Capital Services, Embodied Technical Change and Obsolescence in Japan and Australia

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1 Introduction

This paper focuses on the empirical estimation of the age-efficiency relationship for capital goods, having regard to the effects of embodied technical progress and induced obsolescence. It is ultimately concerned with the measurement of capital services for the purpose of productivity measurement.

In the conventional perpetual inventory model of capital measurement the productive capital stock is a weighted average of past investment quantities, where the weights represent the age-efficiency function (Hulten 1991). The age-efficiency function is a fixed profile assumed to be inherent in the nature of a given type of capital goods. The assumption of a fixed age-efficiency profile was thought to be a necessary condition for defining an aggregate capital stock.

Further development of the vintage capital model by Harper (2007) and Diewert (2009) have focused on capital stock measurement when there is embodied technical progress and induced obsolescence. These are potentially important matters to take into account. In his 1960 paper on 'Investment and Technical Progress', Robert Solow maintained that "many if not most innovations" are likely to be of the embodied rather than the disembodied kind (Solow 1960 p.91). Furthermore, under the Harper-Diewert approach, the marginal productivities of capital of various vintages (ie, the age-efficiency profile) are influenced by short-term optimisation. Changes in output or input prices may alter the optimal allocation of labour between vintages, influencing the timing of asset retirement. These potentially important effects are not taken into account in the conventional methods of capital measurement, such as those of the OECD (2007) and the Australian Bureau of Statistics (ABS 2012).

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This study aims to develop a method for applying the Harper-Diewert vintage capital model. Further research will use this method to test whether there is a relationship between the service potential of capital goods and real input prices, which may exert an influence on maintenance or retirement decisions. If so, this would support the relevance of the Harper-Diewert model. Initially the study will use Japanese data, and may later use Australian data if available. This paper outlines the proposed methodology and research agenda.

1.1 Background & Purpose

There is an important difference between the concepts of depreciation and age-efficiency. Depreciation (or equivalently the age-price function) refers to the loss of value of an asset as it ages, this loss of value being due both to wear and tear and to the reduced remaining life (Triplett 1996). The age-efficiency function refers to the decay of an asset's service potential as it ages. Although these concepts are quite distinct, there is a link between them (OECD 2009).

Most empirical studies to-date sought to establish either the depreciation profiles for different types of assets and their rates of retirement, or the age-efficiency schedule. Studies of this kind include Hulten & Wykoff (1981), Doms (1996), Patry (2007) and Nomura & Momose (2008). These studies have sought to improve measures of the rates of depreciation and/or our understanding of the shapes of the age-efficiency or age-price functions.

There appears to have been less empirical analysis of depreciation profiles in Australia than in other jurisdictions. Age-efficiency schedules used by the statistician in Australia for productivity measurement are not derived from the analysis of Australian business data. They are based on assumptions used by the Bureau of Labour Research (BLR) in the USA, which in turn derive from quite dated engineering research. Some of the studies mentioned have benefitted from detailed data collection in the USA, Canada and Japan, which does not appear to have an equivalent in Australia. For that reason, this study will initially use Japanese data.

This paper is only a beginning of a research program, which aims to:

- empirically examine the influences of embodied technical change, and changes in real input prices on age-efficiency profiles of capital goods, and

- identify the implications for measurement of capital services and Multi-factor Productivity (MFP).

The aim of this paper is to formulate a methodology and apply the theory by empirically identifying the age-efficiency profile for a specific type of asset, including the influences of embodied technical change and induced obsolescence. The aims of wider study are to collect and analyse panel data for new and second-hand capital goods of different ages for selected industries or asset types to estimate the age-price profile for those capital goods and to test whether this profile is influenced by changes in real input prices. Since inferences relating to the age-efficiency function can be drawn from the age-price profile, the predictions of the embodied technical change vintage model will in this way be tested. If sufficient data can be obtained for relevant asset categories, the study will aim to produce alternative estimates of capital services inputs and MFP movements for selected industries. Of particular interest is whether, and what way, exogenous influences on input prices or embodied technical progress affect MFP trends.

