2006), Fulginit and Perrin (1993) nest the shadow price of energy directly in the production structure and define the shadow price equal to the market price of energy and the environmental cost.

The purpose of this paper is to introduce and describe in detail a theoretically consistent economic measure of energy efficiency. The study will address four questions: 1) how does the shadow value measure of energy efficiency compare to common engineering-science definitions? 2) What are the procedures necessary to measure and calculate the shadow value of energy use and which one is most appropriate to model energy efficiency? 3) How important is individual industry or country characteristics in explaining shadow value variations? And 4) how can the shadow value of energy be utilized in advising on national energy policies and in international comparisons of energy efficiency across countries?

This paper is organized as follows. Followed by introduction, we will make a succinct comparison between the science-based definition (energy intensity) and our proposed economic measure (energy shadow value) of energy efficiency, following the energy shadow value definition. In the next section, we will explain methodologies of deriving the energy shadow value by switching on descriptive discussion about, afterwards. Next, we will intuitively describe the shadow value measure of energy efficiency, its drivers, and shadow value decomposition. Then an analysis will be given on the appropriate method of the energy shadow value derivation. Finally, we conclude the paper.

2. Energy Efficiency, Shadow Value, and Energy Intensity: An overall view

2.1The intuition of Energy Shadow Value

According to neoclassical economic theory, generally, by assuming a social welfare function, the marginal net benefits of the last unit of an input to society is commonly called the shadow value of that input. It is important to distinguish between the private and social perspectives whenever there is a ‘distortion’ or market-failure such as market power (monopoly or monopsony), or non-market failure such as externalities (negative or positive), and whenever producers face government regulations(e.g., Maneschi 1995; Papps 1993; Marchand and Pestieau 1984; Silberberg 1978 2001; Intriligator 1971; and Baumol 1961); specifically, if producers act to maximize profits and there are no market-failures such a market power in input markets, each input is applied until the marginal net benefits of an additional unit of the input equals its market price, in particular, that input shadow value equals to its market price; since in the real world we encounter at least with one of these market, or non-market distortions, so the shadow value calculations, and their differences from market prices are significant from a welfare economics’ perspective (Drèze and Stern 1990).

Following the case of energy inputs, the energy shadow value is an implicit (and therefore not necessarily visible, hence 'shadow’) marginal net value, for either costs or benefits associated with the optimization objective function; as in the literature (Pittman 1983, Qi et al. 1993, Färe et al. 1993, Bein and Rintoul 1999, Pearce 2003, Ankarhem 2005) it is common to use the concept of the shadow values to refer to marginal net values measured with reference to a social objective function. From this perspective, one key issue is what the objective function exactly looks like, and whether externalities are included in the function as benefits or costs; for example, whether or not environmental effects are treated as additional costs or reductions in benefits, then the true shadow value of energy could be visible or not. Thus, at the socially efficient energy use, the marginal social costs of one more unit of energy use should be equal to its social benefits, and these values should be derived from the industry actual output decisions on production structure; these values are not necessarily equal to an observed market energy prices at the private optimal point. By government's environmental regulations marginal social costs of one more unit of energy use is paid by the industry, and these costs include an undistorted market energy price plus an extra environmental pollution cost price (hereinafter, referred as wedge). At the social optimal point, the observed market's reaction will reflect the impact of existing governmental regulations, such as environmental laws, which may or may not bring energy use closer to the socially efficient level. If there are still any differences between the marginal social costs and social benefits (shadow values), it could be due to any non-market failures such as an inappropriate implementation of environmental policies, transaction costs, and/or some other sort of error components, including measurement or misspecification errors; the externality of energy use causes a wedge between the energy shadow values and its market prices. Hence, if the regulations are efficient they will close the gap; of course, if the regulations are not efficient they will affect behavior, and typically prices, but still leave some sort of gap between market energy prices and the shadow values. Really bad regulations might generate a gap or widen an existing gap.

In summary, the energy shadow value is an implicit net value which an industry is willing to pay for using one more unit of energy input; it is also called a 'true economic' or 'effective' price of that unit of energy. The modeling of the energy shadow value is specified to recognize that energy market price may not be equivalent to its shadow value due to some reasons[5] including negative externality effects of energy used; so that each of these reasons may impose some implicit costs on the environment and society using one more unit of energy inputs. Thus, the implicit costs cause a wedge between the energy shadow value and its observed market price where the wedge can be a zero or non-zero scalar.

2.2 Marginal Shadow Value vs. Energy Intensity Indicator: An Overall Comparison

In this paper, the energy shadow value is proposed as a marginal-economic measure of energy efficiency; essentially, it is a high–definition of commonly used energy productivity ratio that is given by inverting the energy intensity measure. The key point is that the energy shadow value, unlike its counter-part: energy intensity can be used as a socio-economic measure of energy efficiency as it provides a valid basis whether to incorporate all social externality impacts of energy utilization including its pollution effect; however, in the absence of externalities or marked-failures, the energy market price implies its shadow value. To be more concrete, considering a perfect competition conditions, at the private optimal point without environmental policies, the energy shadow value is not expected to be equal to its actual market price; and it is

[5] As some possible reasons that one can include are such imperfect energy market, or other inputs and output markets such as imperfect competition in factor markets and/or measurement associated with quasi-fixities(adjustment costs), deviation form perfect competition, innovation and quality changes, internal or external adjustment costs, un-marketed (or, unmeasured) characteristics such as unmeasured taxation, the possibility of measurement error, other-non market failures, etc(see., e.g., Morrison and MacDonald 2003; Jaffe and Stavins 1994).

called shadow price when it is measured. When government internalizes energy environmental effect, by taxation or a quota, it is pushing an industry to use energy more efficiently, then at the social optimal point, a social marginal cost is paid by the industry: market energy price and a negative environmental cost price; thus at the social optimal point, an observed market energy price equals to its shadow value, because the energy shadow value is made visible and chargeable by internalizing its negative environmental effects. However, it should be mentioned that turning to normative welfare economic costs economy in price of lowering economic efficiency, as concerning about environment is equivalent to hurting economy depending on timing issues and development level of economies. As, for example, Viscusi et al 1994, Jaffe and Stavins 1994, Brooks 2000 2004 concerned about a perfect socio-economic indicator of energy efficiency, the energy shadow value can be a reliable measure of the industry energy efficiency. Also, it is more socially suitable to study a real energy efficiency behavior over time. In contrast, common-used ratio between energy outputs and energy use, energy intensity, reflects a technical-average ratio of energy efficiency, which considers only a lowering a per se average energy use.

In spite of energy intensity, our energy shadow value is a standard-economic energy efficiency measure; because, this approach has been firmly grounded in the neo-classical economic theory; whereas, energy intensity is a simple statistical- average ratio, which has been drawn from an engineering-science perspective to define energy efficiency in economics(e.g., Patterson 1996; Lovins 2004); in addition, potentially, the former can take into account every economic cost and benefit of using energy input by incorporating its market purchase price, environmental cost, etc. Also, there are some problems and particular issues of measuring energy intensity (See Schurr 1982 1985; Nilsson 1993; Freeman et al. 1997; Gunn 1997; Birol&Okogu1997; Phylipsen et al. 1997; Nagata 1997) especially at more aggregated level such as firm, industry, etc, so that the shadow value measure, due to being grounded upon a microeconomic foundation, enables us to deal with those in a proper manner. In brief, this measure can unravel the real level and variation of energy efficiency within an industry or country than energy intensity measure.

Furthermore, this measure can be more worthwhile for policymakers and researchers to have clear information and knowledge about present and future 'efficiency stance' of energy use in a production process than energy intensity. There are some factors affecting in energy intensity which involve efficient adjustments to changing circumstances, so that using energy intensity as energy efficiency measure, this leads to misleading results about the real variation of energy efficiency; for instance, using PPP based measure of GDP than a traditional exchange rate measure, energy intensity might reflect some results which is against the realities about energy efficiency levels (e.g., Nilsson 1993; Birol&Okogu1997; and Nagata 1997), but we will depict in the following sections the energy shadow value can give the results consistent with real level of energy efficiency changes. On the other hand, the shadow price approach is useful to identify the impact of socio-economic affecting factors such as output and input prices, exogenous and/or endogenous technological changes, environmental and other governmental policies on energy efficiency changes.

Moreover, energy intensity is misleading in energy efficiency comparison among different nations or even at the country level; it is mostly due to some present differences among them in terms of economic development, energy and resource abundance, technology, initial socio-economic circumstances, etc (e.g., Schipper et al. 1993; Schipper et al, IEA-1997, p.4 & p.73;

Birol&Okogu 1997; Phylipsen et al. 1997; Nagata 1997; Lovins 2004, p.836)[6]. On the contrary, the energy shadow value, due to grounding on a microeconomics foundation, internationally can conclude a consistent result by accounting socio-economic and/or policy differences cross-countries, or industries; as it can give us information about the optimal level of energy use based on initial circumstances of each nation, so creating a possibility to compare nations` efficiency gap (see section 6.1 for details). In a better sense, the shadow value indicator does reflect the real adjustments based on a microeconomic framework unlike energy intensity measure.

Finally, when we intend to investigate a real world phenomenon at economics, it is performed by a positive and normative approach. The positive approach gives a reasonable thought of how that phenomenon does work in the real world upon an economic model; and the normative approach debates how it ought to be. Following this, the energy intensity might be interesting as a 'positive' measure, analogous to labor productivity; nonetheless it is not given by microeconomic foundation, and thus can not play a normative role; because it has no normative content or theoretical justification. Hence, despite of the shadow value approach, it misses these points especially normative debate on energy efficiency measuring. (See Appendix for an extensive comparison between the energy shadow value and intensity measures)

3. The Methodology of Deriving Energy Shadow Value: A Theoretical Perspective

3.1. The Key Assumptions

- *A Partial Equilibrium model in the Production Sector of an Economy*

The methodology of deriving energy shadow value is discussed for the production sector of an economy, as it is implemented for intermediate sectors such as agriculture, industry, services, etc. In doing so, we take into account the energy used by these sectors and indirectly consumed by households through consumption of goods and services, but this does not account for the direct energy consumption of households for heating, cooling, cooking, and operating appliances that is commonly known as 'residential energy use'. Hence, for simplicity and limiting the paper scope, we follow up a partial equilibrium model, by optimizing production sector activities. However, it does not consider a computable general equilibrium (CGE) model; this means we do not account for an economy's consumption sector by ignoring direct energy used in a residential sector, and also not accounting for the interactions among outputs, inputs, consumption sector, and other macroeconomic indicators. However, this study is applicable over the residential sector.

- *Aggregation[7] Assumptions on the production Sector*

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[6] For example, the energy intensity of US has been greater than UK through 1950-1997 (See Schipper et al. IEA/1997, and Hennesson 2002), this means the energy efficiency of US has been lower than UK, but it is not necessarily true and can be misleading. Because, it is possible use of energy to be efficient in different level of energy use in both countries based on the energy shadow value, but the differences of energy intensity might be due to differences of economic activities, energy prices, energy resource abundance, fuel mix, activities, structural changes within each sector, etc, and not only because of efficiency differences so that energy intensity misses them.

[7] For details, see e.g., Jorgenson, Gollop, and Fraumeni 1987 and Jorgenson 1990. Based on these papers, the required assumptions to have an aggregate production function have been imposed on constructing each US. Industrial sector's aggregate output and inputs dataset.

Modeling producer behavior based on an aggregate production function originally introduced by Cobb and Douglas 1928 and developed by Tinbergen1942. Until very recently, the study of producer behavior or economic growth at the aggregated level has been based on the notion of an aggregate production function[8]. This concept is one of those masterful simplifications that makes it possible to summarize a detailed information within a single overarching framework, so that the model of production based on an aggregate production function provides a valuable and useful summary of the data; at the same time the concept of an aggregate production function is highly problematic, requiring very stringent assumptions on production patterns at the level of sub-industrial sectors of the economy. Intuitively speaking, the technology of each sub-industry must contain a replica of the industry's aggregate production function. It will be useful to spell out the assumptions underlying the aggregate production function and their implications in more detailed below.

