The use of strong and weak form sustainability to assist in rate development for the valuation of exhaustible resources (part II)

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Abstract
Purpose – This paper is the second of a two part series which offers new theoretical and empirical insights investigating the rates structures appropriate for exhaustible resources with a particular emphasis on urban land, based upon the differentiation of strong- and weak-form sustainability concepts constrained by the objectives of the sustainable criterion of Daly and Cobb (1994). The integration of the concepts and objectives allow the theoretical formulation of discount and capitalization rates that can be empirically tested. This empirical application employs data from 12 diverse national economies. The paper aims to discuss these issues.

Design/methodology/approach – The paper integrates the concepts of discount rate development for environmental and long-term assets and discounted utility analysis to the policy concerns associated with the valuation of public and sustainable resources. The new approach empirically shows the diverse issues of competing sustainable objectives across nations.

Findings – The potential and degree of strong-form or weak-form sustainability application in each nation enabled the identification as to whether alternative capital as defined by the modified Ramsey model used per nation, or the marginal rate of resource return as defined by strong form objective of a constant natural resource endowment, can identify which form of capital becomes the major constraint on the resource valuation and allocation decision appropriate within each nation. The findings showed constraints on nation resource endowments relative to population needs and the culture preferences endemic across nations.

Originality/value – The findings serve as a basis for future research on the optimal levels of sustainable development appropriate for different nations, the impactions of the timing and level of capital re-switching associated with the application of strong- or weak-form sustainability and the develop of rate and risk measures that can assist in the consideration of sustainable resource as a distinct asset class.

Keywords Sustainability, Discount factor, Exhaustible resources, Capitalization rate

Paper type Research paper

1. Introduction
The theoretical formula and development of a methodological process incorporating discount and capitalization rates to help conceptualize and differentiate strong and weak forms of sustainability was evidenced in part I of this research paper. As suggested, there is an established literature base investigating the complexities of valuing long-term environmental assets and sustainable resources (Gollier, 2010). Indeed, the literature pertaining to discount/capitalization rates is diverse in terms of sustainability, exhaustible resources, public goods, natural resources and long-term valuation procedure (Ramsey, 1928; Weitzman, 1998, 2007; Gollier, 2002, 2007, 2008, 2010, model).

The previous paper (part I) highlighted the lack of insight applying strong- and weak-form sustainability to assist in rate development for the valuation of exhaustible resources and identified how to incorporate the development of capitalization/discount rates under uncertainty/risk for the valuation of exhaustible resources, subject to sustainable development objectives. This enabled the estimation and specification of built and natural environment endowment calculations as suggested in earlier approaches of Romer (2001), Barker and Sa-Aadu (2004) and Grissom (2005). Importantly, this also permits the development of a sustainable valuation model where model differentiation of the strong- and weak-form sustainability construct is formulated using Fisher’s Separation theorem. Indeed, this broader form of sustainability is made operational using a Ramsey rule model which enables an estimation of valuation discount and capitalization rates – with the rate structure allowing for weak-form calculations.

This paper proceeds to analyse the rates developed by the integrated methodology and theory previously developed. Empirically the paper applies the model to national markets/economies with diverse resource endowments, levels of urbanization/agglomeration and distinct cultural preferences. The model is tested using the economic data available for 12 countries namely the UK, USA, Ireland, Germany, France, Canada, China, Hong Kong, Japan, Singapore, Norway and Australia, respectively. The data from each nation is developed in the context of a strong-form sustainability format using urban space per capita as the base unit of comparison and economic performance – urban land per capita as a developed unit is formulated as a unit of utility and life style/welfare measurement, originally developed by Grissom (2005)[1]. This approach fits the implementation of sustainable strategies, but also enables a process of measurement that allows for each market or nation’s variance. Empirically it is observed that each of the nations vary in their level of non-renewable resources, opportunity costs and the costs of capital (social) pure time preferences, and the degree of risks and levels of uncertainty that impact behaviour in each distinct economy and market.

