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The economic value of low-energy housing

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ABSTRACT

This paper explores a new perspective towards understanding barriers to ascertaining the economic value of low-energy housing. It examines why the economic value of low-energy housing is less transparent in active markets; this is investigated from the valuation principle perspectives of embodied energy and operational energy in residential dwellings. The focus is placed on the composition of energy consumption associated with the housing product life cycle. Low operational energy of a dwelling is linked to consumer preference by the inter-temporal value estimate of expected benefits. However, "low" embodied energy housing is an ecological construct and does not appear to be directly linked to short-term market value or an expected (intuitive) economic motive. This "gap/disconnect", alongside some practical "barriers" in the market economy, has created a challenge in deriving the economic value of low-energy housing. The barrier to economic value of low-energy housing is methodological and by adopting a life cycle approach to assessing and measuring energy in a house that incorporates embodied energy and operational energy, greater clarity can be achieved which may lead to a better informed market, enhancing transparency and allowing consumer choice to direct and value the broader benefits of low-energy housing.

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1. Introduction

A house, excluding land, is a type of capital: it is productive, performance-valued and durable. A low-energy house is commonly described as one that uses little or no non-renewable energy over its economic life. One should note that energy renewability is a relative term defined by the relative position between nature's operations associated with specific human intentions. In its most holistic sense, this includes energy required for operation (operational energy [OPE]) and energy embedded in materials used in initial construction, on-going maintenance, repair and renovation (embodied energy [EE]) of a house. There are different approaches used for analysing energy use associated with "capital cost" or "income". Understanding the economic value of a capital may involve its production

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cost, value depreciation and value appreciation – EE is relevant to capital formation and durability, whereas OPE is relevant to maintaining capital productivity. Although the OPE and EE split may not be mutually exclusive, it offers an energy approach to economic value of housing. This paper argues that a life cycle approach suits, at least conceptually, the evaluation of total capital formation cost and total operational cost during the life cycle of a built structure. The challenge lies in ascertaining the total economic value, whereby the fundamentals are dependent on an informed actor, their desires and willingness to pay, given resource scarcity, heterogeneous preferences and consumer capabilities.

Value inconsistency exists between capital formation and estimation of market values for built structures. This value gap tends to change over time, suggesting barriers, changes in consumer choice or market inefficiency in estimating the full capital/operational cost. Depreciation replacement is therefore a challenging research area in capital investment theory (Ball, 2003; Baum, 1991). Whipple (2006) describes value change, i.e. economic depreciation, as "departure of present value and replacement cost", which is distinct from accounting analysis of depreciation. Under the assumption of efficient market and private ownership, time-discounting models tend to exclude details of production capital, which may exclude some information about resources consumed (i.e. EE).

EE cost and market preference are not directly observable in factor and consumer markets. It has economic values that the market for property rights does not fully reveal. What a capitalist private property system does not effectively measure is an "outlier" to valuation theory. Objective or action is hard to substantiate. Given the implicit capital value relating to EE, it is interesting to ask: Will market valuations fully appreciate the economic value of a low-energy house? The question relates to the broad debate of the economic value of "sustainability" where market and non-market forces are both relevant. If the exchange environment is efficient and transparent, market value may capture most of the economic value. This is usually not the case for low-energy housing. This paper argues that EE is often left in the public domain where it commands no exchange value, illiquidity, and is treated by decision-maker as sunk cost.

Based on the EE and OPE conceptual "divide", this paper examines the production and consumption perspectives of low-energy housing. Neoclassical theory has linked production to capital service and operating cost to match consumer demand. It is argued that OPE is market driven, while EE is less so, given market failure. OPE and EE are clearly distinctive, yet not mutually exclusive concepts. The paper is structured to discuss and explore the concept and problems; the conceptual conflict and/or inconsistency; the case study of a market-driven low OPE house in Japan; the nature of EE in capital asset over time; and discussion on economic value and methodology in relation to market value and failure. A general conceptual framework is laid out pointing to further research. This paper hopes to stimulate critical thinking about markets of technology, energy and behaviour in valuation. It leaves empirical surveys and analysis to future research.

