The Impact Of Short-life Dwellings On the Total Costs To Sustain Housing

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Summary: This paper uses a simulation model based on classical population dynamics to make exploratory estimates of the maximum impact of short-life dwellings on the total costs to sustain housing. Data and parameters of long-life dwellings are based on a typical New Zealand dwelling of lightweight timber framing. The size and quality of short-life dwellings are set to be the same as that for long-life dwellings and the service life of short-life dwellings is assumed to be 50 years, the minimum required by the New Zealand Building Code. If the entire simulated housing stock of long-life dwellings is replaced with short-life dwellings, then the total average costs to sustain housing are almost 13% greater when the housing stock expands at 1.5% per year and 24% greater when the housing stock is stationary. Exploratory estimates based on realistic scenarios of depreciation indicate there are no reductions in the national average costs to sustain dwelling services after adjustment for depreciation.

Keywords: Dwellings, structural system, service life, refurbishment, national average costs

1 INTRODUCTION

The New Zealand Building Code requires components that contribute to structural stability to have a service life of 50 years (Building Industry Authority 1992). There are two issues here. The first issue is that innovative structural systems need only comply with a service life that falls short of the 90 years average service life of the housing stock as estimated by Johnstone (1994) and well short of the potential service life of most dwellings in the housing stock. Lightweight timber framing has been the predominant structural system used by New Zealand dwellings for over 120 years (Nana 1981) and this structural system has a potential service life of 180 years under New Zealand's climate as illustrated by Kemp House constructed in 1821 (Salmond 1986). Traditional materials used for structural systems such as timber, brick, stone, and concrete have demonstrated an ability to match and exceed a service life of 180 years in other countries (Brand 1997). The second issue is that the most reliable predictor of durability is a successful history of performance. Predictions of the durability of building components based on accelerated aging are fraught with difficulties (Masters 1987). In a recent study of accelerated testing, Rimestad (1998) concludes that field failure data should be used whenever possible to guide the design of accelerated tests. This is not possible with building materials, or combination of materials, that have yet to demonstrate a track record. There is therefore a risk that the projected service life of structural systems based on accelerated aging tests fall short of the minimum service life required by the New Zealand Building Code.

The prudence of allowing structural systems with unproven durability to enter the housing stock and setting a minimum service life that falls well short of the potential service life of most current dwellings needs to be examined for the following reasons. Refurbishment reduces the total costs to sustain housing by extending the service life of dwellings and thereby reducing the replacement rate of the housing stock. In a previous paper, the author estimated that refurbishment of New Zealand dwellings reduces the total costs to sustain housing by at least 15% (Johnstone 2001). The durability of the structural system used by dwellings limits the service life of dwellings and hence restricts potential reductions in total costs. If the durability of the structural systems of new dwellings does not match that of the current housing stock, then future generations will be subject to increased costs to sustain housing.

This paper uses a simulation model based on classical population dynamics to make exploratory estimates of the maximum impact of short-life dwellings on the total costs to sustain housing. Data and parameters of long-life dwellings are based on a typical New Zealand dwelling of lightweight timber framing. The size and quality of short-life dwellings are set to be the same as that for long-life dwellings and the service life of short-life dwellings is assumed to be 50 years, the minimum required by the New Zealand Building Code.

2 THE MODEL

2.1 Description of simulation model

The simulation model can be visualised as a multi-deck stack where the level of each deck represents the age of a dwelling cohort. A new dwelling cohort enters the top deck of the stack at the start of each time interval and previous dwelling cohorts move progressively down to the next deck. Dwellings are lost from each dwelling cohort over each time interval, the level of which is determined by a probability of loss schedule that forms the first column of a standard life table. The construction of life tables is described in any textbook on population dynamics, for example Keyfitz & Beekman (1984), and Johnstone (2000) examines a selection of analytic, life table, and stock and flow models that can be used to estimate the mortality of housing. New dwelling cohorts continuously replace total dwelling losses of all ages. If the housing stock is stationary and stable, then each new dwelling cohort comprises replacement construction only. When the housing stock undergoes expansion, each new dwelling cohort comprises both replacement construction and new-build construction that adds to the size of the housing stock. The size and quality of each dwelling within the simulated housing stock are set to be homogeneous for the sake of model simplicity. Different typologies of dwellings can be addressed by constructing separate simulation models.