2. Data and data development
The main source of the data used is the WDI online databank of national statistics available from the World Bank. This source of nationally developed data is used with several data development techniques to produce the inputs used in both the strong form and weak-form constructs to produce the empirical measure to follow. The data employed in the strong-form sustainability analysis are economic and physical production statistics for periods beginning in 1960 and extending into 2010. These measures are developed in order to complement and fit concerns and considerations of the long-term discounting comprising the Ramsey-Weismann-Gollier paradigm previously noted in the literature. Moreover, adjustments are made for missing or omitted data that might randomly occur and vary across nations. The annual data for land resources is consistently measured across nations in squared kilometres. This base unit measure is expanded to allow a land use intensity/density measure based on modifications of the real estate stock measurement used by Barker and Sa-Aadu (2004) and
Grissom (2005). The measure of urban land stock available across nations is processed using the format in which:

$$L_U(i) = \Lambda_{T(i)} - \left(\Lambda_{Agr(i)} + \Lambda_{F(i)} + \Lambda_{N(i)}\right)$$

where $\Lambda_{U(i)}$ is the urban land stock, is calculated as a residual that varies annually based on the deduction of the economic conditions and policy used to designate green space identifiable in each nation; $\Lambda_{T(i)}$ the total surface land area available per nation per generation over time; $\Lambda_{Agr(i)}$ the measure of agriculture land identified each year by the national accounting process (a green economic allocation of land); $\Lambda_{F(i)}$ the forest land identified each year (a green economic allocation of land); $\Lambda_{N(i)}$ the nationally protected land area (a green policy allocation of land).

The availability of land supply as an issue of resource allocation is further modified by the consideration of total and urban population, with the latter specified by $P_{U(i)}$ and the influence and measure of national agglomeration, which is specified as $A_{(i)}(t)$. The introduction of population as modified by agglomeration enables the impact of demand, land density and the intensity of development to be assessed.

The stock (supply) of urban land varies in time subject to the growth in the general economy, associated demand and the national agglomeration effect of urbanization preferences. The measure varies in their observations across time and nations. These national differences in combination with the levels of agglomeration based on the urban population relative to total population per squared kilometre, the percentage of population in cities over a million in population and the aggregate population in metropolitan areas enable an endogenous measure of the national preference for urban land and arguably an urban lifestyle. The spread developed by comparing the measure of urban land demand adjusted for urban agglomeration effects with the per capita amount of total land to population allows a proxy for intensity of development operating in each of the given markets investigated. These combined interactive effects are used to calculate the ratio variable reflecting effective demand and a measure of the technical efficiency of land use given the incremental supply of land resource available per capita.

The change in the amount of land used or made available per period as an annual flow per unit of time reflects the Hamiltonian to be constructed in the strong-form measures. The total stock of natural capital to be calculated for each nation is the sum of the urban land made available from 1960 to 2010; $\sum_{(i)}(\Lambda_{U(0)}(t))$ (where, the period is from $t = 0$ to $T$). The interaction of supply and demand impounded in these calculations is a measure of the marginal product of land as a proxy of the return on natural capital. This resource measure suggested by Stiglitz (1974) employed in this paper is based on the quantity of urban land per capita ($\Lambda_{U(0)}/P_{U(0)}$) per period. The basic resource unit is further weighted by the agglomeration (i.e., a factor that varies by jurisdiction). This weighting is a key factor defining sustainability differentials and pricing across markets, especially in a strong-form context. The calculation of the agglomeration factor as developed above is a function of the reciprocal of the percentage of national population living in cities with population over a million ($A_{(i)}(t)$). The agglomeration multiplier per nation per period is of the form $(1/A_{(i)}(t))$. This multiplier offers a comparative measure of the preferences or acceptance of dense development and urbanization occurring in a market/nation. When the agglomerative land use ratio is compared to the ratio of total land available to urban population, an estimate of the intensity of land use operating in each of the 12 economies is possible. The general form of this measure is $[(\Lambda_{U(0)}/P_{U(0)}) (1/A_{(i)}(t))] - [(\Lambda_{T(0)}/P_{U(0)})][2]$. Valuation of exhaustible resources
The land-related data from the World Bank and the associated data development conducted in this paper form the input used in an empirical application per nation. The strong-form sustainability measure and the production possibility curve based on the increment flow of the urban land made available is over a 50-52 year period. This period covers the taste and preferences of three to four distinct generations. The model, to follow, uses the data derived from implementing Equation (1). The developed data and additional modification will be used to support the formulation of the Hamiltonian that follows. This systematic approach enables an optimal control dynamic programming approach. The state-control variable format is used to specify the nature of strong-form sustainability for each of the 12 nations investigated in the theoretical paper which developed a resource constrained local discount/reinvestment rate and allows the introduction of a recapture rate that is necessary to enable an operating functional strong-form sustainability construct.