2 Conceptual Framework

Influences on the age-efficiency relationship given most attention are embodied technical change (Harper 2007; Solow 1960) and induced obsolescence—i.e., endogenous influences of decisions to retire assets (Diewert 2009). Embodied technical change occurs when new capital equipment embodies technical advances that enable it to have a higher service potential than previous vintages of the same type of capital. It represents a quality improvement in this type of capital. Endogenous influences on decisions to retire assets come about in the Diewert (2009) model in response to changes in real wage rates, although the term 'wage rate' is used as "a shorthand notation for the aggregate price of all inputs used in the industry" (Diewert 2009 p.3).

This section of the paper firstly expounds familiar concepts of capital stock measurement when there is embodied technical change. It then discusses some key aspects of the Diewert (2009) approach to vintage capital models. These approaches are combined at the end of this section.

2.1 Embodied Technical Change

2.1.1 The Capital Stock with Embodied Technical Change

Following Hulten (1992), in a model without embodied technical change, the capital stock of a given type of capital goods can in principle be measured in units such as the number of machines and can be calculated as:

$$K(t) = \sum_{a=0}^{A} \theta(a) I(t-a) \qquad (1)$$

Where $I(t)$ is investment in period t and $\theta(a)$ is the efficiency of capital of age a. The sequence: $\theta(0)$ … $\theta(\mathrm{A})$, is the age-efficiency profile, where A is the oldest possible age for capital equipment, and: $\theta(0) = 1$ and $\theta(a) \leq \theta(a-1)$.

If there is embodied technical change, capital needs to be measured in efficiency units. Let investment in the *best practice* technology in year t, measured in efficiency units, be $H(t)$. By definition this is equal to the product of the quantity of investment and an index of technical efficiency, $\Phi(t)$. That is:

$$H(t) = \Phi(t) I(t) \qquad (2)$$

The capital stock can be measured in efficiency units as:

$$J(t) = \sum_{a=0}^{A} \theta(a) H(t-a) = \sum_{a=0}^{A} \Phi(t-a)\theta(a) I(t-a) \qquad (3)$$

The sequence: $\Phi(0)$ … $\Phi(\mathrm{A})$, is an index of embodied technical change. Hulten (1992) defines the average embodied technical efficiency of the capital stock as:

$$\Psi(t) = \frac{J(t)}{K(t)} \qquad (4)$$

2.1.2 The Age-Price Profile

Let the market price of a capital good of age a in period t be denoted: $P(a,t)$. At this stage there is no embodied technical change. In equilibrium, the market price of a *new* investment good, $P(0,t)$, should be equal to the discounted value of expected future services from that good:

$$P(0,t) = U(t) \sum_{s=1}^{\infty} (1+r)^{-s} \theta(s-t) \qquad (5)$$

Where: $U(t)$ is the expected rental price of a unit of capital services (expected at time t); and r is the discount rate. The market price of an item of equipment that is aged a (ie, of vintage is $t - a$) is:

$$P(a,t) = U(t)\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t+a) \tag{6}$$

Therefore, absent any embodied technical change, each element of the age-price profile can be expressed as:

$$\Omega(a,t) = \frac{P(a,t)}{P(0,t)} = \frac{\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t+a)}{\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t)} \tag{7}$$

The sequence: $\Omega(0)$ … $\Omega(A)$, is the age-price profile absent embodied technical change. Equation (7) implies that for a given discount rate, the age-efficiency profile, $\theta(a)$, is recoverable from the age-price profile if there is a unique age-efficiency profile that satisfies equation (7), and if the discount rate, r, is known.

To consider the case of embodied technical change, denote the market price in period t of a capital good of age a, embodying technology dated at period m, be denoted: $P(a,m,t)$. The index of embodied technical progress in period m relative to a fixed index base period b, can be measured by:

$$\Phi(m) = \frac{P(a,m,t)}{P(a,b,t)} \tag{8}$$

Usually for this calculation, a would be chosen to equal zero (i.e., new capital goods) and t would be chosen to equal m (although in principle different values could be chosen).

In expressions (5) and (6) the rental price per unit of capital was no different for new and for older capital goods. If there is embodied technical change, this simplifying assumption will no longer be valid. The rental price must in principle be proportionate to the efficiency (or marginal productivity) of the capital goods being rented. We can express this by assuming:

$$U(m,t) = \Phi(m).u(t) \tag{9}$$

Where $u(t)$ is the rental price per efficiency unit of capital defined by the base period *b*, because $\Phi(b) = 1$.