2.2 Dwelling services

A physical dwelling is in itself but a means to an end. We are ultimately concerned with the magnitude and quality of the flow of dwelling services that a dwelling can provide. The model in this paper therefore includes the flow of dwelling services provided by housing stock to enable estimates of the costs to sustain each unit of dwelling services. Dwelling services include only those services rendered by improvements to land. The services of land are excluded in order to avoid confounding separate issues of economic depreciation. The quantity of dwelling services supplied are expressed in units of service year equivalents (sye), the dwelling services provided by a dwelling over one year adjusted for economic depreciation. The proxy for benefits can be converted into dollar terms by multiplying by its price.

Standard notation of classical population dynamics is used throughout this paper. Dwelling service years (L_x) provided by each dwelling cohort over the age interval x to $(x + 1)$ are given by

$$L_x = l_x - d_x . a_0 \qquad (1)$$

where l_x is the number of dwellings from an original dwelling cohort, l_0, which survive to the age x, d_x is the number of dwelling losses from a dwelling cohort of age x over the age interval x to $(x + 1)$, and a_0 is the average number of dwelling service years provided by dwellings lost over the age interval x to $(x + n)$. The value of $a_0 = ½$ when $n = 1$ gives sufficiently precise results for the purposes of simulating the dynamics of a housing stock.

Stock losses (d_x) over each age interval are given by the product of the surviving dwellings at the start of each age interval (l_x) and the probability of loss function $\mathrm{P}(x, r)$:

$$d_x = l_x .\ \mathrm{P}(x,r) \qquad (2)$$

where r is the annual expansion rate of the housing stock. The probability of loss function $\mathrm{P}(x, r)$ is explained in more detail in Section 3.1.

Total dwelling losses of all ages that are lost over the time interval t to $(t + 1)$ are replaced by replacement construction. If the housing stock undergoes expansion, then new dwelling entries include not only replacement construction but also new-build construction. Dwelling entries over the time interval t to $(t + 1)$ are given by

$$l_0 = \sum_{x=0}^{w} d_x + P_{t+1} - P_t = \sum_{x=0}^{w} d_x + (\exp r - 1)P_t = \sum_{x=0}^{w} d_x + (\exp r - 1)\sum_{x=0}^{w} l_x \qquad (3)$$

where P_t is the size of the housing stock at the start of the time interval t to $(t + 1)$ and P_{t+1} is the size of the housing stock at the start of the time interval $(t + 1)$ to $(t + 2)$. The size of the housing stock at time t (P_t) is simply the sum of all the dwelling cohorts that are standing at time t.

Dwelling services are adjusted for depreciation. The flow of dwelling service year equivalents (S_e) provided by a housing stock over the time interval t to $(t + 1)$ is expressed as follows:

$$S_e = \sum_{x=0}^{w} L_x . \mathrm{D}(x) \qquad (4)$$

where $\mathrm{D}(x)$ is an economic depreciation factor that is a function of the age x of dwelling cohorts. This depreciation factor is discussed in more detail in Section 3.2.

The service loss index (SLI) gives the average quality of dwelling services provided by a housing stock expressed in units of dwelling service year equivalents per dwelling per year (sye/dg/yr):

$$\text{SLI} = \frac{S_e}{\sum_{x=0}^{w} L_x} \qquad (5)$$

The service life span of a housing stock (ω) is defined here to be that age beyond which less than 0.1% of the oldest dwelling cohort still stands and provides dwelling service. This definition based on Shryock *et al.* (1973) enables sensible comparisons of the service life span of different housing stocks as exceptional dwellings are excluded.

2.3 Total average costs and national average costs

The costs to sustain housing are expressed in construction units (cu), the cost to construct a standard New Zealand house as described in Section 3.3. The proxy for costs can be converted into dollar terms by multiplying by its price. The real costs of all forms of construction, maintenance, refurbishment, and demolition work are assumed to remain constant over time. Under this assumption the long run supply curve of the construction industry is perfectly elastic and returns to scale are constant.