The Ramsey rate developed in this study uses data furnished by the World Bank WDI on-line databank, the Morgan Stanley Capital Index (MSCI) financial database and various other property and economic data sources operating in the 12 nations investigated[3]. The general economic data used to develop the weak-form sustainability and Ramsey rule models incorporate the pattern of change in GDP per nation, the change and patterns observed in consumption patterns for the period from 1960 to 2010, the changes in fixed capital formulation per nation and the above developed urban land stock changes. Financial data for equity return \((1 + \hat{E}(R_{it}))\) to offset risk options in national resources is also developed for incorporation in this modification of the Ramsey model as suggested by Howarth (2009), Gollier (2010) and Weitzman (2007). This data are derived from national banking statistics, the World Bank Data and equity returns from the MSCI database. The macroeconomic variables and the patterns and associations developed and measured from this array of data sources forms the inputs used in empirical analysis of this paper. The data developed and presented in the empirical section forms the basis for both the strong- and weak-form sustainability measures allowing for nationally distinct recapture rates for the exhaustible or depleting resource and the consumption-investment-based information used to construct the weak-form Ramsey rule models of discount and capitalization rates.

3. Empirical analysis of strong- and weak-form sustainability across national markets

The methodology employed in this paper is an empirical calculation and test of compliance needed to achieve the objectives of sustainable development theory and constructs. The rate development and analysis of the strong-form sustainability supports the construction of a local resource reinvestment and recapture rate. This local-based calculation is standardized by removing the local effects of the end points of the series to allow a globally consistent reinvestment and recapture rate. This enables a direct nation-to-nation comparison in the construction of capitalization and discount rates to assist in pricing of sustainable resources across and between nations.

3.1 Strong-form sustainable endowment of urban-based land stock

The empirical analysis requires an extensive degree of data development. The data needed to quantify the land resource endowment available for urban development for each nation over time requires the application of Equation (1) (Section 2), to the data for each of the 12 nations. The model is constructed for each nation’s annual data from the end of 1959 to the near present. The 52 calculations for the 12 nations are subsequently
adjusted with the Hamiltonian developed (previous paper). These calculations produce the marginal rate of production as a shadow price, with the shadow price the rate of capital return occurring at each point of the nation’s endowment frontier ($\rho \Omega_f$). The measure of $\partial \rho \Omega_f$ that endogenously results is conditioned on the dynamics of consumption which is a function of changes in population and agglomeration. The complex matrices of the data developed form the inputs employed in Equations (6) through (8) discussed in part I (previous paper) which outlines the theoretical model development[4].

3.1.1 Strong-form sustainable data analysis. The output of the analysis required to develop the strong-form sustainable endowment of urban-based land stock is presented in Table I. The data as presented is the average over the long run (52 years) for the 12 nations. The circumference depicted in Figure 1(a-l) is the integral of the flow variables per period that are derived using the Hamiltonian which allows the diverse supply and demand variables for land to be considered as conditions of time.

The first and second columns of data presented in Table I are the average measures of urban and total land endowments available per capita of urban population for the 52 time units observed for each nation. The resource measure shown in column 2 is based on the calculations developed using Equation (1). The urban population is used to reflect the allocation of land per capita as a proxy of intensive and extensive land use relative to urbanization. This variable is used as the foundation for substitution in the consideration of varying combinations with fixed capital used in the weak-form model. Comparison of the urban land per capita over time is then adjusted by the agglomeration multiplier using the data series, whose averages per nation are presented in column 4. The difference between the urban land per population as modified by national agglomeration and the total land per capita forms the basis of the average intensity measure ($\zeta$) in the last column of Table I. The intensity measure ($\zeta$) takes the form:

$$\zeta = \left( \Lambda_{U(i)} / P_{U(i)} \right) \left( 1 / A_{i(t)} \right) - \Lambda_{T(i)} / P_{U(i)} \left( d(t) \right)$$  

This technique is based upon resource and distributive factor measures per capita adopted from Romer (2001). It is consistent with the method employed by Barker and Sa-Aadu (2004) to calculate an aggregated Ricardian rent measure and Grissom (2005) in valuing alternative development options. The benefits of these two measures can be observed in the descriptive insights they offer and support the level of choice of resource use available per nations studied.