In technical Jargon, some restrictive assumptions are necessary for the existence of an industry aggregate production function include of the first, each individual at sub-industry level must have a gross production function which is separable in output values, where the output value is a function of production factors and the level of technology; on other words, the industry aggregate production must be separable in each input, as each input is aggregates of the many components; this assumption guarantees that a measure of each sub-industry output values is quantifiable, so that the quantity of industry aggregate output values can be defined as a function of sub-industry level outputs, reallocations of outputs and inputs incorporate differences in output functions and each aggregate input among the sub-industry's individuals as well as departures from the separability assumptions required for the existence of an output function, and each aggregate input function for each sub-industry's individual. Second, the sub-industrial sector production functions must be homogenous[9] (identical) for all individuals at the sub-industry levels and to the corresponding aggregate industry function, while the functions relating each input to their components must also be homogenous (identical) for all sub-industry's individuals and to the corresponding functions at the industry aggregate level; if all inputs are each homogeneous in their components, this implies that the existence of aggregate production function strongly depends on the existence of constant return to scale at the micro level(Felipe and Fisher 2003, P.251), then the industry aggregate production function is homothetically separable[10]. Third, each component of these input aggregates must receive the same price in all sub-industries; this is a market equilibrium condition when there is mobility of factors across

[8] An alternative strategy for modeling producer behavior is to disaggregate to the level of individual industries or sub-industries and replace the aggregate production model by a general equilibrium model of production (e.g., Berndt and Jorgenson 1973; Jorgenson and Fraumeni 1981; and Jorgenson 1984b). This strategy is far to implement on this thesis due to lack of disaggregate dataset. An important issue in the modeling of producer behavior at the sectoral level is the existence of aggregate inputs such as the capital, labor, energy, and materials inputs. The production function is required to be homothetically separable in the components of each of these aggregates, as this approach for modeling a producer behavior was originated by Berndt and Jorgenson 1973. The methodology for testing homothetic separability was originated by Jorgenson and Lau 1975; this methodology has been discussed by Blackorby, Primont, and Russell 1977 and Denny and Fuss 1977. An alternative approach has been developed by Woodland 1978; for more details on aggregate inputs existence see, e.g., Norsworthy and Harper 1981; Berndt and Christensen 1974 1973; Berndt and Wood 1975.

[9] Homogeneity implies that proportional changes in all inputs result in proportional changes in output, so that the production function is characterized by constant return to scale.

[10] The concept of separability was introduced by Leontief 1947a &b and Sono1961; the concept of homothetic separability was originated by Shephard 1953 1970; Lau 1973 1974 has demonstrated that if the production function is homogenous, then separability implies homothetic separability.

individuals of sub-industry, and equilibrium exists only when all factors of the same type are paid the same price in all individuals of sub-industry level. The second and third assumptions imply that the identical cost dual functions (or, the price of output value functions) exist across all individual sub-industry level and at the aggregate industry level so. If the assumptions are valid, then aggregate industry output is a simple sum of the sub-industry outputs, so that an industry aggregate production function with aggregate capital, labor, energy and non-energy materials, and aggregate technology as arguments exists and will generate this aggregate real output values; under these assumptions, the industry aggregate production function yields a valid representation of the underlying sub-industry level production structure. These assumptions required theoretically for the existence of aggregate industry production function needs to be valid empirically as well and thus are obviously highly restrictive and problematic [11](see Jorgenson 1990, and Felipe and Fisher 2003). However, Jorgenson 1990, for example, concluded that aggregate production function approach is more appropriate for analysis over long period of time than a shorter period, because at the aggregation production function approach, by presuming the restrictive assumptions on output value and inputs at the sub-industry levels, we drop the possibility of reallocation of outputs and inputs among the sub-industry's individuals and this possibility seems to be reasonable over a long time period than shorter periods [12].

- *Quasi-Fixity of Capital Input(s)*

Throughout our discussion, we implicitly presume that capital input(s) is quasi-fixed, so we will deal with a short-run model unless the fixity of capital input to be relaxed or does not maintain based on a statistical test[13]. Also, we presume that the capital input is irrelevant to the energy input variation in short-run; this means that capital is not a function of energy input.

- *The Presence of General Economic Efficiency and CRTS Condition*

It is presumed that an economy `s production sector involves two main characteristics of economic efficiency: pricing (or, allocative), and productive (or, technical) efficiency. The

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[11] However, applying the aggregate production function at the industrial sector level underlying the restrictive assumptions does not seem to be more unrealistic and controversial debate unlike using this approach on the economy level. In addition, from empirical perspective, one can, also, say using duality theory would have more appropriate theoretical resolution to the aggregation problem than directly estimating underlying technology (Gorman1968, and Felipe and Fisher 2003. p.250). Moreover, there are three standard answers ,given by economists, to why they continue using the aggregate production functions: first, based on the methodological position known as instrumentalism, is that the usefulness of this approach is strictly an empirical issue(Ferguson 1971), second, following Samuelson 1961-62, aggregate production functions are seen as useful parables, and finally, for the applications where aggregate production functions are used, there is no other choice yet(e.g., Solow 1988). See Felipe and Fisher 2003 for more details.

[12] See, Jorgenson 1990 and Jorgenson et al 2005, pp. 385-387.

[13] An appropriate statistical test can be implemented based on what proposed by Kulatilaka (1985) whose approach is to test for equality of the capital shadow and market values at each observation in the sample and jointly as well. However, in more extensive version of such test, we can test an alternative hypothesis of a dynamic equilibrium model against null hypothesis of using a static equilibrium model upon Schankeman and Nadiri 1986 and/or Hausman 1978` specification test.

allocative efficiency means that prices equal the marginal costs of producing those goods, inputs, and/or services, throughout the entire economy; productive efficiency gives us the minimization of the cost of operations; and dynamic efficiency gets the optimization of investment decisions, which we do not consider here due to being capital as quasi-fixed (Gunn 1997, pp.242-243). Presumably, we do not have a dynamic efficiency condition due to the assumption which capital input is *quasi-fixed*. To achieve optimization conditions, first order conditions and second order conditions must be satisfied. Second order conditions refer to the curvature conditions imposed by economic theory; if these conditions are not satisfied, at some observations, then it must be imposed. Thus, by maintaining general economic efficiency, we will have a prefect competition model for the production structure of each industry. Alternatively, there would be constant returns to scale (CRTS) assumption in the production structure of each industry(recall that the aggregation conditions strongly depend on the existence of constant return to scale at the micro level, and that with non-constant returns aggregate do not exist in general).

- *No Externality effect and Government Intervention*

We assume that there is no other market-failure in goods, services, and inputs markets; so in a basic model, there is no government intervention in the markets. Yet, basically, energy used by an industry has some negative environmental impact, not necessarily polluting effect, on other industries and society[14], but we do not consider them at this point and assume there are not any sign of governmental regulation in the energy and the other markets. However, there may implicitly be some self-regulating policies implemented by private owners` of individual industries, or some non-market failure explanations[15] for inefficient use of energy input.

Changing the Type of Economic Model

As pointed out by the neoclassical economic theory, economic models of thesis can be given under a static or a dynamic equilibrium framework regardless of whether or not the capital stock is quasi-fixed; this is given whether time matters in the model (or, whether there is no explicit time dimension in the adjustment process). Concurrently, the thesis` model can be flexible in terms of the number of production inputs and whether externality impact of energy used is taken into account; when the externality impact is accounted for, so it is necessary to impose some regulation by the government, and not otherwise. Meanwhile, we encounter with two main economic models, whether there are externality effects, and thus the regulations or not. So essentially, within each case, our economic model is changeable based on a static or dynamic equilibrium context, and a number of production inputs included in the production structure. In the following, the economic model(s) of the energy shadow value are presented in a general framework in terms of production factors included in the model; and we do not consider externality effect of energy use and thus government intervention. This discussion can be applied on a static or dynamic equilibrium framework.

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[14]Other than polluting effects of energy used, when one more unit of energy is used by an industry, it causes economic losses for other industries due to diminishing their chance to get access to one more unit of energy input.

[15] For more details see, e.g., Jaffe and Stavins 1994, P. 805 and Stern 1986.

3.2. Economic Model(s) of Energy Shadow Value (Price)[16], without of Considering Externalities(s) and Regulation(s)[17]

3.2.1 Introduction to the Energy Shadow value Derivation: A Generic Model

Presumably, we would like to determine the energy shadow value of an industry, with and without considering externalities impacts of energy used, which is referred to the energy efficiency measure of that industry[18]; for now, we do not take into account these external impacts and thus the government intervention. The main target is to derive the energy shadow value, and examine the changing effect of technological and non-technological factor(s) on the industry energy shadow value.

The objective function of the industry is maximizing a variable restricted profit function, which is given by the dual theory upon the neo-classical economic theory[19]. The industry

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[16] The shadow value is a non- tangible term and referred to what an economic agent think of valuing one more unit of an input (output) in mind; the shadow price can be referred to the same value if the shadow value to become visible and measurable by a modeling process. On determining the optimal inputs vector, firms compare the benefits of using an additional unit of each input to its cost, the purchase price. Depending on whether a production function approach or a cost or profit function approach is taken, these marginal net benefits-the true implicit economic value for the firm-also referred as the shadow price of the input, which can be measured in terms of the input's marginal benefits or value product, or as reductions in expenditure on the other inputs that can be achieved using one additional unit of the input under given conditions. So, at this point, whenever I refer to the shadow value term, it refers to the shadow price as well and vice versa, hereinafter.

[17] On this section, we show a generic method(s) of the energy shadow value (price) regardless of incorporating negative externality effects of energy use, and thus governmental regulations. However, it should be mentioned that the shadow value notion is bind to existence of negative externality effects of using energy inputs.

[18] The idea of shadow value derivation can be applied in any level of aggregation such as production in plant, firm, Industry, economic sector, and national level. On this study, we discuss the shadow value derivation for an industry; but all discussions here are applicable in any level of aggregation.

[19] Using the dual theory approach is preferred to direct derivation of energy shadow value form underlying technology in the production process. Firstly, since we implement our energy efficiency measure in the aggregate level of each economy such as industry, economic sector, or national level; hence, empirical implementation of aggregate production function is problematic. In the literature, this is referred to as the aggregation problem; without proper aggregation, we cannot interpret the properties of an aggregate production function (e.g. Felipe and Fisher 2003); as said earlier, using dual theory, we may have more appropriate theoretical resolution to the aggregation problem than directly estimating underlying technology. Secondly, according to traditional neoclassical theory, production function describes more technical relationship between inputs and output than economic one while cost or profit functions more rely on the economic relationship underlying prices of inputs and output. Thirdly, households and firms typically take prices as given; it is much easier to understand their behaviors in terms of expenditure, cost or profit functions than the primal production function. Meanwhile access to aggregate quantity of inputs is more cumbersome than prices (Gorman 1968). Moreover, we do not want to impose a specific production structure on data, where the amounts of variable inputs used are exogenous variables in the production function approach. They are the dependent variables in the input demand functions that can be derived from the variable cost or profit functions. Input demand functions are in terms of prices, time-horizon, technology, and quasi-fixed inputs (e.g., Berndt 1991). Thus, the dual function opens the way to direct estimation of substitution elasticity; this process is, however, less complex than with production function.

By comparison, for our main purposes as dynamical measuring and evaluation of energy efficiency, applying a dual-profit function will give us the required additional information such as the system of demand equations for variable inputs and supply function along with the shadow value identities, which produces in a perfect competitive market and buys all required inputs form these competitive markets. Hence, CRTS assumption and other already mentioned key assumptions must be met in the production structure, but disregarding governmental- environmental regulations does not necessarily mean that there are no efficiency policies by individual industries; it might exist. The variable restricted profit function of the industry is given by

$$\pi^{VR} = \pi^{VR}(P_O, P_I, \overline{K}, t) \tag{1}$$

where $\pi^{VR}(.)$ is the variable restricted(short-run) profit function of the industry due to quasi-fixity of capital input and superscript VR denoting the variable restricted function; P_O is output prices index as a variable argument and O denotes the industry `s output; P_I is the vector of variable inputs price index and I stands for the variable inputs; $\overline{K}$ is a quasi-fixed capital inputs index of the industry; and t is a proxy of technology changes.

The industry maximizes its profit function given variable inputs and output prices, the quasi-fixed capital input, and underlying technology in the production structure; in doing so, the first order condition, the first derivatives of profit function with respect to output and the inputs price indexes given by Hotelling`s lemma, must be equal to zero, which indicates the inputs optimal uses to produce a possible maximum level of output. Also, second order conditions must be maintained, which indicates implicitly the curvature conditions as a part of the regularity conditions, and other regularity conditions: monotonicity and homogeneity must be satisfied[20]. Subsequently, estimating the system of optimal inputs demands and output supply functions enable us to obtain indirectly the coefficients of the industry profit function. Thus, this gives us the variable restricted optimal profit function for the industry, as indicated by

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have more benefits for our empirical targets. Also, the profit function approach includes all of empirical implications of using a dual-cost function, where the cost function is a part of the profit function approach. Moreover, cost function studies are special cases of profit functions ones where firms produce underlying perfect competition and maintain the level of aggregate output in economy. Furthermore, we believe that the profit approach sounds more theoretical and empirical than the cost approach in the dynamic socio-economic measurement of energy efficiency. Conversely, we will get additional applied information from the profit function approach (e.g., Diewert, 1973-74 1993 and Silberberg 2001). In the economic literature of shadow value concept, most of applied studies used the cost function estimation (e.g., Berndt, et al. 1981; Morrison 1988; Morrison and Schwartz 1996; Morrison and MacDonald 2003). They defined the shadow value of an input as the potential reduction in expenditures on the other variable inputs, which can be achieved using an additional unit of the input under consideration while maintaining the level of output. Some of the available literature used the profit function approach to derive the input shadow price (For example, see Gorman 1968; McFadden 1966 1970; Diewert 1973-74; Lau 1976; Diewert &Nakamura 1993; Kohli 1993).