The total average costs to sustain housing over the time interval t to $(t + 1)$, (C_t), is the sum of the costs of new-build construction (C_{new}), annual maintenance (C_{maint}), refurbishment (C_{refurb}), demolition (C_{dem}), and replacement construction (C_{replace}) divided by the sum of dwelling service years provided over the time interval:

$$C_{\text{total}} = \frac{C_{\text{new}} + C_{\text{maint}} + C_{\text{refurb}} + C_{\text{dem}} + C_{\text{replace}}}{\sum_{x=0}^{w} L_x} \qquad (6)$$

The units of total average costs to sustain housing are in construction units per dwelling per year (cu/dg/yr).

The costs of new-build construction over the time interval t to $(t + 1)$ is given by the number of new-build entries to the housing stock from equation (3):

$$C_{\text{new}} = (\exp r - 1)\sum_{x=0}^{w} l_x . \text{I}_{\text{new}} \qquad (7)$$

where I_{new} is an index of the costs to construct a dwelling in construction units per dwelling (cu/dg).

For the purposes of this paper, maintenance is defined here as comprising all that work undertaken to retain the provision of essential services such as weather tight shelter, security, lighting, heating, water supply, and waste disposal. The costs of maintenance over the time interval t to $(t + 1)$ is given by:

$$C_{\text{maint}} = \sum_{x=0}^{w} L_x . \text{M}(x) \qquad (8)$$

where $\text{M}(x)$ is a function of maintenance in construction units per dwelling service year (cu/sy).

Refurbishment is defined here as the resurfacing or replacement of building components which results in a reversal of the economic depreciation of dwelling services. Refurbishment may take place a number of times over the service life of a dwelling. For the sake of model simplicity, the duration between successive refurbishment cycles for each component is assumed to be regular.

Not all dwellings undergo refurbishment when due. Deferral of refurbishment may be advantageous for budgeting purposes, but can lead to a hastening of physical depreciation if an injudicious selection of deferral has been made. Some forms of physical depreciation are incurable in that the costs of reversing that depreciation by undertaking refurbishment exceed any increase in value to the property. It is therefore in the best rational interests of a property owner not to undertake such refurbishment.

Dwellings depart from the housing stock at all ages (Johnstone 2000). These departures are largely the result of land use succession where increases in the value of land and economic depreciation of improvements make it viable for a property owner to demolish and replace a dwelling or redevelop the site for an alternative use. A greater proportion of each dwelling cohort departs from the housing stock over each successive age intervals (Johnstone 2000) and hence an increasing proportion of dwelling cohorts still standing at the start of each age interval is unlikely to undergo refurbishment over successive age intervals. The proportion of dwellings (P_y) within each cohort that undergo refurbishment at each cycle is therefore set to be the ratio of the dwellings still standing at the end of a refurbishment cycle of duration z to that standing at the start of the cycle

$$\text{P}_y = \frac{l_{y+z}}{l_y} \qquad (9)$$

where y is the age at which refurbishment takes place.

The costs of refurbishment over the time interval t to $(t + 1)$ are given by

$$C_{\text{refurb}} \quad = \quad l_a.\text{R}_a.\text{P}_a + \; l_b.\text{R}_b.\text{P}_b \; + ... + \; l_q.\text{R}_q.\text{P}_q \tag{10}$$

where l_a, l_b, …, l_q are the number of surviving dwellings within a dwelling cohort of ages $y = a, b, \ldots, q$; $R_{\alpha}, R_{\beta, \ldots}, R_{\alpha}, R_{\beta, \ldots}, R_{\theta}$ are indexes of the costs to undertake refurbishment at the ages $y = a, b, \ldots, q$; and $P_{\alpha}, P_{\beta, \ldots}, P_{\theta}$ gives the proportion of each dwellings within a dwelling cohort which undergoes refurbishment at the ages of $y = a, b, \ldots, q$.

The number of departures from the housing stock from equation (3) gives the costs of demolition:

$$C_{\text{dem}} \quad = \quad \sum_{x=0}^{w} d_x.\text{I}_{\text{dem}} \tag{11}$$

where I_{dem} is an index of the costs of demolition in construction units per dwelling (cu/dg).

The number of replacement entries to the housing stock from equation (3) gives the costs of replacement construction:

$$C_{\text{replace}} \quad = \quad \sum_{x=0}^{w} d_x.\text{I}_{\text{new}} \tag{12}$$

where I_{new} is an index of the costs to replace a dwelling in construction units per dwelling (cu/dg).