The nations with the greater land resource endowment show a significantly greater allocation in total per population that may not be consistent with urban land available per capita or intensity of land use. This can be observed for Australia and Canada, which show urban agglomeration factors of 0.59 and 0.38, with urban intensities of only 0.07879 and 0.10891, respectively. This is further associated with diversities in the urban land per capita and total land per capita[5] which can be directly compared to the low land allocation per capita available for Singapore and Hong Kong with aggregated lows of 0.000896 and 0.000230, respectively. It should be noted that a steady or linear progression for the nation’s situation between the density measures does not occur. Both the USA and China reflect more moderate land allocations of land development given their resource stock, they vary, however, in intensity due to population measures and endogenous preferences for agglomeration. This is significant in the consistency in per capita allocations observed in the European nations despite the land and population mass per country. The per capita adjustment in effect is a measure of land...
<table>
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<tr>
<th>Country</th>
<th>Urban land × per urban population $A_{U} / P_{U}$ d(t)</th>
<th>Land × per urban population $A_{T} / P_{U}$ d(t)</th>
<th>Urban agglom. $A_{i}$</th>
<th>Rate of return on resource at sustainable parity $Q_{f}$</th>
<th>Recapture as function of local agglom. $1/Q_{f}$</th>
<th>Discount as a function of local agglom. $s(Q_{f})$</th>
<th>Recapture as globally standardized measure $1/s(Q_{f})$</th>
<th>Discount as globally standardized measure $1/s(Q_{f})$</th>
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**Note:** "Strong-form sustainability constructs and formulations enable the development of local and globally standardized agglomeration and quasi-exhaustible resource measures and the recapture and discount rates that enable their evaluation."
Notes: (a) Ireland: weak- and strong-form sustainability structure; (b) China: weak- and strong-form sustainability structure; (c) Canada: weak- and strong-form sustainability structure; (d) Australia: weak- and strong-form sustainability structure; (e) USA: weak- and strong-form sustainability structure; (f) Norway: weak- and strong-form sustainability structure; (g) Japan: weak- and strong-form sustainability structure; (h) Singapore: weak- and strong-form sustainability structure; (i) France: weak- and strong-form sustainability structure; (j) UK: weak- and strong-form sustainability structure; (k) Hong Kong: weak- and strong-form sustainability structure; (l) Germany: weak- and strong-form sustainability structure

Figure 1. Strong-form sustainability and the resource endowment frontier
use efficiency equivalent to the technology adjustment employed to account for labour and capital efficiency measures in production theory. The inconsistent variance in land to population allocations observed across the nations is assisted by a focus on the urban land per urban population in combination with the measure of agglomeration presented in column 4. Both Singapore and Hong Kong have 100 per cent of population concentrated in large urban areas. Germany had the lowest agglomeration at 8 per cent with low to moderate measures observed in France, China and the UK (all in the mid 20 per cent range). Interestingly, Canada is not significantly different from the USA, 38 and 41 per cent, respectively, whilst Ireland, Norway and Australia, reflect higher agglomeration and urban concentration of population in urban rates (relative to total population than the USA). The broad array in the national emphasis on resource use shows the importance of geographical features and spatial distribution as well as cultural preferences and traditions across nations in pricing land use potentials[6].

The incremental measures characterized by averages presented in columns 2–4 produce the return of resource (capital) \( q \) at any point on the endowment frontier and can be used to specify the rate endogenous at the point of sustainable parity. The sustainable rate for each nation is presented in column 5[7] are used to form the basis for the recapture of endowment loss as needed to achieve the constant capital standard of strong-form sustainability. The basis of the discount and recapture rates needed to value the exhaustible resource in compliance with a constant capital objective can be observed in column 5, with columns 6 and 7 showing the recapture and discount rates needed to achieve the constant resource capital objective based on the local agglomeration effects. Columns 8 and 9 are simply standardized calculations of the number series that support the averages presented in columns 6 and 7 which allow for a direct international comparison. This globally standardized transformation is achieved by dividing the local series by the initial base measure, this sets \( \Omega f | p \Omega f = 1 \) allowing a direct comparison of the changes in endowment per nation across time. This specification also enables the data to be incorporated into a Fisher Separation model and is equivalent to transforming values to fit a normal distribution analysis[8]. This approach allows the dynamic optimal control analysis employed for the strong-form sustainability to be illustrated with Figure 1(a–l).

The average discount and recapture rates shown in columns 6–9 of Table I are the average of the full period dynamic data used to calculate the discount rates and recapture rates. The averages presented in columns 6–9 are calculated at the sustainable weight needed to set the reinvestment and recapture rates. The data series represented by the averages presented in columns 6–9 of Table I form the basis of data used as the input to calculate the sinking fund factors presented in columns 6 and 7 of Table III.

3.2 Weak-form sustainability data and modified Ramsey model

The link of the data presented in columns 6–9 of Table I to the information contained in columns 6 and 7 allows the empirical association of weak-form sustainability with strong-form constant capital concerns. The empirical specification of the Ramsey model promulgated in this paper produces the weak-form sustainability data for each nation. The average measures of output and input for each nation is presented in Table III. To assist in explaining the different measures and rates developed across the nations it is useful to investigate and analyse the relationship of the various variables used to develop the basic and modified Ramsey model used in weak-form sustainability. Groom et al. (2007), identify a conditional sequential association between shifts in output growth with short rates and hence long-term rates. Groom et al. (2007) support this link based on
Lucas's (1978) CCAPM model predicting a positive relation between the levels of real interest rates and expected future consumption growth over time. They then link this relationship to future output growth. Groom et al.'s (2007) findings with support from De Lint and Stolin (2003) show that if the expectations signalled by long-term real interest rates are greater than output growth in the long run, then there is the possibility of an overall slowdown and an associated increase in uncertainty. This implication of the influence on future interest information on reducing the premium puzzles associated with discount rates supports the proposed modifications of the Ramsey-Weitzman-Gollier models used.