2. Conceptual conflict

The EE concept relates to a production process, value theory and science. Costanza (1980, p. 1219) defines it as "the total (direct and indirect) energy required for the production of economic or environmental goods and services". Treloar, Love, and Holt (2001, p. 49) describe it as "the energy required to provide a product (both directly and indirectly) through all processes upstream (i.e. traceable backwards from the finished product to consideration of raw materials)". They emphasized "energy path" and developed a hybrid method for measuring EE in construction (Treloar, 1997; Treloar, Love, Faniran, & Raniga, 2000; Treloar et al., 2001). The fact that 40% of total life cycle energy in residential buildings is attributed to EE motivated Chen, Burnett, and Chau (2001) to investigate EE use in Hong Kong residential buildings. They suggest EE may be divided into initial (i.e. energy used in producing a building capital) and recurring EE (i.e. energy used in maintaining and repairing over the effective life of a building). They conducted an EE analysis by energy accounting principles. OPE on the other hand, relates to running costs that facilitate the "service flow" the capital asset provides. Chen et al. (2001, p. 324) define OPE as: "the energy use in keeping the indoor environment within the desired range while demolition energy is the energy use for the destruction and disposal processes at the end of the lifespan of buildings". OPE is usually traded in markets with clearly defined liability and rights, thus less costly to price and incorporate in valuation process e.g. time-discounting model of expected service flow, OPE cost and input. The EE cost, however, appears highly implicit in the factor and consumer markets.

Reviewing the extant literature relating to valuing or the value of embodied energy identified few directly relevant studies. It is worthwhile to ask why this is the case, as there is a plethora of research analysing operational energy of homes, although ascertaining the value connections are still limited. The 2015 special edition of Building Research and Information (43(1)) explores net-zero and net-positive energy buildings and value, including the "conflicting" concepts between operational and embodied energy. For Cole (2015) and Mang and Reed (2015), this conflict highlights the radically different ways of defining value within "mechanistic" and "ecological" world views. Farber, Costanza, and Wilson (2002) suggest economic value is anthropocentric in nature. They argue for an ecological concept of value. The mechanistic view is in line with business investment linked to OPE in the private ownership domain, whereas the ecological view is more closely linked to the EE, largely on values that are left in the public domain. In comparison to OPE, it is much more difficult to measure and estimate the cost of EE. If an economic value system is complete, there will be limited scope for the economy theory to include ecological value, because market interaction and institution are required to bring together cost, as a constraint, and value as a motive in economic affairs. In order for users, traders, government, homeowners and other actors to measure and analyse low-energy houses as productive capital, there is an increasing need for knowledge, learning (i.e. obtaining knowledge) and information (availability/quality) as these are critical to then further identifying value relationships.

The subjective theory of demand implies different consumer preferences, knowledge and saving behaviours for OPE and EE. For example, saving behaviour for OPE is closely linked to individual/group interest. In contrast, saving behaviour for EE and the existing user/owner is considerably less obviously linked to an economic agent's motive in a market economy of complex ownership combinations. In fact, capital theory suggests a "trade-off" between EE and OPE. It concerns stability of consumer taste, the homeowner or purchaser's ability to learn, process, absorb and value new information and the use of new technology. This is more easily done due to the ability to tangibly measure and understand the operational energy use of a dwelling. However, the barrier involves solving the monetary vs. non-monetary values when considering the differences between OPE, which can be measured in monetary value by the consumer, and EE, which has a more intangible and unknown monetary value that is difficult to measure and quantify to the layperson or market. The market value of privately owned houses hardly captures EE, because EE contributes little to short-term market-based investment worth (or "utility"). It is capital value, which typically links to EE through replacement cost. In a used (durable) good market, economic value is derived from consumer revealed preference, not producer's capital cost estimate. It may demand quality energy information and its social value translated into enforceable private liability or tradable right. The investment worth of a low-energy property, after including the market contested social value, may help capture the EE cost. However, ascertaining what proportion, if any, the purchaser has attributed to EE will be inherently costly and it depends on knowledge and engagement. Furthermore, to identify and extrapolate the "economic value" of EE will require broader acceptance and demand from market participants, in addition to the valuers' interpretation of this change of preference towards EE and its social value in private market preference and choice.