[20]The curvature conditions, in empirical analysis, means an objective function such as profit function must be ‘convex’ in output and variable input prices and ‘concave’ in quasi-fixed inputs at all observation in the sample: ‘Hessian matrix’, the matrix of second-order derivatives of profit function with respect to output and variable inputs price indexes, and quasi-fixed capital inputs must be positive and negative semi-definite, respectively, also the profit function must be a linearly homogenous and monotone function in all of its arguments; however, if these conditions are not maintained at all observations of the sample, and then must be imposed and verified.; all these conditions referred to regularity condition imposed by economic theory (Diewert 1993, 1974, Diewert and Wales 1987, and Lau 1971).

$$\pi^{VR^*} = \pi^{VR^*}(P_O, P_I, \overline{K}, t) \quad (2)$$

where '*' sign stands for the optimal estimated function.

To obtain energy shadow value of the industry, we have at least two methods given in the literature[21], which depends on the key assumptions and production technology structure of the industry: (a) *quasi-fixed* (or, *semi-fixed*) approach and (b) *agnostic direct-nested* shadow price approach.

Upon the *quasi-fixed* approach, the energy inputs index is supposed to be as a quasi-fixed input[22], so instantaneous energy input adjustment is deemed to be unrealistic; given all the key assumptions and not accounting for externalities impacts of energy used, the rigidity of energy inputs index due to fixity of capital input may be one of the reasons for a wedge between the energy shadow value and its observed market price. One way to deal with the wedge, however, is including $\widetilde{E}$ in stead of energy price index in the optimal profit function. Then the variable restricted profit function given by (1) and the corresponding optimal function given by (2) are changed, respectively as

$$\pi^{VR} = \pi^{VR}(P_O, P_I', \widetilde{E}, \overline{K}, t) \quad (3)$$

$$\pi^{VR^*} = \pi^{VR^*}(P_O, P_I', \widetilde{E}, \overline{K}, t) \quad (4);$$

where P_I' is the vector of other variable inputs price indexes; and $\widetilde{E}$ is the quasi-fixed energy inputs index due to quasi-fixity of capital inputs index. Subsequently, based on Hotelling`s lemma, the energy shadow value is derived by differentiating the optimal variable restricted profit function indicated by (4) with respect to quasi-fixed energy inputs index as

$$SV_{\widetilde{E}}(P_o, P_I', \widetilde{E}, \overline{K}, t) = -\frac{\partial \pi^{VR^*}(P_O, P_I', \widetilde{E}, \overline{K}, t)}{\partial \widetilde{E}} \quad (5);$$

where $SV_{\widetilde{E}}$ is the energy shadow value and this acronym is applied on the rest of paper, hereinafter[23].

[21] For example, see Morrison 1988, Morrison and Schwartz 1996, and van Soest et al. 2002 2006 for *quasi-fixed* approach and Fulginiti & Perrin 1993 and Morrison & MacDonald 2003 for *direct-nested* shadow price method. These are based on the cost function approaches to measure shadow values, but we are developing the profit function approaches using these alternative methods.
[22] The quasi-fixity of energy inputs index may be due to quasi-fixity of capital inputs index, or with the primitive that environmental regulation could impose a constraint on the industry's use of energy; this could be either because it artificially reduces industry-level profitability (in case of, e.g., environmental taxes), or because it directly imposes a cap on the amount of energy used (e.g., quotas). At this point, the quasi-fixity of capital inputs index is the only reason of being energy inputs index as quasi-fixed.
[23]With taking into account expenditures on the quasi-fixed inputs: capital and energy inputs, we accordingly shall have a total restricted profit function than a variable restricted profit function, denoting

Another method, however, derives the energy shadow value by the *agnostic direct-nested* method i.e., by treating energy as a variable input in the profit function. Although the capital is a quasi-fixed input, there is possibility, to some extent, to treat energy input as a variable input. Hence, as alternative way of incorporating the wedge in the profit function, the shadow price of energy input($SP_E = P_E + \lambda$) may be directly incorporated into the profit function (1) where SP_E is the shadow price of energy and λ is the wedge representing a gap between market energy price and its shadow price, with the wedge potentially attributable to capital rigidities(adjustment costs)[24]. In this case, the optimal energy demand equation is added to the system of variable inputs demand and output supply functions and used in the estimation of the profit function's coefficients. So the variable restricted profit function and its corresponding optimal function of the industry can be given, respectively, by

$$\pi^{VR} = \pi^{VR}(P_O, P_I', SP_E, \overline{K}, t) \qquad (6)$$

$$\pi^{VR^*} = \pi^{VR^*}(P_O, P_I', SP_E, \overline{K}, t) \qquad (7);$$

where SP_E is the nested energy shadow price of the industry and it is denoted by the energy market price (P_E) plus the wedge(λ); the wedge can be a zero, positive or negative scalar.

The energy shadow price is calculable by estimating the optimal energy demand function and the wedge by the data, which are obtained along with estimating the system of equations. Then, the energy shadow value equation can be derived by inversing the function of the optimal energy demand function. To demonstrate, the estimated optimal energy demand function is as: $E^* = -\frac{\partial \pi^{VR^*}(P_O, P_I', SP_E, \overline{K}, t)}{\partial SP_E} = f(P_O, P_I', SP_E, \overline{K}, t)$; this along with the estimated wedge and the observed energy prices can give the energy shadow price equation as[25]

$$SP_{\tilde{E}} = P_E + \lambda = -f^{-1}(P_O, P_I', \hat{E}, \overline{K}, t) \qquad (8)$$

where $\hat{E}$ is the estimated energy demand and the superscript '-1' stands for the inverse sign. Upon this approach[26], at the best practice λ is zero, and thus the energy shadow price index can

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by π^R . Then, the energy shadow value is derived by the following relationship: $\frac{\partial \pi^{R^*}(.)}{\partial \tilde{E}} = -\frac{\partial \pi^{VR^*}(.)}{\partial \tilde{E}} - P_E = SV_E - P_E$; Then, $SV_E = P_E + \lambda_E$, the market energy price indicates its shadow value when λ_E is a zero scalar; otherwise the wedge and energy price give the shadow value.

[24] At this point, due to maintaining the key assumptions including not accounting for the externalities effects of energy used, the capital fixity is the only potential reason can be causing the wedge. However, by considering the externality effects and thus environmental regulation including energy taxes or quotas, the wedge is determined by incorporating these regulations along with the capital rigidities effect.
[25] See, for example, Berndt, Morrison, and Watkins 1981, P.270.
[26] Empirically and technically, this approach seems to be more complicated than the *quasi-fixed* method. Because, the estimation of the wedge by the data and extracting an explicit mathematical equation for the

be derived equivalent to its market price index.

Based on the *quasi-fixed* and *agnostic direct-nested* methods, the following section, for deriving the energy shadow value expression, argues a set of the possible economic models, underlying given assumptions. Presumably, the analysis proceeds based on a general framework regardless of number of inputs and outputs involved in the production structure of an industry, and we do not consider the externalities impacts of energy used by the industry.

3.2.2. The Economic Models on the Generic Framework

Scenario #1*: A Short-run (Restricted) Model*

Let's assume the same generic framework on section 3.2.1 so that all of the key assumptions including the quasi-fixity of capital input and ignorance of energy use's externality impacts are maintained. We intend to compute the industry's energy shadow value expression, by applying the *quasi fixed* and *direct-nested* methods depending on specific assumptions of the model. Moreover, it is assumed that no environmental regulation is implemented by the government; however, it might be imposed some self-regulation by the individual industry.

Assumption (1)*: Quasi-fixed Capital and Energy Inputs*

In this context, by duality theory, a variable restricted profit function for an industry is given by equation (3) and the energy inputs index is taken as quasi-fixed due to quasi-fixity of capital input; following the profit maximization by the industry, Hotelling`s lemma gives the first order conditions (F.O.C) as

$$S_O^* = \frac{d\pi^{VR}(P_O, P_I', \tilde{E}, \overline{K}, t)}{dP_O} = S_O^*(P_O, P_I', \tilde{E}, \overline{K}, t)$$
$$D_I^* = \frac{d\pi^{VR}(P_O, P_I', \tilde{E}, \overline{K}, t)}{dP_I'} = D_I^*(P_O, P_I', \tilde{E}, \overline{K}, t) \qquad (9);$$

where $S_O^*(.)$ and $D_I^*(.)$ stand for the short-run optimal output supply and a vector of other variable inputs demand functions, respectively. Curvature condition(s) which are imposed by the economic theory must be satisfied; otherwise it should be imposed on the industry's production technology; this means that the following Hessian matrixes A and B must be positive semi-definite and negative semi-definite, respectively given by S.O.C as

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energy shadow price is analytically more cumbersome. However, note that (8) is identical to (5) if the energy inputs index is assumed to be quasi-fixed; in a theoretical sense, one would expect both approaches to yield similar results. "Yet, from an empirical point of view, the *nested-direct* approach is slightly preferred as additional energy input demand function can be estimated; thus adding an additional structure to the model and hence facilitating estimation", as pointed by (van Soest et al 2006, p.1157; Morrison and MacDonald 2003), but adding the additional function to the model hurts to the degrees of freedoms.

$$A = \begin{bmatrix} \frac{\partial^2 \pi^{VR}(.)}{\partial P_O^2} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_O \partial P_I'} \\ \frac{\partial^2 \pi^{VR}(.)}{\partial P_I' \partial P_O} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_I'^2} \end{bmatrix} ; \text{And } B = \begin{bmatrix} \frac{\partial^2 \pi^{VR}(.)}{\partial \tilde{E}^2} & \frac{\partial^2 \pi^{VR}(.)}{\partial \tilde{E} \partial \bar{K}} \\ \frac{\partial^2 \pi^{VR}(.)}{\partial \bar{K} \partial \tilde{E}} & \frac{\partial^2 \pi^{VR}(.)}{\partial \bar{K}^2} \end{bmatrix} \quad (10);$$

Also, other regularity conditions: monotonicity and homogeneity are presumed to be satisfied.

Through estimating the equations system (9) given quasi-fixed-capital input and energy inputs index magnitudes, and production technology (t), an optimal variable restricted profit function of the industry is given by equation (4); alternatively, the equation (3) can be estimated directly without estimating the system (9). Since energy input is taken as the quasi-fixed input, so the SR[27] energy shadow value expression can be derived based on the *quasi-fixed approach*. Hence, the first derivative of the optimal profit function (4) with respect to the *quasi-fixed* energy inputs index, by Hotelling`s lemma, gives the SR energy shadow value function by expression (5), denoting by $SV_{\tilde{E}}^{SR}(.)$; similarly, the SR capital input shadow value expression can be given by

$$SV_{\bar{K}}^{SR} = -\frac{\partial \pi^{VR^*}(P_O, P_I', \tilde{E}, \bar{K}, t)}{\partial \bar{K}} \quad (11).$$

At the full equilibrium: when the capital input is adjustable to the optimal level, so do other inputs, if the energy shadows value, SV_E and its market price are equal, then, the actual energy use and its optimal levels are the same as well (i.e., $E = E^*$). Otherwise, a gap does exist between actual energy use (E) and its optimal level (E^*), which is representing the extent of measurement of the sub-equilibrium in terms of inputs levels. Hence, by maintaining the full equilibrium at each time-point or the sample mean and given the key assumptions, a producer industry can choose an optimal level of capital stock; it means the capital input is as a variable input and thus the energy input becomes a variable input, where the shadow values of capital and energy inputs would be equal to their respective market prices at each time-point or the sample mean. As a result, the allowing to capital inputs changes put us through a long-run (LR) model context[28]

Considering the SR energy SV equation (5), it has some advantages unlike the energy intensity indicator; it enables us to evaluate a short-run effect of output price, other variable inputs price, quasi-fixed energy and capital inputs indexes, and technology changes on the industry's energy SV measure. The influences of the affecting factors` movements are represented by short-run elasticity of an industry's energy SV with respect to each of the affecting factors. However, if there is the equality between the capital input SV and its market price at the full equilibrium, then the equality of actual and optimal levels of the capital input ($K = K^*$) is incorporated in the energy SV equation (5); so that using the equation (5), also, enables us to compute the LR elasticity of the industry's energy SV with respect to each given argument. The SR and LR elasticities have been outlined in section 4.2.

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[27] SR is used as acronym for the short-run, hereinafter.
[28] See Morrison 1988, 279-80. , this has been given by the assumptions (3), or (4) on the following sections. Also, LR is used as acronym for the long-run, hereinafter.