Now we can expand on expression (7) by comparing two cases. The first case is a comparison of a new capital good embodying new technology with an older capital good embodying older technology. The market value of the new capital good with new technology in period *t* is:

$$P(0,t,t) = \Phi(t)u(t)\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t) \tag{10}$$

The market value of a capital good aged *a* with technology dated to period *t* − *a* is:

$$P(a,t-a,t) = \Phi(t-a)u(t)\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t+a) \tag{11}$$

Using the result from (7), the ratio of these prices can be expressed as:

$$\frac{P(a,t-a,t)}{P(0,t,t)} = \frac{\Omega(a,t)}{\left(\Phi(t)\big/\Phi(t-a)\right)} \tag{12}$$

The term $\Phi(t)\big/\Phi(t-a)$ reflects the changes in the quality of capital goods arising from new models being introduced onto the market.

The second case to consider is to compare a new capital good embodying technology from an earlier period (say *m* = *t* − *a*) against an older capital good embodying technology dated to the same period. The market value of the new capital good with older technology in period *t* is:

$$P(0,t-a,t) = \Phi(t-a)u(t)\sum_{s=1}^{\infty}(1+r)^{-s}\theta(s-t) \tag{13}$$

The market value of a capital good aged *a*, with technology dated to period *t* − *a*, is given by (11). The ratio of these two expressions is:

$$\frac{P(a,t-a,t)}{P(0,t-a,t)} = \Omega(a,t) \tag{14}$$

This expression compares the prices of *new* capital goods *of the same quality* produced at different times, such as the same make and model of equipment produced in two different years. Equation (14) shows that each element of the age-efficiency profile is equal to the corresponding price relative between older and newer capital goods *of the same technology* (or quality).

The overall conclusion is that in order to recover the age-efficiency profile from price data, we need to measure both the age-price effects for capital of the same quality or model, and the changes in the embodied technical efficiency of capital associated with changing models of capital goods. If the available price data permits these two effects can be separated, then (assuming we know the discount rate) the age-efficiency profile, $\theta(a)$, can be identified using expression (7), and the aggregated capital stock measured in efficiency units can be quantified using equation (3).

2.2 Induced Obsolescence

2.2.1 Total and Average Age-efficiency profiles

So far we have talked about the age-efficiency profile an index of the efficiency of a capital good over its life, but have not clarified whether this refers to the 'average' age-efficiency or the 'total' age-efficiency. The former refers to the average efficiency of capital goods that continue to be used in production. The latter refers to the average of age-efficiency profiles of capital goods weighted by their survival probabilities (van den Bergen et al. 2005 p.6). Our age-efficiency profile, $\theta(0) \ldots \theta(A)$, is the total age-efficiency profile. It reflects both the decay in the productive services of a capital good as it ages over time (e.g., through wear and tear), and the timing of the decision to retire the asset (and random factors that affect the life of an asset).

The total age-efficiency profile can be expressed as the product of the average age-efficiency profile and the survival function of the capital goods (van den Bergen et al. 2005). That is: $\theta(a) = \phi(a)S(a)$; where $\phi(a)$, represents the average age-efficiency for assets of age a, and $\phi(0) = 1$ and $0 \leq \phi(a) \leq \phi(a-1)$. The survival function, $S(a)$, has a value of one if the asset remains in use and zero after it is retired, or may represent a probability of survival if there are random factors. In Diewert's (2009) model, asset retirement decision is endogenous, a function of input prices. Clearly, decisions on asset retirement will influence the total age-efficiency function.

2.2.2 *Optimisation & Survival of Vintages*

We follow Diewert (2009) by firstly defining a production function that is separable between machines of different age. (The age of a machine, a, is related to its vintage, v, as follows, $a = t - v$, where t is the current period.) The output produced with machines of age a (Z^a) is a function of the productive services of those machines (K^a) and the labour allocated to them (L^a):

$$Z_t^a = f\left(\frac{L_t^a}{(1+\gamma)^a}, K_t^a\right) \tag{15}$$

As machines age, and their productive potential declines, they may also require more maintenance. For this reason, more labour is needed to produce an equivalent amount of output for older vintages of capital. To reflect this effect, Diewert assumes that the labour requirements per unit increase at a geometric rate of $\gamma \geq 0$ as an asset ages. Since more labour is used in maintenance, the productivity of labour diminishes when used with older capital.