One reason leading to the conflict is an inactive market for production-related energy within which the demand for EE is openly traded. Some natural resources (public good) do not have short-term scarcity, hence no active market to measure their demands and consumption. The markets for such natural resources as oil, natural gas or minerals have never fulfilled the neoclassical assumption of a perfectly competitive market. OPE cost is well recorded and accessible, for example, commercial building operational expense data and energy certification, whilst in the residential sector there is developing reporting (See ACT mandatory energy disclosure for rental properties) and there are active markets to assist organisations or households to estimate and circulate OPE cost information. However, EE is poorly understood in regards to associated cost, economic value and market prices. Market valuation theory is built on a motivation of consumer choice, but it also decrees a number of other factors crucially important to the concept of market value, primarily the knowledge and information available to the buyer. The active housing market reveals a consumer or producer's motive to realize a built structure (e.g. capital cost) and to use the structure (e.g. operational cost). The economic value of low-energy house needs to be estimated by a joint analysis of OPE and EE through the structure's life cycle (time). Major challenges emerge: firstly, the information availability asymmetry of OPE cost and EE cost; secondly, the expected value asymmetry of short and longer term cost and benefit. Theory suggests that users often discount expected benefits using time-varying discount rates. Thirdly, there remains methodological inconsistency to derive the economic value of low-energy housing.

Capital cost captures "all production energy". Whether energy cost is rightly priced, measured by consumption or environmental impact, is an empirical question of allocation efficiency. Notably it is hard to test non-market pricing such as government-led schemes. Likewise, given politico-economic uncertainty, the creation of a new "embodied energy market" is a price control story, for example, EE is defined as "cost" but lacks active markets to trade the "cost". From a market perspective, EE and OPE have quite a different conceptual basis: one being ecologically holistic, the other being rationally individualistic. This brings two further questions: (1) What differentiates OPE and EE in the valuation of residential buildings? And (2) How are OPE and EE treated in the low-energy housing sector?

3. Barriers to valuing embodied energy

Compared to EE, OPE can be captured through the market price as cost flow. Cost-benefit analysis (CBA) is commonly employed. EE, suffering from an information problem, is less understood by and effectively inferred to consumers, if at all. The ignorance and lack of information in EE valuation is related to the DEWHA (2008) observation that visible building features (e.g. window) have greater impact on economic value than invisible features (e.g. roof insulation). This "knowledge problem" may be reduced by the "learning effect", as the Japan case below shows regarding the importance of education and experience in forming consumer expectation and the ethics of saving. This is a highly important consideration for identifying market value.

Given market failure in typical market economy on the allocation and pricing of EE, there are observed barriers to deriving the economic value of EE:

(1) Information scarcity in regard to understanding EE and the benefits of EE available to housing consumers.
(2) Availability of reliable modelling tools, historical statistical and case specific data.
(3) Lack of market wide rating systems for assessment and communication of energy efficiency at point of sale or rental.
(4) Inadequate market development and understanding of the ethics and belief – which will shape value as the market develops its understanding of the ideology and has an interest and desire to minimize EE.
(5) The development of home purchaser preference and the influence of short-term vs. long-term benefits on decision-making that will affect value.
(6) Market competition – the EE component may lose ground in market value due to its weak link to market competitiveness as a result of the points above; and
(7) Cost premiums that creates a barrier to efficiency and trade/circulation.

It has been argued that the concept of energy may be a more suitable unit of comparison than monetary value in evaluating capital goods, as an energy unit allows proper comparison of building structures without taking into account the land component and other disturbance. In the emerging ecological economics literature, Costanza (1980) relates EE to economic value estimation. He examined input–output energy accounting and advocated the "embodied energy theory of value". He suggests, "the flow of energy is the primary concern of economics", which is the focus of ecological economics. Some interesting ideas relating markets (and non-market) and energy measures, as well as policy implications are also addressed. Costanza and Herendeen (1984) further integrate energy theory of value through reaching consensus in their theoretical development and debates.