3.2.1 Weak-form sustainability data analysis. The combinations of possible variable relationships are tested across the 12 nations. This table presents the relationships of real interest, growth in consumption and growth in output/wealth effect and the relationship of the financial gain/loss to real interest and growth in consumption. These variables form the input for the weak-form sustainability Ramsey model.

Observation of correlation analysis shows that the short-term real rates of interest are significantly associated and moderately to highly correlated. However, the associations between output growth, consumption levels and equity returns as they account for national pricing of uncertainty and cultural concerns per nation considering the impacts of financial gains and loss tend to vary significantly. The extent of these differences has a significant impact on the discount and capitalization rates that are developed for resource valuation across the nations. The specification of the differences is essential in pricing capital costs of alternatives to natural resources. The rates constructed by the Ramsey model for the cost of substitutable capital can then be compared to the rate of resource capital return which is contingent on marginal rate of production/resource use over time. Alternatively, the weak-form measures are contingent on national preferences of consumption, time impatience and concerns with the impact of financial loss or gain on preferences for resource use. The comparison of these two perspectives allows the specification of the most restrictive factors to achievement of sustainable development as will be noted dependent on the specific nation, either the rate of capital or natural resource endowment determine the major constraint on development opportunities.

Column 2 in Table II shows for each nation the correlations between the real interest rate and level of growth in consumption for each period from 1960 to 2010. The association between the real interest rate and growth in output (a proxy for the national wealth effect) is illustrated in column 3. In addition, column 4 shows the

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<th>Nations</th>
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</table>

Table II. Correlation and associations for weak-form sustainability
associations between the growth in consumption and national output growth. As theory suggests, a high correlation between consumption and output growth is illustrated, suggesting a significant association between all nations' wealth effect and short-term consumption. This relationship infers a dominance of present value over future value. This conflicts with the general relationships noted in the strong-form sustainability rate development. Column 5 shows the association of the real interest rate to equity returns for the term of analysis and column 6 shows the correlation measure between equity returns and consumption growth. The issue of utility and consumption growth is the foundation of the Ramsey rule and the evaluation of weak-form sustainable development.

The analysis of the associations between components of the weak-form sustainability and the Ramsey rule show a significant potential for differences across the nations studied. These intra-national distinctions, in part, explain the spread observed in the average long-term measures of the discount and capitalization rates presented in Table III. Observation of demand and financial measures in the model considering the substitution of heterogeneous capital required to achieve intergenerational parity is presented in Table III. The nations with limited natural capital and land tend to produce a lower discount rate suggesting that limited resources relative to high population results in higher prices being required to acquire or control the exhaustible resource. Those nations or markets with resource abundance relative to population support lower valuation of land resources in comparison to nations with limited resources.

Column 2 of Table III presents the average of the time preference series ($\delta$) observed in each nation, where $\delta$ is a function of the level of impatience operating in each society. Higher levels of social impatience infer a dominance of present consumption and wealth effects offsetting a preference for deferred future consumption, producing lower future values. This should contribute to more restrictive capital constraints in the near term. The negative time preference rate suggests a tolerance for deferring benefits into the future. A high impatience reflected in a high-time preference rate should result in a flat (or flatter) yield curve inferring little or zero value associated with differences in present and future value calculations, see Gollier (2010).

As discussed earlier, in order to value and allocate exhaustible resources in a weak-form context, the elasticity of capital-resource substitution series over the multi-generation term is considered. The averages of the factor elasticity per nation are presented in column 3 of Table III. This resource elasticity is used to adjust the measure of changes in periodic consumption of the expected utility discount rate. The averages per nation based on the consumption rate series is presented in column 4. This resource elasticity adjustment alters the utility discount rate, as typically modified by Ramsey's traditional measure of consumption elasticity, enabling an accounting of the effective demand for exhaustible resources. The basic Ramsey model adjusted for capital-resource substitution of weak-form sustainability is further modified to consider the impact of financial gains or losses on resource allocations and sustainability decisions. As per Howarth (2009) and Dasgupta and Heal (1974), this is achieved by incorporating the nationally specific equity return rate into the expected utility component of the Ramsey construct. The average of the equity return rate per nation is presented in column 5 of Table III.