The national average costs (NAC) to sustain dwellings services after adjustment for economic depreciation is given by

$$\text{NAC} \quad = \quad \frac{C_{\text{total}}}{\text{SLI}} \tag{13}$$

The units of national average costs to sustain dwelling services are in construction units per dwelling service year equivalents (cu/sye).

3 PARAMETERS AND DATA

3.1 Probability of loss schedule

Johnstone (1994) established that the mortality of New Zealand housing stock between 1858 and 1980 had been a function not only of age, but also the annual expansion rate (r) of the housing stock. The best-fit probability of loss schedule $P(x,r)$ for New Zealand housing stock is given by a probability of loss schedule which applies for a stationary and stable housing stock and a multiplier function of the annual expansion rate of the housing stock (Johnstone 2000):

$$\text{P}(x,r) \quad = \quad l_x.q_x.(1+78.6r)^{0.70} \tag{14}$$

Each column in a standard life table is a transform of another column (Keyfitz & Beekman 1984). The probability of loss schedule (q_x) in the above equation is a transform of the stock losses schedule (d_x):

$$d_x = \text{INT}\left[\frac{l_0.s}{s\sqrt{2p}} e^{-\frac{1}{2}[(x-m+0.5)/s]^2} \right] \tag{15}$$

where INT is a function that truncates fractional stock losses to the nearest integer, l_0 is initial dwellings entries to a life table at age 0 (the radix of a life table), s is an adjustment factor that ensures the sum of truncated dwelling losses over the service life span of a dwelling cohort equals the initial dwelling entries l_0, s *is* the standard deviation of stock losses from a dwelling cohort within a stationary and stable housing stock, and μ is the mean age of stock losses from a dwelling cohort within a stationary and stable housing stock.

The standard deviation and mean age of stock losses from a cohort of long-life dwellings within a stationary and stable housing stock are set to be 31.08 years and 130 years respectively. The mortality of short-life dwellings is set to be the same as that for long-life dwellings over the age interval 0 to 49 years. Dwellings within each cohort that are still standing at the age of 49 years depart from the housing stock over the age interval 49 to 50 years.

The average annual expansion rate of the New Zealand housing stock has averaged 1.5% per year over the past decade (Statistics New Zealand 1998). Positive net migration has formed the major source of additional household formation because the fertility of the natural population has declined since the 1960s to the extent that the natural population now barely replaces itself.

The average number of persons per household (pph) has declined from over 6 pph at the start of the 20^{th} century to 2.9 pph at the last census in 1996. Further decreases over the next number of decades are likely to be gradual. The annual expansion rates of 1.5%, 1.0%, 0.5%, and 0% per year are selected for the purposes of estimating the maximum impact of short-life dwellings entering the housing stock.

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3.2 Economic depreciation of dwelling services

An empirical study of the economic depreciation of dwelling services provided by New Zealand housing stock has yet to be carried out. Extensive literature surveys of empirical studies of economic depreciation of dwellings by Malpezzi *et al*. (1987) and Baer (1991) do not provide satisfactory guidelines which can be applied with confidence to New Zealand housing stock as no study estimates the economic depreciation of dwelling services or rent (excluding rent for land) over the full service life of dwellings. A depreciation schedule based on first principles is therefore used instead.

Economic depreciation of dwelling services is due to a combination of physical degradation and obsolescence. A survey of the physical condition of a representative sample of 465 New Zealand dwellings has shown that the average costs of outstanding maintenance (many of these items are refurbishment as defined in this paper) generally rise with house age and the condition of the average house appears constant beyond an age of around 60 years as a consequence of renovation of the older housing stock (Clark *et al.* 2000). Economic depreciation due to physical degradation would therefore decline to a threshold level with fluctuations in the process due to reversals in depreciation after undergoing refurbishment. The rate of economic depreciation due to obsolescence would be gradual over the first years of life of a dwelling, would increase during the middle years, and then diminish in later years due to a vintage effect. The combination of economic depreciation due to physical degradation and obsolescence would follow a fluctuating reversed S-shaped curve that declines to a threshold value. Fluctuations in economic depreciation are ignored for the sake of simplification and a reversed S-shaped curve function is taken to be a likely schedule of economic depreciation. Reversed S-shaped curve depreciation is based on the logistic curve

$$Q(x) = \frac{K}{1 + ce^{-r_m x}}, \quad c = \frac{K}{Q(0)} - 1 \qquad (16)$$

and

$$D(x) = \frac{P - Q(x)}{P - Q(0)} \quad \text{for} \quad P \geq Q(x) \qquad (17)$$

The units of D(x) are dimensionless and $0 \leq D(x) \leq 1$. For convenience, P = 10,010, Q(0) = 10, and r_m is varied.