The EE theory of economic value is not without criticism, given some of the conceptual conflict discussed earlier remains unresolved or underdeveloped. Huettner and Costanza (1982) debate on the progress and problems of the EE theory of economic value, showing critical review and response for theory development and validation. Hornborg (1998) argues that EE is a metaphysical concept, which is not a property relating to exchange value. At the least not all energy are embodied in final productive capital good. The rest has dissipated. Hornborg (1998) offers a critical view to the energy theory of economic value.

In advanced economies, the inter-temporal differentiation of capital value and cost is clearly documented by available building cost and transaction (or appraisal) price indices. However, an apparent challenge in examining value–cost consistency is that market value indexes contain combined land and structure values. Furthermore, in housing markets, estimating value through the summation of building costs and land does not equate to the market value. The approach used by Lutzkendorf, Follente, Balouktsi, and Wiberg

(2015) is inspiring, as they consider the full life cycle resource use efficiency and environmental impact reduction of housing projects. Georges, Haase, Wiberg, Kristjansdottir, and Risholt (2015) adopt a holistic approach that includes building OPE and EE. Cole's (2015 pp.4) points out: "both studies advocate reducing energy demand, increasing onsite renewable energy and minimizing the initial and recurring embodied emissions". Adan and Fuerst (2015) examined residential housing on an operational energy only basis utilizing a difference-in-difference analysis to ascertain building improvement following the Carbon Emission Reduction Target programme of installing energy efficiency measures. While Fuerst, McAllister, Nanda, and Wyatt (2015) examined the price effect of Energy Performance Certificate (EPC) ratings (OPE) on dwelling prices in Wales utilising two methods, they failed to find that an EPC rating had any affect on the price. Given the challenges in identifying the economic value of low-energy housing, the OPE and the EE cases are discussed below.

4. The market for low OPE housing in Japan

The OPE-related arguments are based on data from Japanese house manufacturers' sales and production facilities (Noguchi, 2011). The ultimate low-energy house, i.e. a zero-energy house, falls into two categories: self-sufficient and net zero-energy (Noguchi, 2008). The former is a stand-alone house whose OPE relies solely on its own power generation and storage. It is independent from a commercial grid or power from external sources. The latter means the energy "use" becomes net zero over a fixed period of time. Moreover, domestic OPE can further be classified into two sources: primary and delivered. The primary energy is considered as energy before it is transported from production plants, while the delivered energy is energy imported from the grid. Generally, the distinction of such energy sources affects the level of domestic carbon dioxide (CO_2) emissions; it widens the definition of net zero energy houses. "Net zero source energy" is based on the net zero balance of primary energy use; therefore, transport loss of energy delivered from power plants, for instance, is taken into consideration (Aelenei et al., 2013). "Net zero site energy" means that the annual balance of operational energy use is based on the grid interaction at the boundary of the building site. A house whose OPE cost is net zero under the same conditions is termed a "net zero-energy-cost" house. To achieve net zero-energy-cost, a house needs to be connected to a commercial grid where electricity can be exported and imported between the energy user and the supplier under a net metering arrangement. The notion of "zero carbon house" is from time to time likened to these above-mentioned homes; perchance, the performance may entail the further steps to cover CO_2 emissions from not only operation but also construction and end of life demolition or recycling – i.e. over the full life span (Dave, 2014).