This weak-form model requires further modification to address the concerns of endowment recapture addressed in strong-form sustainability. This is active with the development of the sinking fund factors discussed earlier, linking the data illustrated in Table I with the calculations presented in Table III. The empirical measure of the sinking fund factors, both locally and standardized for global comparison are present
### Table III

| Country   | Time preference rate (\(d\)) | Capital/land income elasticity (\(\eta_{Kx/A}\)) | Periodic rate of utility as function of consumption \(U(C_{x,t})\) | National equity rate \(E(Re)\) | Recapture with local constraints \(t_{SG} \rightarrow |\) | Recapture with global constraints \(t_{SG} \rightarrow |\) | Modified Ramsey rate sustainable/exhaustible resource\(^a\) | Difference rate spread between strong and weak sustainable |
|-----------|-------------------------------|--------------------------------------------|-------------------------------------------------|-----------------|------------------------|------------------------|-----------------------------|-----------------------------------------------|-----------------------------------------------|
| USA       | 0.020000                      | 0.58871                                    | 0.07153                                         | 0.106323        | 0.0533                 | 0.0722                 | 0.07521                     | 0.09411                                      | 0.026613                                      |
| UK        | 0.018163                      | 1.85635                                    | 0.08342                                         | 0.145652        | 0.0780                 | 0.0883                 | 0.09619                     | 0.10648                                      | -0.184973                                     |
| Ireland   | 0.020700                      | 0.82123                                    | 0.07153                                         | 0.071686        | 0.0872                 | 0.0797                 | 0.17086                     | 0.15714                                      | 0.136235                                     |
| France    | 0.034419                      | 1.32756                                    | 0.088690                                        | 0.145570        | 0.0607                 | 0.0823                 | 0.22729                     | 0.24885                                      | -0.191780                                     |
| Germany   | 0.029200                      | 2.93683                                    | 0.04640                                         | 0.103515        | 0.0688                 | 0.0879                 | 0.25480                     | 0.27389                                      | -0.276923                                     |
| Norway    | 0.042000                      | -2.3782                                   | 0.06963                                         | 0.192300        | 0.0481                 | 0.0579                 | 0.01273                     | 0.00290                                      | -0.162070                                     |
| Canada    | 0.029740                      | 1.98922                                    | 0.05505                                         | 0.129080        | 0.0520                 | 0.0565                 | 0.20596                     | 0.21048                                      | 0.061824                                     |
| Australia | -0.040770                     | 0.8751                                     | 0.04796                                         | 0.134543        | 0.0462                 | 0.0673                 | 0.04288                     | 0.05392                                      | 0.044209                                     |
| China     | 0.040400                      | 0.24766                                    | 0.10436                                         | 0.210422        | 0.0785                 | 0.0734                 | 0.08894                     | 0.08377                                      | 0.065458                                     |
| Japan     | 0.029300                      | -12.8813                                   | -0.02406                                        | 0.118835        | 0.0842                 | 0.0885                 | 0.14775                     | 0.15205                                      | -0.242733                                     |
| Singapore | 0.030625                      | 5.93881                                    | 0.10192                                         | 0.196756        | 0.0607                 | 0.0823                 | 0.81570                     | 0.83726                                      | -0.377130                                     |
| Hong Kong | 0.027000                      | -3.84824                                   | 0.11431                                         | 0.237209        | 0.0865                 | 0.0912                 | 0.43075                     | -0.42605                                     | -0.247985                                     |

**Notes:**
- The positive rates in the spread between the modified Ramsey rule calculations and the constant capital measures suggest that the supply of land is sufficient in relation to the level of consumption, time preference and risk pricing observed in a given market/nation. This reinforces expectations of development at the extensive margin as opposed to projections of highly intensive development. Land as a distributive resource is the relatively available resource and alternative capital is the limiting constraint on development. The negative, especially high negative differences based on the spread between rate of change in discount rates based on the Ramsey rule and the strong-form land/capital rate illustrate those markets/countries that require or prefer high-intensity land use development. Land becomes the dearer or more restrictive resource for development, the cost of alternative capital affording the less constraining factor on development. These relationships are illustrated in Figure 1(a-l). This is directly observed in the land structure and pattern of the built environment in Singapore and Hong Kong. Alternatively, in jurisdictions with cultural preferences for low intensive development, constrained urbanization, green space and strong land use regulation observed for France, Germany and the UK.
in columns 6 and 7, respectively. The average sinking fund presented in Table III and developed for each period included in the dynamic programming underlying the analysis used to create the recapture weighting multiplier \( (a) \) for each marginal cost measure, \( \partial p N f (i) \) defining the endowment frontier. The measures presented in columns 6 and 7 are based on the \( \bar{m} \) measure derived to produce the sinking fund factors at the recapture weighting needed to achieve the sustainability objectives. The local sinking fund rate, \( l S f k | a \) and the global rate of \( l S G k | a \), illustrated in columns 6 and 7, respectively, are used to calculate the average local and global discount rates shown in column 8. These rates are the averages calculated for the total period for each of the 12 nations. The measures in column 8 form the capitalization rates for each of the nations comprised on the discount and recapture rates allowing for the consideration of consumption preferences and resource maintenance and recapture over time and across nations. The rates are developed based on the local economic and resource constraints and are adjusted to enable direct and standardized comparisons across the nations studied. The global Ramsey rate is used to compare with the strong-form sustainable rate of resource endowment recapture over each nation.