In the absence of empirical data on the value of the dwellings services provided by the oldest dwellings in the housing stock immediately prior to departure from the housing stock, the threshold value of the depreciation function D(ω) is set to a value of 0.50 and 0.25. The same schedules of depreciation are set to apply for long-life and short-life dwellings.

The probability of loss of dwellings increases as the expansion rate of the housing stock increases and there is a corresponding decrease in the average service life and service life span of the housing stock. A decline in the value of dwellings services and hence a decline in capital value would hasten departures from the housing stock. An increase in the rate of economic depreciation of dwelling services would therefore accompany an increase in the probability of loss of dwellings.

Straight-line depreciation is included for comparison:

$$\begin{aligned} D(x) &= 1 - \frac{(x+1)}{w_p} \quad &\text{when} \quad x < w_p \\ D(x) &= 0 &\text{when} \quad x \geq w_p \end{aligned} \qquad (18)$$

where ω_p is that age at which D(ω) = 0.50 and D(ω) = 0.25.

3.3 Costing data

The costs of new-build and replacement construction of long-life dwellings are based on the National Modal House (NZIV 1996) which comprises a typical New Zealand dwelling of lightweight timber framed construction with a floor area of 100 m^2. The floor and sub-floor structure is particleboard on timber joists, bearers, and timber piles. The wall cladding is fibre cement planks, windows and exterior doors are aluminium, and the roofing is galvanised mild steel. Interior linings are gypsum board. The costs of the Modal House are $94,110.40 in June 1997 New Zealand dollars. This paper includes vinyl flooring (10 m^2) in the kitchen and a 3-coat polyurethane floor finish in all other areas which brings the total average costs of a long-life dwelling to NZ$95,155.40.

Dufaur (2001) has compared the costs of five alternative structural systems to lightweight timber framing as used in New Zealand. Two of these alternatives, lightweight steel framing and wood-fibre panels, use non-traditional building materials which have yet to demonstrate a service life which matches the 90 year average service life of the housing stock. Although cost savings of up to 3% can be achieved by using either lightweight steel framing or wood-fibre panels to construct a dwelling to the same size and quality as the National Modal House (Dufaur 2001), the costs of short-life dwellings are taken to be the same as that for long-life dwellings because these cost savings fall within the margin of error. The possibility of future reductions in costs of lightweight steel framing and wood-fibre-panels are also examined.

Estimates of the costs of maintenance are based on the maintenance records of 25 New Zealand Housing Corporation dwellings that date back between 24 and 39 years prior to 1988. Table 1 sets out the average annual costs of maintenance based on these records. The total annual costs of maintenance ($269.91) are set to apply for both long-life and short-life dwellings and these costs are assumed to remain constant over the full service life of dwellings.

Table 2 lists the cycles and costs of refurbishment including removal and disposal of existing components and making good to collateral damage in the process. The cycles and costs apply for both long-life and short-life dwellings with exceptions as listed. Refurbishment of short-life dwellings is not undertaken when the remaining service life of dwellings is shorter than the refurbishment cycle *z*. The replacement of component costs are based on the schedule of the National Modal House (NZIV 1996) and pricing data provided by Rawlinsons Group (1997). The cost of demolition and disposal of both short-life and long-life dwellings is $1,700. Recycling of building materials is not examined in this paper.

Table 1. Average annual costs of maintenance

Item	*Cost (1997 NZ$)*
Electric range: repairs	26.20
Hot water cylinder: repairs	20.52
Electrical: outlets, lighting, meter board, minor wiring	27.01
Taps: washers, replacement	10.58
Waste pipe work: clear blockages, repair soil pipe junctions	13.09
Water supply	15.90
Drainage system: clear blockages, repair soil line	23.18
Spouting and downpipes: clean out, repair	26.24
Flashings: repair	3.24
Hardware: door locks, window catches	6.75
Glazing: repairs to windows	4.08
Miscellaneous	56.63
Unspecified due to illegibility or inadequacy of entry on card	36.49
Total	269.91