Japanese manufacturers are at the forefront of commercializing mass-customisable homes to correspond with market demand for low (zero) operational CO_2 emissions, affordability and design customisability (Noguchi, 2013). They compete to produce net zero-energy mass-produced custom homes equipped with renewable energy technologies – e.g. a solar photovoltaic electric power generating system, an air source heat pump, a micro combined heat and power system and a hydrogen fuel cell. Under the Kyoto Protocol, Japan is assigned the target to reduce its emissions of CO_2 by 6% from 1990 levels from 2008 to 2012. In Japan, PV systems rated at 3 kW or less use to be common. Today, the high-capacity systems at power levels of 5 kW are being installed in houses. Some leading manufacturers have created a new sector for residential PV systems, developing all-electric houses whose energy can be fully or partially supplied by the micro-power generation systems. In early 2004, Sekisui Chemical Co., & Ltd (2004a) launched a new zero-energy-cost home "Parfait AE" with zero utility expense specifications. It includes thermal barrier-free systems applied for the foundation and floors, passive ventilation heat-blocking system for high heat dissipation skylight and heat-blocking screens to control sunlight intake. In collaboration with Sumitomo Trust and Banking Co., they jointly developed a new home loan to assist in the purchase of a house equipped with high-capacity PV systems. "The higher the power generating capacity of the photovoltaic generator, the lower the loan's interest rate". (Sekisui Chemical Co., & Ltd, 2004b). The rate was estimated at as low as 2.8%, comparing favourably with long-term fixed-rate bank loans. Such partnership enhances the economic appeal of low-energy PV solar technology and housing.

Japanese manufacturers tend to install costly renewable technologies as standard features rather than optional (Noguchi, 2011). To initiate and maintain the sales of their low-energy houses, they bring into effect their quality-oriented production and user-oriented services, which reflects their cost-performance marketing strategy. They have succeeded in developing a good reputation for their net zero-energy-cost product. This is also to show the distinguishing features of high cost-performance house products where a variety of amenities including renewable energy technologies are treated as standard features. According to a 1997 housing survey by the Government Housing Loan Corporation, the average initial cost of a conventional home was estimated at 175,404 JPY/m^2 and a prefabricated home was at 190,033 JPY/m^2 (Noguchi & Collins, 2008). These results indicate that the price of a pre-fabricated house in Japan is 8% more expensive than that of conventional site-built ones, though manufacturers argue that they have been producing better quality homes for about the same price as conventional ones. The manufacturers' way to commercialize new innovative products is a cost-performance marketing strategy, which is applied in other industries, for example, automobile. Although today's automobiles can be produced with lower production costs than those in the past, their selling price does not seem to be heavily affected by productivity. Consumers may still regard new automobile models as expensive. The list of items now offered as standard features in new cars, such as air conditioning, a stereo set, airbags, remote-control keys, power steering, power windows and adjustable mirrors, were offered only as expensive options in older models. Clearly, the quality of newer models is much higher than that of older models. The same is true for the Japanese housing industry, where quality-oriented production contributes to deliver high-cost-performance houses (e.g. renewable energy technologies), active markets and market values.

Value assurance helps reduce buyer risk via "follow-up" services and warranties. In order to assure homebuyers of product quality, post-purchasing services are of high importance in reducing perceived risks during home buying decision-making. Most manufacturers provide a 10-year warranty and reassure their clients with free post-purchase services based on the warranty. They also keep in contact with their clients post sales to offer periodic product inspections with information update on maintenance and renovation. Such long-term post-purchase services assure potential homebuyers of product quality throughout the product life cycle. It helps anchor and elevate the customer's trust on company product reputation. The 2007 market survey of Japanese prefabricated housing, which was conducted by Japan Prefabricated Construction and Suppliers and Manufacturers Association (2008), indicates that 2% of the homebuyers who preferred to purchase a prefabricated home, considered the selling price as reasonable despite the fact that the initial cost is 8% more expensive than that of conventionally built housing. Homebuyers may be well convinced of both the superior quality and the economic value of prefab homes of net zero-energy-cost.

The Japan case study demonstrates the ability of a market to overcome many of the barriers previously evident in current markets that restricts the ability of EE and OPE to be valued. The Japan case study shows a robust low OPE house market, as a result of a number of key elements that have assisted in driving the sector. Firstly, the education and communication with consumers or purchasers of homes; minimizing distrust in technology and new-age homes through post construction services and warranties; the incorporation and implementation of "standard" features; and the encouragement by government and the finance sector in embracing low-energy homes. Consequently, this has assisted the market for consumers, being the home purchasers, in providing a product and creating value in that product. As a result, consumers *value* the low-energy homes and desire and choice engages the enhanced premium perceived by the market for low-energy homes. However, extrapolating out exactly what this premium is for low energy is still relatively unknown and difficult to quantify because of the tangible and intangible components to be considered. Furthermore, timing and discounting of both the tangible and intangible components in the same process needs to be considered in the overall assessment of value.