4. Results and discussion of strong- and weak-form sustainability across national economies

The comparison of weak- and strong-form sustainability in the Fisher Separation format are illustrated in Figure 1(a-l). This approach allows a concise presentation in the analytics of the dynamic programming of the ten equations developed for each nation’s empirical measures (previous paper). As the figure illustrate, different capital-resource restraints are observed and the potential for implementing strong-form/weak-form sustainability standards or a combination of them can be identified. Ireland, China, Canada, Australia and the USA, show a potential for the exercise or capacity to practice and implement strong-form sustainability. This potential for strong-form procedure is possible because the land resource is comparatively cheaper than the capital cost incurred substituting alternative capital as measured with the use of the weak-form Ramsey model. As illustrated by Figure 1(a-e), the capital required to achieve high levels of intensive development and urbanization in the near term are more constraining than the marginal production cost or rate of return on resource capital. The difference in capital forms is measured by the integral of their sequential spreads over time. The incremental differences in the marginal rates developed from the Ramsey model for alternative capital and the marginal rate of productivity for the resource endowment identify which component of urban land development is the most significant constraint. If the spread between the resource endowment \( ER_{pQ} (j) \) and the alternative capital costs \( ER (s) \) is positive \( (ER_{pQ} (j) - ER (s) > 0) \), then the returns and opportunity costs of the alternative capital are the most restrictive decision factor in cost-benefit analysis. If the difference is negative \( (ER_{pQ} (j) - ER (s) < 0) \), then the level of the available resource stock is the most restrictive variable.

This relationship can vary over time within a given nations sustainability structure. As noted for the five nations illustrated in Figure 1(a-e), the \( (ER_{pQ} (j) - ER (s) > 0) \) scenario dominates up to point where the weak-form value and the resources endowment are equal \( (ER_{pQ} (j) = ER (s) \) or \( (ER_{pQ} (j) - ER (s) = 0) \). For Ireland this intersection occurs at a standardized measure of 17-18 units. This regime switch from the substituting costly alternative capital for available resources to one of relative lower cost alternative capital for more restrictive natural capital is incurred about three-quarters into the full 52 period time horizon studied. Within this time horizon,
the sustainable level is indicated by the vertical line indicated at 25 units. This shows that the policy maximizing measure may vary from the empirical implications given the constraints of the resource endowment and the preferences revealed in the rate structure.

The situations between the $E(R_{pM})$ and $E(R|s)$ relationships in Ireland, China, Canada, Australia and the USA shows that the average value difference inferring a lower capital and recapture cost for property over the cost of alternative capital cost in the short-term results in the concave quadratic curve depicting the dominance of property (positive measure) as a distributive input over capital in the near term. The negative component of the capital restriction curve shows that alternative capital inputs will dominate the natural resource as the more feasible input to employ in the long run future. As illustrated in the future component of the Fisher model, capital values exceed resources, where the latter becomes the more expensive factor of urban production.

The situation of Norway’s sustainability structure is the nearest example of a possible equilibrium situation between weak- and strong-form sustainability. This is indicated by the capital restrictive calculation approaching zero. Equilibrium between the two perspectives would suggest that the optimality possible with the use of alternative capital measured with the use of the modified Ramsey model appropriately recaptures the land resource lost with the sinking fund and reinvestment rates incorporated in the analysis. The estimations for Australia and the USA are approaching the equilibrium measures, but still reflect positive capital restrictions for the near present term (first quarter of total time frame). Canada denotes a change about half way into the total time frame.