Table 2. Costs of refurbishment

Component	*Short Life Dwellings*	*Propn (%)*	*Cost (1997 NZ$)*	*Cycle z (years)*	*Source of cycle and proportion*
Substructure	no	15	1,326.87	40	Tucker & Rahilly (1990)
Wall framing	no	15	1,246.02	40	Tucker & Rahilly (1990)
External cladding & trim	no	100	5,611.42	50	Page (1997)
Internal linings & trim	no	30	2,138.27	40	Tucker & Rahilly (1990)
Alumin. Windows & doors	no	100	7,975.61	40	NBA Consultants (1985)
Fittings: kitchen, bathroom	yes	100	8,307.88	25	NBA Consultants (1985)
Combustion heater	no	100	3,472.78	40	NBA Consultants (1985)
Roofing	no	100	4,530.88	50	Page (1997)
PVC spouting, downpipes	yes	100	1,128.60	20	NBA Consultants (1985)
Plumbing piping & traps	no	100	1,812.82	40	NBA Consultants (1985)
Plumbing fittings	no	100	2,825.88	40	NBA Consultants (1985)
Electrical: wiring	no	50	1,452.42	40	Tucker & Rahilly (1990)
Electrical: stove & HWC	yes	100	1,477.80	25	NBA Consultants (1985)
Prep & painting interior	yes	100	3,575.09	8	Tucker & Rahilly (1990)
Prep & painting of roof	yes	100	1,117.80	7	Page (1997)
Prep& painting of cladding	yes	100	1,705.72	9	Page (1997)
Floor covering: vinyl sheet	no	100	360.00	30	NBA Consultants (1985)
Polyurethane floor finish	yes	100	1,027.40	10	NBA Consultants (1985)

4 RESULTS

Housing stocks are comprised entirely of either long-life or short-life dwellings. Table 3 summarises the results for housing stocks that are subject to reversed S-shaped curve economic depreciation with a threshold depreciation of D(ω) = 0.50. The total average costs of short-life dwellings (cu/dg/yr) are 23.9% greater than that for long-life dwellings when the housing stock is stationary and are 12.7% greater when the expansion rate r = 1.5%. Refurbishment costs of short-life dwellings are smaller, but replacement costs are much greater for all expansion rates. Refurbishment of long-life dwellings forms a larger proportion of total average costs and this proportion decreases by a greater extent as the expansion rate increases (60.0% when r = 0% and 36.9% when r = 1.5%) compared to short-life dwellings (29.4% when r = 0% and 23.1% when r = 1.5%).

The national average costs to sustain short-life dwellings (cu/sye) are 4.4% greater than that for long-life dwellings when the housing stock is stationary and are 5.8% greater when r = 0.5%. Increases in national average costs peak at 7.8% when r = 0.5%. The increases in national average costs are substantially less than increases in total average costs at low expansion rates due to short-life dwellings undergoing much less depreciation over a shorter service life. The mean ages of short-life and long life dwellings are 24.7 and 68.1 years respectively when the housing stock is stationary compared to 21.7 and 36.3 years when r = 1.5%.

Table 4 tabulates the national average costs for housing stocks that are subject to straight-line curve economic depreciation with a threshold depreciation of D(ω) = 0.50. Increases in national average costs to sustain short-life dwellings are greater when subject to straight-line depreciation because short-life dwellings undergo relatively greater depreciation. The national average costs to sustain short-life dwellings (cu/sye) are 7.9% greater than that for long-life dwellings when the housing stock is stationary and are 6.6% greater when r = 1.5%. Increases in national average costs peak at 9.3% when r = 0.5%.

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Table 3. Results for reversed S-shaped curve depreciation D(w) = 0.50