__Assumption (2)__: Quasi-fixed Capital and Variable Energy Inputs

An alternative method of derivation of the energy shadow value expression is the direct way of nesting energy shadow price in the profit function model; this method theoretically can give the same results given by the *quasi-fixed* approach. When the capital input is supposed to be quasi-fixed and we have a restricted model, there is a possibility of presuming variability of energy input to some extent. So by this assumption, energy shadow price or its price index can be nested in the profit function than a quasi-fixed energy input.

With possibility of the wedge between energy shadow price and its market price due to capital input rigidities(adjustment costs), energy shadow price is nested in the profit function, as $SP_E = P_E + \lambda$; where SP_E is energy shadow price; P_E is the market energy price; and λ is the wedge. Given maintaining all key assumptions in the restricted model including not incorporating the governmental regulations, the wedge(λ) might be a non-zero number due to the possibility of transaction costs caused by the industry` self-regulations, and/or being the capital input as quasi-fixed, or other non-market failures. By having energy variability assumption, in general the conjecture of an industry's profit function is given by equation (6).

Similarly, the industry optimizes its own profit function given the variable inputs price and outputs price indexes, available production technology, and the key assumptions; then, the first order conditions which are representing a short-run system of optimal energy and the vector of other variable inputs demands and output supply functions are given by

$$
\begin{aligned}
E^* &= -\frac{\partial \pi^{VR}(P_O, P_I', SP_E, \overline{K}, t)}{\partial SP_E} = E^*(P_O, P_I', SP_E, \overline{K}, t) \\
D_I^* &= -\frac{\partial \pi^{VR}(P_O, P_I', SP_E, \overline{K}, t)}{\partial P_I'} = E^*(P_O, P_I', SP_E, \overline{K}, t) \\
S_O^* &= \frac{\partial \pi^{VR}(P_O, P_I', SP_E, \overline{K}, t)}{\partial P_O} = S_O^*(P_O, P_I', SP_E, \overline{K}, t) \qquad (12)
\end{aligned}
$$

It is implicitly assumed that the model satisfies the regularity conditions for the given production technology; otherwise it must be imposed in the production structure; on this case, to demonstrate curvature conditions, the Hessian matrix A and B , given by (10), are replaced

by
$$
A = \begin{bmatrix}
\frac{\partial^2 \pi^{VR}(.)}{\partial P_O^2} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_O \partial P_I'} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_O \partial SP_E} \\
\frac{\partial^2 \pi^{VR}(.)}{\partial P_I' \partial P_O} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_I'^2} & \frac{\partial^2 \pi^{VR}(.)}{\partial P_O \partial SP_E} \\
\frac{\partial^2 \pi^{VR}(.)}{\partial SP_E \partial P_O} & \frac{\partial^2 \pi^{VR}(.)}{\partial SP_E \partial P_I'} & \frac{\partial^2 \pi^{VR}(.)}{\partial SP_E^2}
\end{bmatrix}; \text{ and } \quad B = \frac{\partial^2 \pi^{VR}(.)}{\partial \overline{K}^2} \le 0. \qquad (13).
$$

The system of equations (12) is estimated to get estimation coefficients of the optimal profit function given by (7). To derive the short-run energy shadow price function, $SP_{\tilde{E}}^{SR}(.)$ we derive the inverse of optimal energy demand function by using the estimated wedge, given from estimating of the system (12); the conjectured function is given by (8) and similar to equation (5) when the energy inputs index is as quasi-fixed. Based on the given all key assumptions above, it is expected the energy shadow and its market prices would be equal to one another $(SP_E = P_E)$, unless there might be a wedge due to the capital rigidities or the industry self-regulations, or other non-market failures.

The capital shadow value can be the same given by equation (11). Maintaining the full equilibrium condition gives rise to the capital to be as a variable input. Then we can have a long-run model of energy demand and thus a long-run shadow price function can be derived as has been discussed upon the next *assumption (3)*. Moreover, it is possible to investigate the effects of affecting factors on the SR energy demand equation of the industry given in the system (12). In doing so, we need to calculate a short-run elasticity of the energy demand with respect to output, other variable inputs, energy shadow price and quasi-fixed capital indexes, and technology changes. The same long-run elasticities are computable only if the full equilibrium condition is met and thus the capital input becomes a variable input. The SR and LR elasticities have been outlined in section 4.2. Using the *nested-direct* method given by the *assumption (2)*, as explained on the *assumption (1)*, if the derivation of an explicit shadow price function would be achievable, then the computation and discussion of these elasticities are applicable as well. However, as said, the wedge estimation and shadow price function derivation are cumbersome.

***Scenario #2**: A Long-Run (Unrestricted) Model*

Thus far, we have shown that an industry's shadow value equation is derivable through a restricted (short-run) model by making different assumptions. This scenario addresses the derivation based upon an unrestricted (long-run) model, when the capital input is adjustable to its optimal level. Essentially, this scenario is an extension of two *assumptions (1) and (2)* given by the scenario #1, when the capital input is a variable input. To demonstrate, first we need to test whether the quasi-fixity assumption of capital input is statistically reliable; so if the null hypothesis of the capital being quasi-fixed can be rejected by enough statistical evidence, then the capital input fixity presumption should be relaxed. Choosing an appropriate test is crucial in performing such a statistical test; for example, a recent test proposed by (Kulatilaka 1985) or (Hausmen`s specification test 1978, or a version of it) are the most applied and reliable in applied econometrics work[29]. However, other than using empirical inferences to relax the capital fixity assumption, a log-run model is an implication of relaxing the capital fixity assumption in *the scenario #1*, the model given by the following *assumption (3)* is analogous to a long-run model of *the assumptions (*2) *and/or (1)*, and the following *assumption (4)* is equivalent to a long-run model of *the assumption (1)*. Hence, we can discuss and derive the energy shadow value based on a long-run model, theoretically and empirically, by applying both *direct-nested* and *quasi-fixed* approaches. Even though by relaxing the sole restriction of being capital as quasi-fixed, it is expected that an industry's energy shadow value would be the same as a market energy price at each time-point or the sample mean unless there is any non-market failure.

***Assumption (3)**: Variable Capital and Energy Inputs*

This assumption follows a long-run model, which the capital input is not assumed as quasi-fixed and is adjustable to its optimal level in a dynamic context; violation of quasi-fixity of capital input may be resulted from a statistical testing or at least we can make it by assumption. The *assumption (3)* case is a full equilibrium model of *the assumption (1)* when the capital is a variable input and thus the energy input can not be assumed as quasi-fixed; this case is also a full

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[29] See footnote 13.

equilibrium model of *the assumption (2)*.

An industry's objective is the derivation of the LR energy shadow value model by maximizing an unrestricted (long-run) profit function. All given key assumptions are presumed to be met other than quasi-fixity of the capital input. Since the capital and energy inputs are variables, the *direct-nested* shadow price method can be an appropriate way of deriving the industry `s energy shadow value, though plugging the market energy price index (P_E) than its shadow price (SP_E); having an unrestricted long-run model, we expect the wedge to be equal to zero; so it is expected that the energy shadow price function would be simply the inverse energy demand function.

The industry's unrestricted (long-run) profit function is defined by (6) but replacing $\pi^U(.), P_E, and P_K$ instead of $\pi^{VR}(.), SP_E$, and $\overline{\mathrm{K}}$, respectively, where $\pi^U(.)$ is the industry `s unrestricted (long-run) profit function and $U$ is superscript denoting the long-run function; $P_E$ is energy inputs price index; $P_K$ is the capital input price index. Then a long-run system of energy and capital stock demands and output supply functions of the industry, given by Hotelling`s lemma, is as

$$
\begin{aligned}
E^* &= -\frac{\partial \pi^U (P_O, P_I', P_E, P_K, t)}{\partial P_E} = E^*(P_O, P_I', P_E, P_K, t) \\
K^* &= -\frac{\partial \pi^U (P_O, P_I', P_E, P_K, t)}{\partial P_K} = K^*(P_O, P_I', P_E, P_K, t) \\
D_I^* &= -\frac{\partial \pi^U (P_O, P_I', P_E, P_K, t)}{\partial P_I'} = D_I^*(P_O, P_I', P_E, P_K, t) \\
S_O^* &= \frac{\partial \pi^U (P_O, P_I', P_E, P_K, t)}{\partial P_O} = S_O^*(P_O, P_I', P_E, P_K, t) \qquad (14);
\end{aligned}
$$

where $E^*(.)$, $K^*(.)$, $D_I^*(.)$ *and* S_O^* indicate the industry's optimal energy, capital, the vector of other variable inputs demands and output supply functions in LR, respectively given the inputs and output price indexes, and production technology. To verify the regularity conditions, unlike *the assumptions (2) and (1),* the only corresponding Hessian matrix A must be positive-semi definite along with maintaining monotonicity and homogeneity; empirically to estimate the coefficients of the long-run profit function, an efficient way is to estimate the system equations (14) and use the estimated coefficients in getting the optimal long-run profit function similar to (7), by including the arguments of the LR profit function.

To derive the industry's energy shadow price equation, we need to draw the inverse of energy demand from the optimal energy demand function given by the first function in the system of equations (14). Since there is a perfect competition situation and no regulation or constraint exists, we expect the industry to choose the optimal level of energy utilization at a given competitive energy input price; this means the LR industry shadow price is given by

$$SP_E^{LR} = P_E + \lambda = -f^{-1}(P_O, P_I', \hat{E}, P_K, t) \qquad (8)'$$

This is a modified case of (8) but changing SP_E to $\mathrm{SP_E^{LR}}$ *and plugging* $\lambda = 0$ at the LHS of the equation, and replacing $\overline{K}$ by $\mathrm{P_K}$ at the RHS corresponding to the LR profit function arguments.

However, even in this case, there is some possibility for the wedge to be not equal to zero, when there is any non-market failures such as administrative or institutional transaction costs, or self-regulated policies imposed by the individual industry.

If the capital input is not quasi-fixed, theoretically, *the assumption (3)* is analogous to a dynamic case of the models given by *the assumption (1) and/or (2)*; so the optimal energy demand and its inverse functions are expected to be equivalent to the same functions drivable by dynamic cases of *these assumptions*. Moreover, the same discussion about the evolution of shadow price and energy demand, and evaluating the effects of affecting factors are applicable here as well, which has been given in section 4.2.

Assumption (4)*: Variable Capital and Quasi-Fixed Energy Inputs*

When the quasi-fixity of capital input is violated, to derive LR equation of the energy shadow value by the *quasi-fixed* approach, the energy inputs index must be assumed as quasi-fixed, by assumption. This is what is discussed by *the assumption (4)*; so that this assumption is analogous to the dynamic model of *the assumption (1).*Then this allows us to determine whether the answer given by the LR shadow price equation upon *the assumption (3)* is correct and re-check the accuracy of its derivation by the *quasi-fixed* method. For maintaining the energy input as quasi-fixed, since there is no apparent reason such as the quasi-fixity of capital input, efficiency policies, or environmental regulations, etc, so we need to suppose the energy input is quasi-fixed by a math assumption. Mathematically, this assumption is made at a very short span of the time-period to get a possibility to derive the energy shadow value expression, as this is acquired by the *quasi-fixed* approach; this means an industry does not able to adjust instantaneously energy inputs. Otherwise, to legitimize the energy quasi-fixity, this assumption might be held for some energy supply scarcity and demand-side self-regulating reasons, or other non-market failures particularly the environmental regulations can be responsible for this matter.[30]

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[30] As a matter of fact, most oil producing regions, specifically OPEC members, deal with compliance issues of assigned quotas, (for example, see Al-Osaimy and Yahyai 2003; Ait-Laoussine 1997; Bakhtirai 1992, etc), so by institutional regulation, they are not able to produce more than committed levels of oil quotas. Hence, due to the scarcity of energy resources and high demand for energy use, the energy prices tend to be increased over time. This pushes an industry to substitute other inputs mostly the capital instead of energy input and impose some sort of self-regulations to lower energy input utilization. Thus, literally, there is an upper bound for energy utilization by an industry because of self-regulations on the demand-side and ongoing constraints on the supply side of energy resources. On the other hand, one can say this might be true that the energy factor use can be quasi-fixed by these given reasons, but it is still possible to substitute capital and other inputs for energy resources by some technological innovations. For not hurting the optimal level of output and its growth rate, the capital and other factors can be substitutable for energy up to some specific points; this imposes a lower-bound on the energy use, it does not matter up to where as long as this lower-bound is equal or less than the upper-bound of energy use; then the energy inputs are utilized within an assigned domain by the industry. Therefore, underneath the long-run production process within each industry, the quasi-fixity of energy resources can be justified based on demand-side self-regulations and energy supply constraints by institutional-type regulation(e.g., OPEC`s allocated quotas), and underlying technological innovations. However, alternatively, if the assumption of not incorporating the governmental policies is relaxed, then the environmental regulation due to the polluting effect of energy

Subsequently, this assumption enables us to plug energy inputs quantity as quasi-fixed index than in the profit function of (3) but changing $\pi^{VR}(.)$ to $\pi^{\mathrm{U}}(.)$ at the LHS and $\overline{K}$ to $\mathrm{P_K}$ at the RHS, defined as the LR profit function. The LR system of optimal capital and the vector of other variable inputs demands, and output supply functions is, given by Hotelling`s lemma, as the system (14) but including the demand function of energy input and substituting capital price index in stead of the capital inputs index at each equation. As long as the regularity conditions[31], given by the economic theory, is satisfied; an estimation of the corresponding system of equations gives the estimated coefficients for the unrestricted profit function, $\pi^{\mathrm{U}^*}(.)$. The similar to (5), Hotelling`s lemma gives the LR industry's shadow value equation as

$$SV_{\widetilde{E}}^{LR} = -\frac{\partial \pi^{U^*}(P_O, P_I', \widetilde{E}, P_K, t)}{\partial \widetilde{E}} \quad (15).$$

This expression is the same as the LR energy SP which is derived upon *the assumption (3)*. Based on all given assumptions, it is expected that an estimated SV of energy would be equal to given market energy price; otherwise, the wedge between the energy shadow and market price is attributable to the quasi-fixity of energy inputs index for the explained reasons.