The remaining nations studied Japan, Singapore, France, the UK, Hong Kong and Germany illustrate situations in which the land resource is treated as a more expensive factor in urban development based on the inferred cost of capital return ($E(R_{pM}) - E(R|s) < 0$). All of these markets show that the weak-form values, based on the Ramsey model produce capital rates that exceed the strong-form sustainable resource endowment return rates. The opportunity cost of natural capital defines the restrictive development input in each of the nations illustrated in Figure 1(f-l). The capital restriction rates in each of these nations are negative over the entire range approaching zero in the present term. The preference or occurrence of capital substitution dominating land as a development input reflects variant causes or relationships across nations and over time. In the context of Japan, Singapore and Hong Kong, the physical limitations of the resource endowment relative to populations forms the basis for restrictive resource costs and the use of alternative capital substitutes for resources. The land constraints observed in the comparative positions of land resources relative to capital, is given the quantitative constructs developed in Section 2.

In contrast to the resource constraints observed in the Asian nations, the European countries emphasis on using social and cultural preferences to define the intensity of resource use in effect mandates the substitution of alternative capital for resources to achieve intergenerational parity. This is observed in the relationships for France, the UK and Germany as illustrated in Figure 1(i, j and l), respectively. The conjecture of sustainability being defined as functions of the cultural preferences of land use intensity and urbanization revealed in the structure of the economies and land use patterns is conditioned on the low urban agglomerations effects observed in these three European nations, given their resource endowments relative to population and behavioural relations to the possibility of financial gains and losses. For example, Germany, one of the larger resource endowed nations in Europe, has the lowest urban agglomeration measures of the 12 nations considered.
5. Conclusion
The paper has extended the theoretical insights of applying discount rate development to sustainability concepts, to construct rates structures appropriate for the valuation of exhaustible resources, with a conceptual emphasis and empirical application conducted on urban land development. The theoretical formulation of discount and capitalization rates, as identified in the previous paper, were empirically applied and tested. This empirical application employed data from and developed for 12 diverse national economies. Alternative levels of strong- and weak-form sustainability are observed across the 12 nations studied. The potential for and degree of strong-form or weak-form sustainability application in each nation enabled the identification as to whether alternative capital (as defined by the modified Ramsey model used per nation or the marginal rate of resource return as defined by strong-form objective of a constant natural resource endowment) can identify which form of capital becomes the major constraint on the resource valuation and allocation decision appropriate in each nation. The findings showed constraints on nation resource endowments relative to population needs and the culture preferences endemic across nations.

The findings serve as a basis for future research on the optimal levels of sustainable development appropriate for different nations, the impact of the timing and level of capital re-switching associated with the application of strong- or weak-form sustainability and the development of rate and risk measures that can assist in the consideration of sustainable resources as a distinct asset class. The findings also shed important light on the public policy associated with urban development, presenting useful metrics regarding the relative level of resource consumption across the major international economies. It can be seen that many decisions regarding land use, such as the relatively restrictive planning regime of the UK, have less to do with practical space concerns and more to do with the economic and legal outworkings of complex societal norms. In the context of sustainable development this is important, as the figures would suggest that in the UK context, for example, large scale house building could be countenanced, whilst complying with weak-form sustainable principles, within international benchmarks of resource depletion. Alternatively, restriction of such activity, often blamed for housing shortages and spiralling house prices and often characterised as NIMBYism and overly nostalgic economic myopia, could find a new legitimacy as a mechanism to deliver strong-form sustainability, linking to a more traditional “conservative custodian” view of national land management. Delivering the sustainability agenda requires the removal of the “temporal proximity bias” in resource use decision making whilst avoiding any “morally repugnant” bias against those in need (of resources and their products) in the present. It must also try to balance the needs of mankind against those of “nature” and negotiate acceptable compromises if any form of workable consensus is to be reached. If the decisions facing policy makers (including industry actors operating policies of corporate social responsibility) are to be hard headed and factually informed, then temporally neutral valuation and pricing methodologies are essential, as is empirical evidence base for past, current and likely future consumption, depletion and replacement behaviour. This paper offers insights, evidence and a way forward in addressing these issues.

Notes
1. For a full discussion see Grissom (2005).
2. See Barker and Sa-Aadu (2004) and Grissom (2005) for more detailed discussion of this concept and associated topics and issues.
3. These nationally specific databases will be identified when they are directly employed.
4. Given the magnitude of these spreadsheets and files, they are not presented in the paper, but are available on request.
5. Canada and Norway required adjustments for arctic lands that reduced the land surface area available for rational economic purposes, especially as viable for urban development, see Barker and Sa-Aadu (2004) for a development of the land and space available for urban land use and development.
7. A test was conducted to investigate the association of urban land and total land to urban population with the strong-form rate of return to land resources. The test shows an $R^2$ of 90.5 and 70.6 per cent, respectively. These associations support the links between the data developed in the weak-form rate structure.
8. See Grissom (2005) and Howarth (2009) for in-depth support for this procedure in the analysis of sustainable and environmental resources.

References
Further reading


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