	R = 0%		*r = 0.5%*		*r = 1.0%*		*r = 1.5%*	
	(value)	*(%)*	*(value)*	*(%)*	*(value)*	*(%)*	*(value)*	*(%)*
Long-life dwellings								
Average service life (years)	129.3		104.0		97.2		93.1	
Service life span (years)	180.0		169.0		155.0		148.0	
Mean age (years)	68.1		49.0		41.6		36.3	
New-build costs (cu/dg/yr)	0.0000	0.0	0.0050	16.7	0.0101	30.1	0.0152	41.0
Maintenance costs (cu/dg/yr)	0.0028	10.6	0.0028	9.4	0.0028	8.5	0.0028	7.7
Refurbishment costs (cu/dg/yr)	0.0161	60.0	0.0147	48.8	0.0141	42.2	0.0136	36.9
Demolition costs (cu/dg/yr)	0.0001	0.5	0.0001	0.4	0.0001	0.3	0.0001	0.3
Replacement costs (cu/dg/yr)	0.0077	28.9	0.0075	24.7	0.0063	18.9	0.0053	14.2
Total average costs (cu/dg/yr)	0.0268		0.0302		0.0335		0.0370	
Service loss index (sye/dg/yr)	0.837		0.901		0.914		0.929	
National average costs (cu/sye)	0.0320		0.0335		0.0366		0.0398	
Short-life dwellings								
Average service life (years)	49.5		49.4		49.3		49.3	
Service life span (years)	50.0		50.0		50.0		50.0	
Mean age (years)	24.7		23.7		22.7		21.7	
New-build costs (cu/dg/yr)	0.0000	0.0	0.0051	14.1	0.0101	26.2	0.0152	36.5
Maintenance costs (cu/dg/yr)	0.0028	8.6	0.0028	7.9	0.0028	7.3	0.0028	6.8
Refurbishment costs (cu/dg/yr)	0.0097	29.4	0.0097	27.2	0.0097	25.1	0.0096	23.1
Demolition costs (cu/dg/yr)	0.0004	1.1	0.0003	0.9	0.0003	0.7	0.0002	0.6
Replacement costs (cu/dg/yr)	0.0202	61.0	0.0179	49.9	0.0157	40.6	0.0137	32.9
Total average costs (cu/dg/yr)	0.0332		0.0358		0.0386		0.0417	
Increase in total average costs (%)	23.9		18.5		15.2		12.7	
Service loss index (sye/dg/yr)	0.993		0.992		0.990		0.990	
National average costs (cu/sye)	0.0334		0.0361		0.0390		0.0421	
Increases in NAC (%)	4.4		7.8		6.6		5.8	

Table 4. Results for straight-line curve depreciation D(w) = 0.50

	r = 0%	*r = 0.5%*	*r = 1.0%*	*r = 1.5%*
Long-life dwellings				
Service loss index (sye/dg/yr)	0.811	0.854	0.865	0.876
National average costs (cu/sye)	0.0331	0.0353	0.0387	0.0422
Short-life dwellings				
Service loss index (sye/dg/yr)	0.930	0.929	0.926	0.926
National average costs (cu/sye)	0.0357	0.0386	0.0417	0.0450
Increase in national average costs (%)	7.9	9.3	7.8	6.6

Table 5 tabulates the national average costs for housing stocks that are subject to reversed S-shaped and straight-line curve economic depreciation with a threshold depreciation of D(ω) = 0.25. Increases in national average costs (cu/sye) for short-life dwellings are substantially reduced to the extent that there are savings of 5.4% and 1.1% when the housing stock is stationary and subject to reversed S-shaped curve and straight-line curve depreciation respectively. Increases in national average costs for short-life dwellings are otherwise modest peaking at 2.5% and 3.9% at *r* = 0.5% when subject to reversed S-shaped curve and straight-line curve depreciation respectively.

Table 5. Results for reversed S-shaped and straight-line curve depreciation D(w) = 0.25

	r = 0%	*r = 0.5%*	*r = 1.0%*	*r = 1.5%*
Reversed S-shaped curve depreciation				
Long-life dwellings national average costs (cu/sye)	0.0354	0.0353	0.0383	0.0413
Short-life dwellings national average costs (cu/sye)	0.0335	0.0362	0.0391	0.0422
Increase in national average costs (%)	-5.4	2.5	2.1	2.2
Straight-line curve depreciation				
Long-life dwellings national average costs (cu/sye)	0.0374	0.0386	0.0420	0.0454
Short-life dwellings national average costs (cu/sye)	0.0370	0.0401	0.0435	0.0469
Increase in national average costs (%)	-1.1	3.9	3.6	3.3

Some structural systems, for example lightweight steel framing, are direct substitutes for lightweight timber framing in that interior linings and exterior cladding systems can be the same. The costs of lightweight timber wall and roof framing are $13,181.69 or 13.9% cost of the total average costs of $95,155.40 for the National Modal House including floor finishes. If the costs of a direct substitute short-life structural system for the walls and roof are 75% and 50% of that for lightweight timber framing, then the costs of new-build and replacement construction would be $91,859.98 or 0.9654 construction units and $88,564.56 or 0.9307 construction units respectively. Table 6 tabulates the increases in total average costs (cu/dg/yr) and national average costs (cu/sye) for short-life dwellings when the costs of structural systems for the walls and roof are 75% and 50% of that for long-life dwellings. The housing stocks are subject to reversed S-shaped curve economic depreciation with a threshold depreciation of D(ω) = 0.50.