The *assumptions (4) and (3)* would result the same LR energy shadow value equation because, as discussed earlier, both *quasi-fixed* and *direct-nested* methods are expected to yield, theoretically, the similar results[32]. This means both shadow value equations (15) and $(8)'$ is expected to be the same if energy is quasi-fixed. Hence, likewise *the assumption (3)*, *the assumption (4)* is expected to be equivalent to the dynamic case of model given by *the assumption (1)* when the capital input is variable and the *quasi-fixed* method is applied. Further, the same discussion about the changes of the energy shadow value and evaluating effects of affecting factors are applicable here as well, that has been displayed in section 4.2.

In summary, an economic model given by *the assumption (1)* gives the SR energy SV equation (5), which is extensible to a long-run model (15) when the capital is a variable input, so that the models given by *the assumptions (4) or (3)* are an exposition of the long-run cases of the model on *the assumption (1)*, depending on specific assumptions. The method followed by *the assumptions (1) and (4)* is called a *quasi-fixed* approach of deriving the energy SV. Alternatively, an economic model given by *the assumption (2)* gives the SR energy demand function and then its inverse function: the energy shadow price expression (8); it can be extended to a long-run context when the capital input is not quasi-fixed, so that it is given by the model $(8)'$*;* on deriving the energy SP model, the economic models underlying *the assumptions (2) and (3)* apply the *direct-nested* method; the derived energy SP is comparable by the competitive energy inputs price index at each point of time, or the inverse of energy demand equation derived by data. Subsequently, if we prefer to derive the energy SV by a *quasi-fixed* method, then it is better to

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used can be a legitimized reason on the presumption of quasi-fixity of energy input, but disclaimer of this reason applies on this model; and thus this is why the given model considered as a long-run model.

[31] Similar to the conditions (13), but replacing a quasi-fixed energy input in stead of capital inputs in Hessian matrix B, and changing the capital price index rather energy shadow price in Hessian matrix A.
[32] See footnote 26 for more details.

start modeling under *the assumption (1)*, and extend the discussion to a dynamic model; so that this extension is pursuable either by the *direct-nested* method or the *quasi-fixed* approach, depending on *the assumptions*. On the contrary, if the energy SP function is intended to be derived out of an optimal energy demand, then the model is made based on *the assumption (2)*, and thus is extended into a dynamic framework.

As a result, theoretically is expected that both models based upon *the assumptions (1) and (2)* determine the same SR energy shadow value expression (5) if the energy would be as quasi-fixed, and the same is carried over for the LR shadow value function (15) on *the assumptions (3) and (4).* Therefore, the main concern can be a comparison between two energy SV deriving approaches: *quasi-fixed* and *direct-nested* methods, to come up with an appropriate method. At this point, as already stated, it seems that the *quasi-fixed* method is better to be chosen, but this is discussed more in below later on.

4. An Economic Measure of Energy Efficiency: Energy Shadow Value and the Sources of Changes:

Considering the shadow value function derived on the previous section, this shadow value measure is introduced as an economic measure of energy efficiency. One might ask of us, what are the main reasons of proposing it as such measure while energy SV is not a tangible concept, and it is an implicit imagination, by an economic agent such a producer, about the value of using one more unit of energy used. It may be accurate in terms of the SV definition, but the missing point is that it is derived based on the economic theory, so that this enables us to draw a mathematical expression for this measure out an economic model, which it is a way of quantifying and visualizing such a non-tangible concept, and this is also the reason why we call it 'shadow price'; as such a modeling characterizes the visibility of energy SV concept. In doing so, hence, we deduce 'the energy SV' expressions (5) or (8) on *the assumption (1) or (2), respectively,* and potentially it can be quantified by experimenting such shadow value models with some historical dataset of a specific region. Meanwhile, following the SV indicator derived from a microeconomic foundation, it is a marginal measure as it is derivable by marginal changes of an optimal profit function with respect to energy input variation. Since it visible and marginal, so it is comparable by actual market energy price unlike energy intensity, as it is an average and science-based measure. On the other side, on the production theory of neo-classical economics, the optimal level of applying an input is the point where its market price and value of marginal net benefits is equalized; otherwise that is not efficient; also, on the literature, the marginal net benefits of one more unit energy used is referred to the energy SV, so that the efficiency stance of energy used by an industry can be determined by comparison of the energy SV and its actual price, given in the competitive market. Therefore, the energy SV, or it is better to mention its SP, is proposed as a marginal-economic indicator of energy efficiency.

Moreover, despite of the energy intensity indicator, the modeling characteristic of the energy SV expressions (5) or (8), gives us an economic model to identify the changing sources of the energy SV variation and their effects on this measure, so that we can estimate the degree effects of each affecting factor by elasticity the energy SV with respect to each affecting factor, as so the same analysis does carry over for energy efficiency changes. Then, the decomposition of the energy SV, and thus energy efficiency changes are determinable by applying these elasticities. In addition, empirically, modeling the energy SV gives us possibility of determining and estimating such elasticities in SR and LR time period. As a matter of fact, since an industry energy demand changes in response to the socio-economic characteristics, so each affecting factor aims the energy SV through a direct and an indirect impact through the energy demand changes; hence, it acquires us to determine degree effect, or elasticity of an industry's energy SV changes using both components, as the model given by *the assumption (2)* follows in order this notion. In the following, all of the SR and LR elasticity of each affecting sources on the energy SV, and the SV decomposition are brought in details.

4.1 The Energy SV and its Price's Relationship: Energy Efficiency's Analysis

Following the SR expressions (5) or (8) and their modified cases (15) or $(8)'$ in the LR, these measures, refer to the marginal net benefits of utilizing one more unit of energy input, can be taken as energy efficiency's economic measure; this means the efficiency stance of energy used of an industry is tractable through the energy SV evolution, and a comparison between the SV of energy used and its actual market price given in a competitive market. So one can say whether or not energy input is used optimally, as shown in the following:

$$\begin{array}{lll} \textit{Energy is less utilized} & \textit{iff} \quad SV_E > P_E, & \mathrm{E} < \mathrm{E}^* \\ \textit{Energy is utilized optimally} & \textit{iff} \quad SV_E = P_E\ , & \mathrm{E} = \mathrm{E}^* \\ \textit{Energy is overutilized} & \textit{iff} \quad SV_E < P_E. & \mathrm{E} > \mathrm{E}^* \end{array} \qquad (16).$$

where '*' stands for the optimal level of energy used.

When the energy shadow value and its market price are equal at a time point or the sample mean then the energy is used the optimally ($\mathrm{E} = \mathrm{E}^*$), but otherwise it is utilized inefficiently. When the SV is greater than energy price, this means the industry less utilizes energy inputs than the optimal level ($\mathrm{E} < \mathrm{E}^*$) and tends to increase its use into the optimal level; otherwise, the industry over utilizes energy inputs ($\mathrm{E} > \mathrm{E}^*$), and thus intends to decrease its use of energy to the optimal level, under competitive market circumstances. In the SR model, due to the capital fixity constraint, is expected that the *quasi-fixed* level of energy input would be used near by the optimal point but as inefficiently, and it might not be the case in the LR. In the following an industry efficiency stance of energy used is depicted by the Figure (1-1).

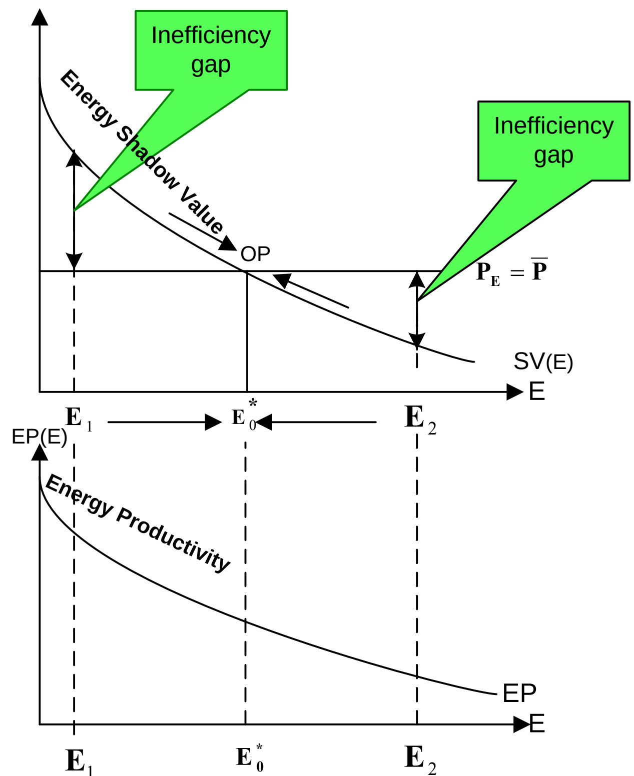

Figure (1-1): Exposure of energy shadow value of an industry at relationship to the given market energy price: A marginal energy efficiency measure

The upper chart of the Figure shows the generic shape of the industry's energy shadow value, and in a relationship with given market energy price; so that the horizontal line represents the given market energy price to a competitive industry, by energy market demand and supply forces, and the vertical and horizontal axes show the energy shadow value (SV_E) and energy use levels (E), respectively. The lower chart shows the common energy productivity measure, reciprocal of energy intensity, against energy input as puts the energy productivity measure(EP) and energy use levels on vertical and horizontal axes, respectively. As shown, underlying the neo-classical economic theory drawn on a variable restricted profit maximization, the industry's energy shadow value is supposed to be a convex and down-ward sloping curve as energy use increases; on the contrary, the energy productivity, an average ratio of the industry `s output value added to its energy used, is also presumed to be a down-ward sloping, but it is not consistent with the economic theory. Moreover, despite of the energy productivity indicator, the shadow price is a marginal measure given by the theory and is comparable to given market energy price. Basically the price horizontal line is the industry's inverse energy demand.

The point is that one can choose either the energy shadow value or energy productivity indicator to measure the industry's energy efficiency stance and changes. But the main question is that from the economic perspective which measure is more credible and reliable than other, and so gives more economic information about the real level and variation of energy efficiency? To answer the question a brief comparison between these measures in different energy utilization levels is indicated below. At all points of energy used such as $E_0^*, E_1, E_2, \ldots$, on the Figure (1-1), the shadow value indicator enables us to determine whether the industry's energy used level is the optimal or not, but this characteristic is not attainable by using energy productivity indicator; the same advantage is carried over in determining the existence and extent of energy inefficiency gap[33], at each point; this helps to study the market barriers including non-market failures particularly environmental externalities, that cause the energy inefficiency gap, and thus identifying the mean(s) and extent of the desirable government policy intervention as possible remedies. Then the energy SV gives an appropriate definition of the optimal level of 'energy efficiency' which is consistent with the efficient overall resource use, including efficient use of government resources. In addition, "the determining the real amount of this gap, also, is crucial point on starting an examination of what called 'the energy conservation paradox'[34] debate", as concerned by Jaffe and Stavins 1994, P.804; thus, using the energy SV measure assists to determine the real inefficiency gap, and so that understanding whether or not the 'energy paradox' exists. Hence, using the shadow value measure provides more economic information than the energy productivity, so that the latter is misleading at some energy utilization points than the former such as E_1 or lowers points.