5. The economic value of embodied energy

Placing an economic value on the energy embodied in a building is difficult as there is a distant connection between the building owner/purchaser and the energy expended. In contrast, building users are typically provided with OPE data as part of their energy bills. Homeowners and users have much less control over EE demand once a house is built as opportunities for intervention e.g. renovation occur far less frequently and are more costly. On the phenomenon of capital cost and market value departure, it has been suggested that the money (financial) economy and the real economy are linked by market price and replacement cost of productive capital (Keynes, 1936; Tobin & Brainard, 1976), which is the motive of monetary policy to intervene financial institutions and markets, i.e. the primary transmission channel. Therefore, instead of market mechanism, the economic value of EE is likely to be directly associated with government fiscal distribution policy to connect and to enforce, as well as to standardize the non-market treatment for socio-environmental costs. There is uncertainty for the extent and consequence of fiscal distribution policy. It is also interesting to ask whether the quality of the initial building material and equipment and its EE consumption are positively correlated – an empirical question worth investigating.

An increasing number of studies show that EE can be just as, if not more, significant in terms of energy consumption than the OPE demand of housing. This is even more pronounced for low-energy buildings where the focus tends to be on lowering OPE demand. This becomes all the more relevant for houses that are self-sufficient or autonomous by being off-grid as such buildings require larger-than-usual energy generation and storage systems and this further exacerbates the EE debt (Dave, 2014). However, providing an economic value for the EE aspect of low-energy housing may still be possible. It is critical that this occurs on a life cycle basis, just as operational efficiency upgrades are typically considered. Crawford (2011a) explores the concept of zero-emissions housing in Australia and offers a life cycle approach to built environment assessment (Crawford, 2011b). A low initial EE house may result in a low upfront capital cost for the user or owner, but will often result in a high demand for recurrent EE and on-going costs through the more frequent replacement of materials throughout the life of the house. In this sense, durability and quality of materials and equipment is critical. Higher EE materials that will last longer and minimise the frequency of material replacement will be more highly valued. As the on-going energy cost of housing from an EE perspective is its expected recurrent EE, this is the component that will be of most interest to an actor (or the society) in placing a value on a "low EE house". Assessing the economic value of recurrent EE may be linked to the service life remaining for the main materials and components as well as the EE that is required to produce the replacement materials and equipment.

As for the value placed by owners and users on the potential cost savings of OPE efficient housing, the EE invested in more durable components must ideally result in an equal or greater reduction in on-going recurrent EE demands compared to business as usual. This EE saving can easily be translated to economic value, as a reduction in recurrent EE resulting from a reduced demand for materials should lead to lower replacement costs for the house owner. Just as is the case for low OPE housing, a low "life cycle" EE house has the potential, given resource scarcity and barriers in the economy, to be highly valued in an economic sense, especially as energy and thus replacement costs (which are intrinsically linked) tend to rise over time. Determination of life cycle EE demands for a house provides information that can then be used to inform a homeowner or potential home purchaser of expected future costs. There is an expectation that any additional materials and systems invested in a building to reduce OPE demand will result in a net life cycle energy and cost saving. While it is beyond the scope of this paper, the typical EE increase associated with these energy efficiency-related upgrades is usually not included in this analysis, resulting in what is usually an overestimation of the net energy benefit of these efficiency improvements. Consideration of the value of a low EE house must therefore also be made in the context of its OPE demand. A house with low EE, even over its life cycle, may lead to a higher demand for OPE, especially if less insulation materials, lower performance windows or less thermally efficient envelope materials are used.