Equation (15) defines the output that can be produced if the capital of vintage ($t - a$) is used, and labour L_t^a is allocated to that capital. However, the decision whether to use the capital of vintage ($t - a$), and if so how much labour to allocate to it, is determined by profit maximisation.

If the capital of vintage ($t - a$) is used, then the productive services it provides is the product of the number of machines of that vintage at period t, N_t^a, and their average age efficiency, $\phi(.)$. Because labour is a homogenous input, it will be allocated between the vintages so that its marginal product is the same in each application, and equal to the real wage. That is, in equation (15), the capital of vintage ($t - a$) can be expressed as: $K_t^a = \phi(a) N_t^a$.

Before considering the optimisation decision, it is useful to generalise (15) to take into account different models of machines and embodied technical change. Embodied technical change is taken into account using the index of technical efficiency, $\Phi(t)$, as shown in equation (2).

To take account of embodied technical change, the vintage production function at (15) is modified as:

$$Z_t^{a,m} = f\left(\frac{L_t^{a,m}}{(1+\gamma)^a}, K_t^{a,m} \right) \tag{16}$$

where:

$$K_t^{a,m} = \Phi(m).\phi(a).N_t^{a,m} \tag{17}$$

The total capital stock in this industry sector is:

$$\begin{aligned} K_t &= \sum_{a=0}^{A} \sum_{m=t}^{t-M} K_t^{a,m} \\ &= \sum_{a=0}^{A} \sum_{m=t}^{t-M} \Phi(m)\phi(a).N_t^{a,m} \end{aligned} \tag{18}$$

Aggregate labour and output are:

$$L_t = \sum_{a=0}^{A} \sum_{m=t}^{t-M} L_t^{a,m} \tag{19}$$

$$Z_t = \sum_{a=0}^{A} \sum_{m=t}^{t-M} Z_t^{a,m} = \sum_{a=0}^{A} \sum_{m=t}^{t-M} f\left(\frac{L_t^{a,m}}{(1+\gamma)^a}, K_t^{a,m} \right) \tag{20}$$

Aggregate labour is assumed to be in fixed supply, and it is assumed that the quantities of equipment of all cohorts $a \geq 0$ are given,[1] and treated as sunk investments for the purposes of short-term optimisation. The short-term profit function can be expressed as:

$$\pi_t = p_t Z_t - w_t L_t \tag{21}$$

where p_t is the output price and w_t is the wage rate. Short-term profit can be expressed in real terms as follows, where deflated variables are indicated with an asterisk, and where the expression in square brackets represents the real operating profit for each vintage and model of machine:

[1] Capital is measured at the beginning of each period.

$$\pi_t^* = \sum_{a=0}^{A} \sum_{m=t}^{t-M} \left[f\left(\frac{L_t^{a,m}}{(1+\gamma)^a}, \Phi(m).\phi(a).N_t^{a,m} \right) - w_t^* L_t^{a,m} \right] - u_t^* N_t^0 \qquad (22)$$

The first-order conditions for static (short-run) profit maximisation with respect to the labour inputs allocated to capital of each age group and model are:

$$f_L^{a,m} \frac{1}{(1+\gamma)^a} = w_t^* \qquad \forall a,m \qquad (23)$$

This is satisfied if labour is allocated to all vintages and models of capital such that its marginal product, in each case, is equal to the real wage. This first-order condition is usually rearranged to express the demand for labour as a function of the real wage. For example, suppose that *f*(.) is a Cobb-Douglas function with the exponent on the labour input as β and the exponent on the capital input as (1 – β). Then: $L_t^{a,m} = \beta Z_t^{a,m} \big/ w_t^*$. In the more general case we can express the functional relationship between labour demand and the real wage rate as: $L_t^{a,m}(w_t^*)$.