Moreover, as matter of fact, energy efficiency and the economically efficiency use of energy are different policy goals, the former promoting the use of fewer energy resources, the latter promoting the efficient use of all resources. Policies intend to enhance energy efficiency are unlikely to contribute to the economically efficient use of energy and are therefore likely to waste resources; and policies enhance the economic efficiency with which resources are used may increase or decrease energy efficiency, or leave it unaffected (Sutherland 1994). Having said this, the energy intensity is only a technical measure of energy efficiency and aims an environmental target to improve efficiency using a fewer energy input (e.g., Schipper et al 1993; Sutherland 1994; Brooks 20002004). On the contrary, the shadow value characterizes both economic efficiency and energy efficiency aims; nonetheless, unlike Sutherland 1994, when the energy inputs are over utilized than the optimal level, employing the SV measure enables us to pursue concurrently both targets. Hence, the energy intensity only contains a technical notion of energy efficiency knowledge but the shadow value gives information about energy efficiency and efficient use of energy inputs; also, from technical and science perspective, both measures disseminate the same amount of information but, from economics perspective, the shadow value measure is preferable to the energy intensity ratio.

To illustrate, following the Figure, at E_0^* level of energy use, the energy shadow value intersects with its market price, because of being both as marginal variables, and thus it says the industry utilizes the optimal level of energy use denoting by OP; then the energy inefficiency gap is zero. But corresponding energy productivity is an average scalar, not equal to the marginal measure, and do not provide the same information. Essentially, based on the given assumptions of the restricted model, a profit–maximizing industry is expected to use energy near by this point,

[33] As asserted by (e.g., Jaffe and Stavins 1994a 1994b; Schipper et al 1993), the energy-inefficiency (or, efficiency) gap is defined as: the difference between what appears to be optimal and what consumers actually purchase, but the critical question is how to define and determine the optimal level of energy efficiency. However, this study, by defining an economic measure for energy efficiency concept, attempts to disentangle some confusing strands of this question and ongoing the arguments; so that, we do not consider energy efficiency only as a goal itself, but as a means to the end of overall optimal resource allocations.

[34]As described by Shama 1983 and elaborated by Jaffe and Stavins 1993 1994, this paradox says even by considering optimal economic approach and diffusion of energy-efficient technologies, the economic agents such firms due to some market barriers, including non-market failures ones, use energy inefficiently particularly over utilizing it; literally speaking, "they appear to under invest on the energy-efficient technologies" as pointed out by Schipper et al 1993.

but not on it due to capital being fixed, and/or some possible non-market failure barriers.

When the industry over utilizes the energy input, denoting by E_2, the shadow value measure indicates the inefficiency gap as a distance between the shadow value levels at the actual(E_2) and the optimal(E_0^*) level of energy used; so that, by declining energy use, the shadow value is increasing, thus energy efficiency is improving as its gap with energy price is declined; and in reality it means that actual energy use(E_2) getting closer to the optimal point(E_0^*); whereas, the energy productivity indicator exposes only information on the technical energy efficiency improvement as it increases by decreasing energy use(declining energy intensity). Balanced against, this is the main advantage of the shadow value measure to energy intensity indicator. Besides that, from economics perspective, given energy efficiency level by the shadow value at E_2 is more reliable than what is determined by the energy intensity. In addition, using the shadow value measure, unlike Sutherland 1994, the policies intend to enhance energy efficiency, so concurrently is encouraging the economically efficient use of energy when the energy is used more than the optimal level, but otherwise, when the energy less-utilized than the optimal level, this is not the case and only one target prevails.

Also, alternatively, when the energy productivity diminishes, this means that energy efficiency is deteriorated, but decreasing the energy SV can not be merely in sense of efficiency deterioration if its gap with market energy price is diminished either by changing one of those prices. To demonstrate, when the industry less utilizes energy inputs at the point E_1, the given energy productivity is a higher than the same measure at the optimal energy use (E_0^*), so it demonstrates an improvements in energy efficiency with respect to the optimal level of energy. In contrast, the SV measure provides more information than this indicator, so that it shows, at point E_1, the given energy price is greater than its shadow price, and thus there is an inefficiency gap using energy input; however, this is a deterioration in efficient allocations of energy inputs; the same counter-comparison carries over when the industry intends to increase energy utilization into the optimal level. Meanwhile, despite energy intensity, using shadow value model given by (5), or (8), the industry can determine that how much and by what means the socio-economic factors, particularly technology changes, or the industry-specific efficiency policies need to be alerted for reducing the inefficiency gap, if any would exist, at E_1 and E_2 levels; this barley states another benefits of employing the SV measure to study energy efficiency changes.

In brief, concerning efficiency situation of energy used, therefore, the given result by the energy intensity measure can be imperfect and misleading. As a result, increasing energy productivity (or, its reciprocal energy intensity) is more appropriate to be in meaning of declining intensive use of energy resources, or a ‘technical’ indicator of energy efficiency, than translating it to an energy efficiency improvement and vise versa. The following section states the SV drivers and affecting factors based on derived shadow value models.

4.2 The Energy Shadow value and its Source of Changes: Energy Efficiency Drivers

Considered the energy SV as marginal energy efficiency measure, the energy SV expressions derived upon *the assumptions (1) and (2),* corresponding to equations (5) and (8), respectively, enable us to examine the effect of affecting factors specifically technological change (t) and capital inputs index($\bar{K}$) on the energy SV changes in SR and LR time period[35].

The short-run elasticity of the energy SV with respect to output price index, ε_{SVP_O}, is given by

$$\varepsilon_{SVP_O} = \frac{\partial SV_E}{\partial P_O} \Big/ \frac{(\bar{SV}_E)}{\bar{P}_O} \qquad (17);$$

where $\bar{P}_O$ and $\bar{SV}_E$ denote the industry output prices index and the energy SV at each time-point or the sample mean, respectively. The corresponding long-run elasticity, η_{SVP_O} , is defined at the equilibrium level of the quasi-fixed capital, and thus quasi-fixed energy inputs; the effect of P_O on which can be found by differentiation of corresponding energy and capital demands functions such in (14), as

$$\eta_{SVP_O} = \left(\frac{\partial SV_E}{\partial P_O}\bigg|_{K=\bar{K}} + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial P_O}) + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial P_O}) \right) \Big/ \frac{(\bar{SV}_E)}{\bar{P}_O} \qquad (18);$$

where, in square braces, the first term referred to the SV elasticity to the output price, defined by (17), and other terms get the output cross- price elasticities of the energy SV. The sign of SR and LR elasticity formulas given by (17) and (18), respectively, depends on whether the capital and energy inputs are substitutes or complements.

Similarly, the short-run elasticity of the energy SV with respect to the i^{th} variable input price, $\varepsilon_{SVP'_I}$, is given by

$$\varepsilon_{SVP'_I} = \frac{\partial SV_E}{\partial P'_I} \Big/ \frac{(\bar{SV}_E)}{\bar{P}'_I} \qquad (19);$$

And the corresponding long-run elasticities, $\eta_{SVP'_I}$, defined at the equilibrium levels of the quasi-fixed capital, and thus quasi-fixed energy inputs, is given by

[35] All the SR and LR elasticity formulas are drawn intuitively by the author based on the literature; in a static equilibrium framework see, for example, Morrison 1988, and in a dynamic equilibrium model see Berndt el al 1977 1980 and Wing and Eckaus 2004.

$$\eta_{SVP_I'} = \left. \left(\frac{\partial SV_E}{\partial P_I'} \right|_{K=\bar{K}} + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial P_I'}) + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial P_I'}) \right) \middle/ \frac{(S\bar{V}_E)}{\bar{P}_I'} \qquad (20);$$

where, in square braces, the first term gives the ith variable input price elasticity, defined by (19), and other terms stand for the same corresponding cross-price elasticities of the energy SV. The sign of SR and LR elasticity formulas depends on whether of energy inputs are substitutes or complements with ith variable input and the capital input.

The Capital Effects:

Moreover, the short-run elasticities of the energy SV with respect to the quasi-fixed capital inputs and quasi-fixed energy inputs indexes, $\varepsilon_{SV\bar{K}}$ and $\varepsilon_{SV\tilde{\bar{E}}}$, are undefined, respectively, or we can say are zero by definition; thereby the corresponding long-run elasticities, $\eta_{SV\bar{K}}$ and $\eta_{SV\tilde{\bar{E}}}$, respectively are given by

$$\eta_{SV\bar{K}} = \left. \left(\frac{\partial SV_E}{\partial K} \right|_{K=\bar{K}} + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial K}) + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial K}) \right) \middle/ \frac{(S\bar{V}_E)}{\bar{K}} = \left. (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial K}) + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial K}) \middle/ \frac{(S\bar{V}_E)}{\bar{K}} \right. \qquad (21)$$

$$\eta_{SV\tilde{\bar{E}}} = \left. \left(\frac{\partial SV_E}{\partial E} \right|_{K=\bar{K}} + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial E}) + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial E}) \right) \middle/ \frac{(S\bar{V}_E)}{\tilde{\bar{E}}} = \left. (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial E}) + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial E}) \middle/ \frac{(S\bar{V}_E)}{\tilde{\bar{E}}} \right. \qquad (22);$$

As represented by the formula (21), the LR elasticity of the energy SV with respect to fixed capital inputs changes comes by the direct effect of its own, the first term in numerator, and its indirect effect through changing energy demand, or calls it the cross-elasticity of intensity effect indicated by the second compartment in numerator. Thus, the same description also holds at estimating LR elasticity of the SV with respect to a quasi-fixed energy input given by (22). The second compartment in the numerators of formulas (21) and (22), cross-elasticity of intensity effects, are included because of presuming quasi-fixity of energy inputs due to capital inputs quasi-fixity, so as if the quasi-fixed capital changes then the energy could be changed, and thus its reversal can be applied due to intensity effect. Following the formula (21), if energy and capital inputs become substitutes, then the LR elasticity is expected to be positive as the energy SV can be increased using more energy efficient capital inputs; otherwise, if these inputs are complements then the elasticity` sign is expected to be negative, as long as the SV curve is constant. Also, following the formula (22), the LR elasticity sign is expected to be negative regardless of whether capital and energy inputs are substitutes or complements.

The Figures (1-2) and (1-3) depict the effect of capital changes on the energy SV; we pursue the SV improvements as long as re-adjusting into an optimal level of energy use. Considering the LR equilibrium, following the capital increases and depending on whether capital and energy becomes substitute or complement, the industry is expected to be at the LR optimal point denoting by op_0, then it is re-adjusted into a new LR optimal point op_1 by shifting the SV curve, with the energy SV changes. To illustrate, following the Figure (1-2), when capital and energy are substitute, and the quasi-fixed energy is overused at $\tilde{E}_0$, then capital increase renders the energy SV increases through substitution instead of energy, and thus the industry can close the efficiency gap optimally using energy at op_0. However, energy-saving technological changes embodied in the capital variation, then the energy SV curve shifts up to RHS, and subsequently the industry re-optimizes energy use at E_2^* by moving toward op_1. Following the Figure (1-3), the similar story applies when capital and energy are complement, and energy is less-used at initial level of $\tilde{E}_0$, the SV declines through increasing energy use as the capital increase, optimizing energy use at the optimal point op_0, and then the industry re-adjusts energy utilization to the new optimal point op_1 occurring energy-efficient technology changes.

As a result, improving energy efficiency by increasing capital, on both cases, is made by moving toward a new optimal point while the overall energy use increases[36]; and at that new optimal point the overall shadow value increases with respect to the initial SV curve as shadow value shifts to RHS. This is a benefit of the energy shadow value measure application against energy intensity indicator.

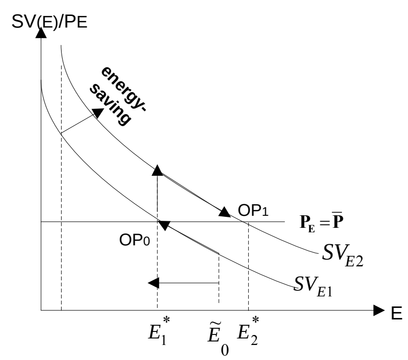

Figure (1-2): The effect of capital input increase on the energy SV when energy and capital are substitute.

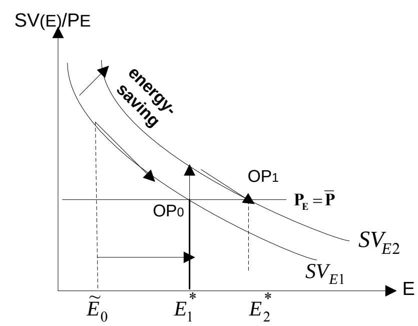

Figure (1-3): The effect of capital input increase on the energy SV when energy and capital are complement.