6. Valuing low-energy housing

Valuation of green buildings has attracted major attention over the past decade, however is plagued by a multitude of issues in both process and practice (Warren-Myers, 2012, 2013). The focus has been on the investment value and private benefit or the OPE analysis and modelling. The consideration of OPE analysis in market valuation is limited to a broader overview of operational expenditure that affects the net income of the commercial property. Time-discounting valuation model and hedonic pricing model are available to analyse OPE scenarios. EE is rarely if ever explicitly treated in valuation process, reflected by a lack of explicit treatment of EE in production function and cost accounting of building, as well as formal building regulations concerning EE assessment in Australia (see www.nathers.gov.au). It is envisaged that under mainstream price theory, time series expectation system and hedonic substitution comparison system shall be integrated to model economic value of long-life capital. This would allow holistic evaluation of EE and OPE to guide intervention and to device incentives to better relate capital cost and its exchange value.

Pan and Ning (2015) pointed out that human behaviour is poorly understood in building energy, design and construction research. Behaviour assumptions of time discounting include that, firstly, given stable preference/taste, people tend to demonstrate time-varying value (discounting) choice, for example, heavily discounting more recent or immediately relevant events, measured by inter-temporal variation of time discounting behaviour or inter-temporal discount rates. Behavioural economics suggests that people assign lower value to less certain, more distant future and less immediate needs. Climate change or EE belongs to this category of very long-term discounting. But it seems to be in conflict with the empirical evidence of lower rate discounting for long-term cash flow observed in the case of leasehold vs. freehold housing markets, for example, Giglio, Maggiori, and Stroebel (2014) and Wong, Chau, Yiu, and Yu (2008).

There is debate on the stability of consumer taste between the behavioural and rational expectation theories. Cochrane (2011) explains time-varying valuation through a rational choice perspective. Neo, Ong, and Tu (2008) compare the relative explanatory power of the two approaches. Given asymmetrical information and learning effect, people tend to establish time-varying valuing (discounting) choices, which suggest time-varying preference through knowledge accumulation or change of perception/belief. This implies the possibility of counteracting the time-preference discounting behaviour by learning. Education, environmental awareness programmes and growth of wealth, for example, the Environmental Kuznets Curve would vary time-discounting behaviour under rational choice hypothesis. This is consistent with the long-term discounting behaviour. However, from an individual decision-making perspective, certain long-term decisions are irreversible. The mechanistic approach to economic value is closely measured according to the human life span. OPE, although human (owner) benefit oriented, may be influenced by social value-driven saving behaviour. EE, due to abstraction and measurement difficulty, demands higher order social value-driven motives. This "value-disconnect" is said to be a major barrier, a theoretical challenge, in economic theory and analytics. As Pearce (1993) suggests, the economic value may not be ranked highly amongst other social values. The question is: Is it not relevant? If not, what are the connecting principles?

The Japan case shows an active OPE market where OPE is linked with market institutions of regulations and industry standards. It includes such factors as market efficiency, learning, saving motives, standard (low transaction cost), reputation (i.e. intangible value), technology, finance incentive and policy environment. One question is: Would EE of capital (e.g. low-energy house) over its life cycle be subject to the "incentive package" of robust consumer sentiment, industry standard and government–market interactions, similar to OPE in the Japanese market? It seems clear that low OPE capital is well connected to perception of quality and competitiveness, whereas EE content of capital tends to be connected to such perceptions as high production cost.

7. A framework for low-energy housing

This paper calls for a framework to link market efficiency of private property, and ecological welfare of public good. Equilibrium of the two (mitigation) of private–public interests is the economic value. This may include the following elements: (1) allocation institution (market vs. non-market), (2) ownership contract (public nature of EE), (3) information (e.g. EE process, non-market (in firm)), (4) state intervention (law and political forces) and (5) the exchange–production linkage.