Table 6. Results for reduced costs short-life dwellings

	r = 0%	*r = 0.5%*	*r = 1.0%*	*r = 1.5%*
Cost of wall and roof structural system 75%				
Total average costs (cu/dg/yr)	0.0325	0.0352	0.0381	0.0412
Increase in total average costs (%)	21.3	16.6	13.7	11.4
Increase in national average costs (%)	2.2	6.0	5.2	4.5
Cost of wall and roof structural system 50%				
Total average costs (cu/dg/yr)	0.0318	0.0346	0.0376	0.0407
Increase in total average costs (%)	18.7	14.6	12.2	10.0
Increase in national average costs (%)	0.0	4.2	3.6	3.3

The total average costs of short-life dwellings (cu/dg/yr) are 21.3% and 18.7% greater than that for long-life dwellings when the housing stock is stationary and the costs of the wall and roof structural systems are respectively 75% and 50% of that for long-life dwellings. These increases in total average costs decline to 11.4% and 10.0% respectively when *r* = 1.5%.

The costs to construct a short-life dwelling to the same size and quality as that of the National Modal House would need to be between 68.5% to 65.5% of that for long-life dwellings in order for the total average costs (cu/dg/yr) to be the same as that for long-life dwellings when $0 \le r \le 1.5$.

Increases in national (cu/sye) costs decline to a peak of 6.0% (*r* = 0.5%) and a low of 2.2% (*r* = 0%) when the costs of the wall and roof structural system is 75% of that for long-life dwellings and decline to a peak of 4.2% (*r* = 0.5%) and a low of 0.0% (*r* = 0%) when the costs of the wall and roof structural system is 50% of that for long-life dwellings.

5 CONCLUSIONS

This paper uses a dynamic simulation model to make exploratory estimates of the maximum impact of short-life dwellings on the total costs to sustain housing. Long-life dwellings are based on a typical New Zealand dwelling of lightweight timber framing. Short-life dwellings of the same size and quality are assumed to have a service life of 50 years, the minimum required by the New Zealand Building Code. If the entire simulated housing stock of long-life dwellings is replaced with short-life dwellings, then the total average costs to sustain housing are almost 13% greater when the housing stock expands at 1.5% per year. This increase is equivalent to an additional expenditure of $600 million on New Zealand housing in 2001. Total average costs are 24% greater when the housing stock is stationary and are the same as that for long-life dwellings when the costs to construct short-life dwellings are 65% of that to construct long-life dwellings. The quality of dwelling services provided by a short-life, and therefore younger, housing stock is higher than that provided by long-life housing stock. Nonetheless, exploratory estimates based on realistic scenarios of depreciation indicate there are no reductions in the national average costs to sustain dwelling services after adjustment for depreciation when the costs to construct short-life dwellings are the same as that to construct long-life dwellings.

The results of this paper signal that it is imprudent to allow short-life dwellings to enter the New Zealand housing stock unless the costs to construct short-life dwellings are substantially less than the costs to construct long-life dwellings. In addition to significant increases in costs to sustain housing, the penalties of short-life dwellings entering the housing stock include increases in environmental pollution from manufacturing processes, waste products from demolition, and CO_2 contributions to the atmosphere due to activities by the construction industry. The full extent of these penalties would be carried by future generations, as it would take one service life span for the entire housing stock to be replaced by short-life dwellings. Some may therefore dismiss the need to restrict the entry of short-life dwellings into the housing stock. Under the principles of intergenerational justice, we should do unto the next generation as we would have the previous generation do unto us. Intergenerational justice would be assured under Rawls' (1973) veil of ignorance where no one knows which generation they belong to when they make decisions which have an impact on future generations.

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