-The Technology Effects:

An additional advantage as the key provided by the SV modeling is that the coefficient on the time trend gives a direct estimate of the secular trend in the energy SV within an industry. It usually stands for the effect of technology changes on the energy SV given by:

$$\frac{\partial SV_E}{\partial t} = -\frac{\partial^2 \pi^{VR^*}(P_O, P_I, \tilde{E}, \overline{K}, t)}{\partial \tilde{E} \partial t} \tag{23}$$

Using this helps us to find the short-run average change rate of the energy SV with respect to technology changes, ε_{SVt} as given by

[36] This shows that using the energy shadow value measure of energy efficiency reconciles 'energy conservation paradox' pointed by Shama 1983, and Jaffe and Stavins 1993 1994.

$$\varepsilon_{SVt} = \frac{\partial SV_E}{\partial t} \Big/ (S\overline{V}_E) \qquad (24);$$

Allowing to changes of quasi-fixed capital input ($K = \overline{K}$), it is possible to calculate the corresponding long-run average rate, η_{SVt}, in a long-run context as

$$\eta_{SVEt} = \left(\frac{\partial SV_E}{\partial t}\Big|_{K=\overline{K}} + (\frac{\partial SV_E}{\partial E^*})(\frac{\partial E^*}{\partial t}) + (\frac{\partial SV_E}{\partial K^*})(\frac{\partial K^*}{\partial t}) \right) \Big/ \overline{SV} \qquad (25);$$

where in the square braces the first term states the SR effect of technology changes when the capital inputs index is quasi-fixed as it includes both disembodied energy saving and using technological changes; in addition, the second compartment gives the LR effect of the technology changes through quasi-fixed energy which is rendered by capital variability, called an embodied energy saving or using technological changes in LR, and the third compartment indicates the LR effect through quasi-fixed capital changes, called an embodied non-energy saving or using technological changes[37]. In the SR, if the technology changes are energy-saving then the SR elasticity formula (24) is expected to be positive; otherwise the expected elasticity sign is negative or zero in case of energy-using or neutral technology changes, respectively. In the LR, the overall impact of technology changes is expected to be at the same direction but rendering more effects.

To be more concrete, following the Figure (1-4), for instance, since in the SR energy is quasi-fixed, so the industry is expected to use energy near by the optimal point at $\widetilde{E}_1$ or $\widetilde{E}_2$, and then there is a gap between the energy SV and its market price. When the exogenous technology changes is energy-saving or using, the given inefficiency gap can be declined through substituting other variable inputs; since capital level is quasi-fixed and we are in SR, so the industry would enable to increase or decrease the energy SV through decreasing or increasing energy use, respectively, by some specific points given that at least we are keeping constant the given level of output, or may move toward the optimal level OP_0. Thus, the industry may end up at the optimal level. Even though the capital input is quasi-fixed, however, overall impact of exogenous technology changes is more, as long as the time period is longer, so that overall impact of energy saving or using technology changes is shown as SV curve shifting from SV_0 to SV_2, and SV_0 to SV_1, respectively; otherwise, if the technology changes are Hicks-neutral then the industry stays at the energy quasi-fixed level, and its effect on the SV curve is ineffective. This effect is given by the first term in formula (25), or by (24); following the energy-saving or using technology, this means that the energy efficiency has been increased or decreased at each level of energy use including the optimal point, respectively.

However, when we are in the LR and capital is variable, following the Figure (1-5), obviously by some specific point the variable capital stock can be substituted in stead of energy to being able to keep the given output level constant, or close the remaining inefficiency gap, if any,

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[37] See, for example, Wing and Eckaus 2004, Popp 2001 2002. For more details on embodied and disembodied technology changes.

thus the industry can end up at the optimal level OP_0 , the effect of capital changes on the SV denoted by the LR elasticity formula (21). Yet, in the LR, changes in level and composition of capital input allows for embodied technology changes as well, and thus causing more shifting the SV curve than Figure (1-4), as indicated by the second and third compartments in square braces in formula (25); the SV shifting can be to RHS or LHS whether total technology changes is energy saving or using, respectively. Subsequently, considering the overall energy-saving technological changes, since the energy SV at OP_0 is greater than its market price, then the industry moves into the new optimal point OP_2 with increased energy use to E_2^*; this means the industry adjusting onto optimal condition by economic approach while at E_2^* the industry energy efficiency level is higher than before technology changes when the industry was performing on the initial SV curve.

As a result, considering marginal the energy shadow value measure and thus optimal allocation of resources, this discussion can reconcile consistently 'energy conservation paradox; this means employing and investing on the energy-efficient technological makes the industry to end up at a higher energy utilization but optimally and containing a higher energy efficiency level. The same story carries over in the case if overall technology changes is energy-using, and thus the industry utilizes the energy inputs at decreased level E_1^* by a lower energy efficiency level than before. The overall impact of technology changes in the LR is given by the formula (25). The Figure (1-5) is a generalized case of Figures (1-2) and (1-3). Therefore, demonstrating technology impact on energy efficiency changes on economic theory is another advantage of the marginal SV over energy intensity measure.

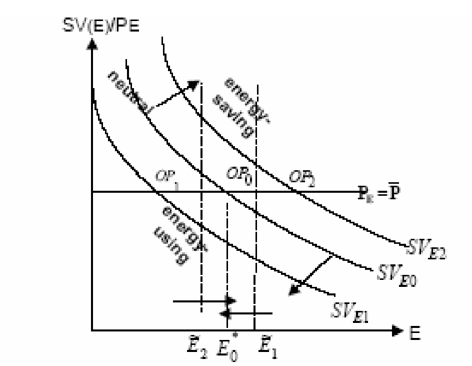

Figure (1-4): The SR effect of technology changes on the energy SV: Disembodied Hicks neutral, energy-saving, and energy-using cases

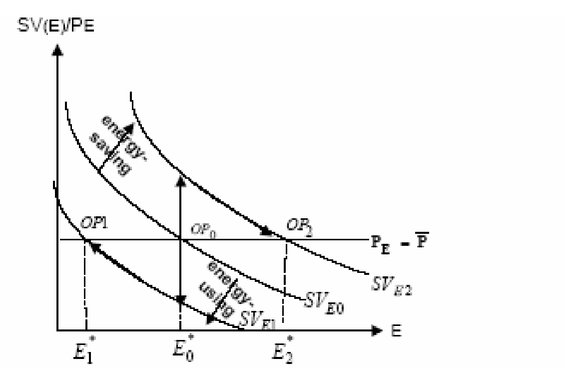

Figure (1-5): The LR effect of technology changes on the energy SV: Total embodied and disembodied energy-saving and using cases

4.3 The Energy Shadow Value Decomposition: Energy Efficiency Changes

- The Gross Shadow Value vs. the Marginal Shadow Value (MSV)

Following the energy SV model (5) derived underlying *the assumption (1)* and the key assumptions on section 3.1, the capital input(s) is assumed to be irrelevant and not function of energy inputs index in the SR model (i.e. $K = \overline{K}$) . If we relax this assumption and then the capital is a function of energy inputs index given by

$$\overline{K} = K(\widetilde{E}) \qquad (26);$$

then we need to take into account the impact(s) of energy changes on capital(s) variation, referred to the 'energy elasticity of intensity effect' (Dupont and Gordon 2007) on deriving the SV function (5), so the given energy SV is called the gross energy shadow value, SV, that is divided to 'energy elasticity of intensity effect' plus a net (actual) energy SV, which is referred, hereinafter, to 'marginal energy shadow value'(MSV) component of the gross energy SV. Considering the economic model (5) and thus *the quasi-fixed* approach, the gross energy SV decomposition is defined as

$$\frac{\partial \pi^{VR^*}}{\partial \tilde{E}} = \left.\frac{\partial \pi^{VR^*}}{\partial \tilde{E}}\right|_{K=\bar{K}} + \left(\frac{\partial \pi^{VR^*}}{\partial K} . \frac{\partial K}{\partial \tilde{E}}\right)$$

$$\mathrm{SV}_{\tilde{E}} = MSV_{\tilde{E}} + (SV_{\bar{K}}).(\frac{\partial \bar{K}}{\partial \tilde{E}}); \quad \Rightarrow \ \mathrm{MSV}_{\tilde{E}} = SV_{\tilde{E}} - (SV_{\bar{K}}).(\frac{\partial \bar{K}}{\partial \tilde{E}}) \qquad (27);$$

where we define the marginal energy SV as a marginal energy efficiency measure; so that, to derive this measure, we need to obtain the gross energy SV and 'energy elasticity of intensity' component, and its sign depends on the capital and energy whether are substitute or complement. The equations (27) are given in the SR; but considered the LR equilibrium, these expressions are applicable. However, the gross energy Shadow value ($SV_{\tilde{E}}$) is the same as the marginal energy SV (MSV) as long as we do not violate the irrelevancy of capital input(s) to the energy inputs index. Similarly, following the model (8) on *the assumption (2)*, and *direct-nested* method, the marginal energy SV derivation ends up to the same result, because, theoretically, both *quasi-fixed* and *direct-nested* methods conclude the same energy SV equations. The implication of finding the energy MSV is that it gives the actual energy efficiency variations excluding the intensity effect(s) through other fixed factor(s) such capital inputs changes.

-The Energy Shadow value Changes` Decomposition: the Energy Efficiency Pattern

Followed the energy SV as energy efficiency measure, decomposition of the SV growth rate allows us to determine contribution effect of each affecting factor on the overall energy efficiency changes over time; also, this decomposition characterizes factors in order from lowest to the highest contributors to the energy efficiency growth rate. We follow the decomposition when all key assumptions maintain but depending only on whether the assumption of capital input(s) not being as a function of energy input is violated.

In doing so, if capital input(s) are irrelevant to energy changes, given the restricted –short run SV model upon *the assumption (1)*, decomposition of the energy SV growth rate at the sample mean is conjectured as

$$\frac{d\ln SV_{\tilde{E}}^{VR}}{dt} = \left(\frac{\partial SV_{\tilde{E}}^{VR}}{\partial P_O} . \frac{\bar{P}_O}{\bar{SV}_{\tilde{E}}} . \frac{d\ln P_O}{dt}\right) + \left(\frac{\partial SV_{\tilde{E}}^{VR}}{\partial P'_I} . \frac{\bar{P}'_I}{\bar{SV}_{\tilde{E}}} . \frac{d\ln P'_I}{dt}\right) + \left(\frac{\partial SV_{\tilde{E}}^{VR}}{\partial \tilde{E}} . \frac{\bar{\tilde{E}}}{\bar{SV}_{\tilde{E}}} . \frac{d\ln \tilde{E}}{dt}\right) + \left(\frac{\partial SV_{\tilde{E}}^{VR}}{\partial \bar{K}} . \frac{\bar{K}}{\bar{SV}_{\tilde{E}}} . \frac{d\ln \bar{K}}{dt}\right)$$

$$+ \left(\frac{\partial SV_{\tilde{E}}^{VR}}{\partial t} . \frac{t}{\bar{SV}_{\tilde{E}}} . \frac{d\ln t}{dt}\right) \qquad (28)$$

Using the SR elasticity formulas given by (17), (19), and (24), and in regard to the SR elasticity for quasi-fixed energy and capital input are zero by definition, the expression (28) manipulated as

$$\frac{d \ln SV_{\tilde{E}}^{VR}}{dt} = \left(\varepsilon_{SVP_o} \cdot \frac{d \ln P_o}{dt} \right) + \left(\varepsilon_{SVP_I'} \cdot \frac{d \ln P_I'}{dt} \right) + \varepsilon_{SVt} \tag{29}$$

where $\frac{d \ln SV_{\tilde{E}}^{VR}}{dt} = \frac{d \ln MSV_{\tilde{E}}^{VR}}{dt}$ because the capital input(s) are irrelevant to energy changes Hence, in the SR, the expression (29) decomposes the growth rate of the energy SV as weighted sum of growth rate of each variable argument in the SV model as the weights are the SR elasticities of the corresponding arguments. Moreover, in the LR equilibrium context, the formula (28), using the LR elasticity formulas given by (18), (20),(21),(22), and (25), is modified as

$$\frac{d \ln SV_{\tilde{E}}^{U}}{dt} = \left(\eta_{SVP_o} \cdot \frac{d \ln P_o}{dt} \right) + \left(\eta_{SVP_I'} \cdot \frac{d \ln P_I'}{dt} \right) + \left(\eta_{SV\tilde{E}} \cdot \frac{d \ln E}{dt} \right) + \left(\eta_{SV\bar{k}} \cdot \frac{d \ln K}{dt} \right) + \eta_{SVt} \tag{30}$$

where the expression (30) decomposes the LR growth rate of the energy SV as weighted sum of growth rate of each variable argument in the SV model as the weights are the LR elasticities of the corresponding arguments.