This section discusses EE plus OPE to reflect the total resource constraint through the life cycle of a durable capital (housing). A suitable valuation framework needs to incorporate (1) competitive market value model feed back to the valuation of OPE and (2) market failure – government intervention and pricing policy. Market failure and state intervention feed back to price mechanism, especially focusing on the valuation of the EE component. OPE may also be assessed from an EE perspective, i.e. OPE as service flow is usually generated by capital device, which underpins EE in its production. As discussed earlier, OPE is an external cost, which does not form the productive capital, whilst EE is internal. Even when OPE is openly traded in inefficient markets, it has an EE component, that is, production process related lower order energy consumption. The same OPE (e.g. electricity) may be produced by different energy consumption sources or methods i.e. "energy path". The theoretical barrier is a lack of a coherent framework of price (or other measure) to link or integrate utility and expectation, which, respectively, drives hedonic and investment values.

The economic value analysis of low-energy housing is challenged by the following inter-connected conceptual issues, which suggests inefficiency in the low-energy housing market:

(1) Information and knowledge;
(2) Measurement and enforcement;
(3) Ethical value vs. private value;
(4) Behavioural ambiguity on uncertainty i.e. short vs. long term;
(5) Market competitiveness and comparativeness;
(6) Analytic tools: cross section vs. time series; and
(7) Expected investment (expected marginal utility) vs. utility (static preference).

It is clear that energy science links to environmental science, whereas subjective theory of demand applies to human welfare and decisions. The two need to reach some coherence or consensus by moral and practical debates.

8. Conclusions

This paper explores the economic value of low-energy housing, with a specific focus on the EE–OPE conceptual divide in a market context and their contributions to capital value. Humans adding value to the ecological system remains a much debatable topic of critical importance. This paper compares building EE and OPE by relating their relevance to the concept of market value and argues that either lower EE or lower OPE may be a "positive" social value creator. They, however, have different "market derived values" in modern capitalist society. Being less costly to measure, OPE is usually more transparent and valued more highly by the market than EE. One could look at either EE or OPE separately, or both together in a holistic sense. This paper suggests that in order to overcome aforementioned barriers, an integrated theoretical framework or a "life cycle" approach to assess and measure the OPE and EE in houses is needed, so that when valuing energy performance of any building the actual energy use or reductions can be easily identified, clarified and valued. If EE is not effectively reflected in the economic value of capital, then it becomes a kind of "externality" or tax, and one needs to consider then why the market system lacks such effectiveness to indicate and allocate such social liability.

There are two key aspects for a consumer to consider in the valuation of EE: firstly, the purchase and construction implications of using higher EE materials, especially if there is a price on carbon, as this would motivate consumers to purchase/build a low EE building; and secondly, valuing the life cycle EE implications would be an important aspect to future-proof an investment. This is where the life cycle approach becomes important. A building with a low EE to build is no good if it requires substantial investment of materials/EE over its life (much akin to high on-going maintenance costs). This is similar to purchasers/occupants being more inclined to lease/buy a property with low on-going OPE demands as it will cost them less in the long run, if they are aware of these benefits and these align with their own values, behaviour and attitudes. However, the demand for low OPE or EE is going to be balanced with a range of other criteria (e.g. size, comfort, layout, location) in the process of valuing a house. The expectation model needs to be developed, not only to combine/link production and trade in an inter-temporal style, but also the variation of behaviour and taste through the process, especially the need to involve multi-agents in the capital life cycle of low-energy housing.

The discussions on OPE and EE over the building life cycle show distinctive potential in built-environment research. The life cycle approach will assist in defining and measuring the benefits of a future energy efficient house (from an OPE and EE perspective). It may also help pave the way for measuring economic value of low- and zero-energy buildings. The study may be connected to such areas as collective buildings or "net-positive approach" to energy efficiency (e.g. Hamilton, Summerfield, Steadman, Stone, & Davies, 2010; Cole & Fedoruk, 2015). Although the land component is intentionally excluded from the discussion, location and other site-specific factors may have indirect EE or OPE relevance on a house's economic value. Various versions of energy efficiency performance (e.g. zero-energy, net-positive) have emerged, but maybe a more appropriate approach is progressive total energy efficiency for housing. Economic value under such conditions is likely to better reflect social value optimization.

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