However, when the capital input(s) are a function of energy changes, then expression (27) is maintained; in this case, the energy SV is not the same as the energy MSV, and thus growth rate of 'energy elasticity of intensity effect' is added to the formula (29) or (30) as defined by

$$\frac{d \ln SV_{\tilde{E}}^{VR}}{dt} = \frac{d \ln MSV_{\tilde{E}}^{VR}}{dt} + \frac{d \ln SV_K}{dt} + \frac{d \ln(\bar{K}/\tilde{E})}{dt} \quad (31);$$

Through transforming the energy elasticity of capital intensity formula (ε_{KE}), then ($\frac{\partial \bar{K}}{\partial \tilde{E}}$) is substituted by $(\varepsilon_{KE} \cdot \frac{\bar{K}}{\tilde{E}})$; so that the expression (31) is changed as

$$\frac{d \ln SV_{\tilde{E}}^{VR}}{dt} = \frac{d \ln MSV_{\tilde{E}}^{VR}}{dt} + \frac{d \ln SV_K}{dt} + \frac{d \ln \varepsilon_{KE}}{dt} + \frac{d \ln(\bar{K} / \tilde{E})}{dt} \quad (32);$$

Subsequently the MSV of energy growth rate can be obtained by

$$\frac{d \ln MSV_{\tilde{E}}^{VR}}{dt} = \frac{d \ln SV_{\tilde{E}}^{VR}}{dt} - \frac{d \ln SV_K}{dt} - \frac{d \ln \varepsilon_{KE}}{dt} - \frac{d \ln(\bar{K} / \tilde{E})}{dt} \quad (33).$$

where $\frac{d \ln SV_{\tilde{E}}^{VR}}{dt}$ is defined by either (29), or (30).

As a result, investigation of the energy SV decomposition shows that outputs price, variable inputs, level, and composition of energy and capital inputs, biased and non-biased-technological change, and industrial intensity effect are given drivers of energy efficiency on which can be relatively item of interest in analyzing a pattern of energy efficiency evolution.

5. An Analysis on the Selection Criterion of the Appropriate Method: Quasi-fixed or Direct-Nested Approach

Already we said that the main concern is only a comparison between two energy SV deriving approaches: *quasi-fixed* and *direct-nested* methods, to come up with an appropriate method. Of empirical and technical perspective, that approach is chosen which is the less complicated, take fewer steps, and is easier to be derived and implemented. Basically the main remaining question is that which model, a *quasi-fixed,* or an *agnostic direct-nested* method would be selected to maintain these characteristics?

Firstly, it really depends on the purpose of the study and what we pursue to achieve based on appealing that target; the volume of information and data is necessary to emerge the target empirically, and simplicity and ease empirical estimation of the chosen model. As our study problem, we would like to measure energy efficiency indicator by deriving a mathematical specification of the energy SV and computing the level and changes pattern of energy efficiency in relationship to actual energy price. In doing so, given the mathematical specification, we enable to achieve to these goals by estimating the SR and LR elasticity of each affecting factor, and decomposing the energy SV model. To achieve these goals, therefore, applying a *quasi-fixed* method through modeling on *the assumption (1)* is more beneficial than a *direct-nested* approach underlying *the assumption (2)*. Despite the fact the SR energy SP function (8) given by the latter approach is, theoretically, similar to what is given by function (5) on the former method, but technically and empirically, the energy SV derivation and estimation by the *direct-nested* approach is more complicated than the *quasi-fixed* method. Because, the first we need to compute the wedge by the data to obtain the energy SP and then it should be used on extracting an explicit mathematical equation for the energy shadow price, which is analytically more cumbersome and may be subject to some level of difficulty. When the *direct-nested* approach is applied, the energy SP equation is derived indirectly from an estimated energy demand function[38]. In addition, since the energy SP must be estimated numerically first, so testing, and imposing the curvature condition given by the economic theory adds up to the technical difficulty of this approach. Hence, it can be caused some sort of difficulties on estimating the SR and LR elasticity of affecting sources and decomposing the energy SP over time. However, then both *quasi-fixed* and *direct-nested* methods had same theoretical characteristics by no specific advantages to each other based upon what so ever have been given, as the equation (8) is identical to (5) if the energy would be supposed as quasi-fixed. Similarly, in a LR context, the equation $(8)'$ is identical to (15) if energy would be as quasi-fixed input.

Secondly, if our purpose of doing this thesis research was only calculating the energy SP numerically for some purposes such as using it as pollution cost price, then, theoretically and empirically, one may expect the both methods yields similar results, and thus an appropriate method can be applied depending on given assumptions, constraints, and available data in terms of the model, but our main target of doing this research is more beyond that and appealing more to emerge as the results, as explained on the above and the previous sections. Although applying the *direct-nested* approach have some advantages to the *quasi-fixed* method, through adding more equations including energy demand equation and thus adding more parameters to the production structure, and facilitating more convenient estimation (e.g., van Soest et al. 2002 2006 and

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[38] I call it an 'implicit' way of deriving the energy shadow price because, for example, upon *the assumption (2)* when energy is taken as a variable input, the direct-nested method gets the energy shadow price indirectly by inversing the energy demand estimation.

Morrison and MacDonald 2003). In contrast, the main purpose of our work is different than the literature which applied mostly a *direct-nested* method to follow an estimation of additive parameter or the wedge (λ) to achieve their own research targets; meanwhile, having more equations and so more parameters to estimate, can cause to deal with more difficulty of empirical estimation including appealing more data and information and missing estimators` degrees of freedom.

Therefore, consequently, we do prefer an application of the *quasi-fixed* method to the *agnostic direct-nested* approach.

6. Briefly on Experimenting with the Approach of the Energy SV Derivation

We will apply the *quasi-fixed* approach using a short-run restricted model given by *the assumption (1)* in a static equilibrium framework[39]. On the contrary, the derivation methods of energy SV can be experimented on a dynamic optimization framework, when time matters or there is an explicit time dimension in the adjustment process (e.g., Berndt et al. 1977 1980 1981; Wing and Eckaus 2004)[40].

For empirical implementation, we need to impose a specific functional form, from the flexible and non-flexible forms on the literature, on an industry's restricted profit function. Then we need to estimate a system of variable inputs demand and output supply functions to determine all coefficients estimation of the profit function. The main reason of estimating a system of equations is to obtain enough free parameters; as it enables us to approximate an arbitrary, twice-continuously-differentiable technology function to the second order; whereas the estimation of a system hurts the degrees of freedoms by including more coefficients in the model. Hence, it is useful to have a system of functional forms that has flexibility while satisfying the appropriate regularity conditions imposed by the microeconomics theory over a large region of the sample space (e.g., Diewert and Wales 1987-88). In the literature using duality theory, five leading flexible-systems are: (a) the Translog system (e.g., Jorgenson et al. 1982); (b) the Generalized Leontief system (e.g., Berndt et al. 1977); (c) the most ideal demand system (e.g., Deaton& Muellbauer 1980b); (d) the Minflex Laurent system (e.g., Barnett&Lee 1985); and (e) the Symmetric Normalized Quadratic and Normalized Quadratic system (e.g., Kohli 1993 and Diewert &Wales 1992). On our experimentation, we may apply the group (e) of the system of flexible functional forms; those functions would allow global, rather than just local, regularity conditions to be imposed without destroying their flexibility. Moreover, it is statistically more efficient to estimate the system of output supply and variable inputs demand equations using time-series dataset for an industry and/or a panel datasets cross-industry. We will proceed in estimations upon data availability; the system of equations estimation is performed using appropriate methods of estimating a system of regression equations; for example, it could basically be an iterative version of Zeller` Seemingly Unrelated Regression equations (SUR), which is numerically equivalent to Maximum Likelihood Estimation (MLE) method, when the specification conform a linear system of equations. If there is an inconsistency in the estimated results due to simultaneous equations problem such as endogeneity, then we need to resolve the

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[39] On this framework, for instance, see Morrison 1988; Kohli 1993; Morrison and Macdonald 2003, and van Soest et al. 2002 2006.

[40] Basically, I will start and complete my work by experimenting on a context of static equilibrium model. Then I will turn to experiment my shadow value model(s) on a dynamic optimization approach, depending on time constraint and the scope of my thesis work; this could be my future work after completing work under a static equilibrium framework.

problem by using IV methods such as an Iterative Three Stage Least Squares (I3SLS), or GMM method (e.g., Wooldridge 2002 and Greene 2003)[41]. Therefore, by estimating the system of equations, and thus the restricted profit function, we will derive the energy shadow value model.

In general, the procedures of the energy shadow value derivation are applicable for the production process with any multiple-inputs and outputs through short-run and long-run` scenarios; and thus the similar theoretical and intuitive results are achievable. However, theoretically and empirically, we obtain more number of variable inputs demand equations, parameters to estimate, and a complicated imposition of the regularity conditions under the case study assumptions and hypotheses. On the Whole, the calculations become extremely complex when there are more inputs and outputs, as it is the case on KLEM models.

-An Extension: A Note on the Violation of Energy Externality Assumption(s)

Thus far, we discussed the energy SV derivation only by violating the quasi-fixity of the capital input, with maintaining other key assumptions including no energy externalities impacts. As a matter of fact, energy utilization has negative environmental impact, and for declining the environmental effect of energy utilization, the governments usually intend to impose some regulations such as quoting, taxing, etc. Subsequently, industries in the production sector persist against the environmental policies, by ruling those out; this can cause an extra externality effect of energy used by each industry, so that seemingly there is an hidden temptation to increases the regulated energy utilization for making more profits; and thus this means that it would may lower the other industries profits; however, this type of externality exists by considering at least two industry on the production sector regardless of the hidden temptation impact . Therefore, energy used by production sector contains at least two types of externalities: a negative environmental impact, as spreading pollutants materials (e.g., co_2), and a negative profits effect by each industry on others (e.g., see Jaffe and Stavins 1994, P.806 810 endnotes 18-20; Schipper et al 1993).

By bearing this in mind, the energy SV measure can distinguish the impact of energy externalities on energy efficiency changes, so that, by taking into account the energy externality impacts, the economic model(s) of the energy SV (5) and (8) will be changing; the details of these models and how these externalities can affect on the energy SV model, both theoretically and graphically upon a *quasi-fixed* method, are a subject of an extension to this paper.

7. Conclusions

This study unlike the literature seeks to legitimize measuring energy efficiency concept by drawing on the economic theory, because energy intensity (or, its reciprocal energy productivity) the most common indicator used in the literature, is a simple average ratio, and not compatible with economics theory. Considered the production sector, the paper searches a marginal measure of energy efficiency upon the neoclassical economic theory; since the energy shadow value is an implicit marginal value(or, willingness to pay) of one more unit of energy input, so we introduce and visualize it as a marginal economic measure of energy efficiency by using duality theory.

Followed by a dual-profit model upon different assumptions in the SR and LR, either *quasi-fixed* or *direct-nested* methods are appropriate approaches to derive the energy shadow value, as

[41] For example, see the papers by Schankerman and Nadiri 1986, Morrison 1988, Morrison and Schwartz 1996, Morrison and MacDonald 2003, Wing and Eckaus 2004, van Soest et al. 2002 2006, etc.

consistent with the literature. As the most important reason, since the *quasi-fixed* method, by treating energy as quasi-fixed in the model, is mostly consistent with the study target and gives directly an explicit socio-economic expression for the energy SV, so we conclude that it is preferred to the *direct –nested* approach; so that, also, the former, technically and empirically, is more easier to estimate and analyze energy efficiency changes than the latter method. However, *the underlying assumptions* and the *study purpose* are important and crucial as well on determination of the appropriate economic model, and thus the method of energy shadow value derivation, but we end up again on the selection between two approaches of the energy shadow value derivation, as said it more appropriate to choose the *quasi-fixed* method.

On a brief and succinct comparison of the SV measure with energy intensity, this paper unravels that the energy SV, unlike energy intensity, is a marginal indicator consistent with microeconomics foundation; as it takes into account economic efficiency considerations. Also, it can show the beneficial information of tracking the optimal energy utilization, and thus inefficiency gap alongside of indicating energy efficiency real level and trend. This distinguishes the SV measure more informative and beneficial, than energy intensity from economic perspective; as much as energy intensity is misleading. Therefore, we conclude that the referring and measuring to energy efficiency concept with the SV is more sensible and reliable than energy intensity, as it is better to re-call 'energy intensity' a measure of intensive energy use, or technical indicator of energy efficiency than as 'energy efficiency' measure.

As a result, having consensus on the energy shadow value as energy efficiency measure, studying this measure's drivers particularly capital input level and its composition, and technology impacts, determining their degree effect, and thus applying the SV decomposition, enable us to realize and better understand the real pattern of energy efficiency changes and its deriving forces over time. Thus, this analysis enhance ability of governments who seek the policy goals to identifying the impacting degree of each argument associated with energy efficiency changes ,and choosing the most appropriate policy decision.

The most importantly, the paper concludes that the fist step of studying energy efficiency dynamic and related issues within a country, or internationally, is the determination of its real level and trend over time as it would be based on standard economic model; so that the validity and credibility of next steps are doubtlessly relevant to this initial step. Since energy input changes involves non-market failures explanations particularly environmental effect of energy utilization alongside of market-failures ones, so violating the assumption which an industry energy use has externality effects including polluting impact on the environment will change the energy SV measure, graphically and technically; but this is not included here due to limiting the paper's scope to the basic issues related to the subject matter. However, this extension and an extensive comparison between the shadow value and energy intensity measures are available as appendix upon request. On the next work, we will perform experimentation of the energy SV model with some U.S. industrial sectors dataset.

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