Maximisation of profit (equation 22) also implies that no machines will be used if doing so would decrease profit. Therefore:

$$f\left(\frac{L_t^{a,m}(w_t^*)}{(1+\gamma)^a}, \Phi(m).\phi(a).N_t^{a,m} \right) - w_t^*.L_t^{a,m}(w_t^*) \geq 0 \text{ , for all } a \text{ and } m \qquad (24)$$

Expression (24) essentially defines an asset survival function, $S_t^{a,m}$, where $S_t^{a,m} = 1$ if (24) is satisfied, and zero otherwise. Since $L_t^{a,m}$ are all a function of the real wage, and since ϕ(.) and γ are given, and $N_t^{a,m}$ and $\Phi(m)$ for past investments are fixed, it follows that the survival of an asset of a given age and model is a function of the real wage rate (w*) as well as the asset's age. For example, if the wage rate increases, it may become infeasible to continue producing with aged assets that require relatively high maintenance and have relatively low productivity. Because asset efficiency may deteriorate with age, and maintenance requirements increase with asset age, the retirement of assets through obsolescence will be ordered by asset age.

Using the derivation in the previous section, the total age-efficiency profile of an asset can be defined as:

$$\theta(a,w)=\phi(a).S(a,w) \tag{25}$$

2.3 Aggregation

It is sometimes assumed that the necessary and sufficient conditions for defining an aggregate capital stock for a given type of asset of various vintages require the age-efficiency profile for that type of asset to be a pre-determined function over time. This ensures that the marginal products of vintage assets are in fixed proportion to the marginal products of new assets (Hulten 1991). However, the requirements of aggregation do not restrict changes in the age-efficiency function over time (Harper 2007). This will happen when there is both age-efficiency deterioration and embodied technical change. Index methods may be used when the age-efficiency function is influenced by economic variables.

Although the age-efficiency function is commonly assumed to be a fixed profile for each type of capital goods, as we have seen, under the Harper-Diewert approach it is influenced by optimisation decisions, such as to the allocation of labour between vintages, in response to changes in input prices. This allows for induced obsolescence of older vintages. Quality-adjusted capital is now in principle influenced by input prices via the total age-efficiency function. For example if we use the formulation in equation (3), this becomes:

$$J_t=\sum_{a=0}^{A}\Phi(t-a).\theta(a,w_t^*).I(t-a) \tag{26}$$

Diewert (2009) adopts the solution to the associated aggregation problem which was developed by Diewert & Lawrence (2000), and applies this to the context of embodied technical change. This approach is also relevant when taking the influence of changes in real wages into account. It uses a superlative index method such as the Fisher index, and can be summarised as follows.

$$\left(J_t/J_{t-1}\right)^F=\left[\left(J_t/J_{t-1}\right)^P\left(J_t/J_{t-1}\right)^L\right]^{0.5} \tag{27}$$

where:

$$\left(J_t/J_{t-1}\right)^P = \frac{\sum_{a=0}^{A}\Phi(t-a).\theta(a,w_t^*).I(t-a)}{\sum_{a=0}^{A}\Phi(t-a-1).\theta(a,w_t^*).I(t-a-1)} \quad (28)$$

$$\left(J_t/J_{t-1}\right)^L = \frac{\sum_{a=0}^{A}\Phi(t-a).\theta(a,w_{t-1}^*).I(t-a)}{\sum_{a=0}^{A}\Phi(t-a-1).\theta(a,w_{t-1}^*).I(t-a-1)} \quad (29)$$

3 Approaches to Measuring Age-Price Profiles

This section discusses approaches that can be taken to attempt to test the theories discussed and the data that we propose to use.

3.1 Data

One of the main difficulties in this field of study is the lack of available data on used asset prices. Some of the approaches that have been used to gather data for empirical studies of asset age-price profiles studies include: transaction data from markets for second-hand capital goods;[2] standard values for assets of different ages for a given type used by insurance companies; and surveys of business asset disposals to obtain information on the original purchase price of the asset (or gross book value at historic prices), dates purchased and sold, and selling value.[3]

This study will rely on transaction data from second-hand markets for motor vehicles in Japan, including trucks, vans and passenger motor vehicles. This data does not entirely represent capital goods, because passenger motor vehicles are used by households as consumer durables as well as by businesses as capital goods. However, this data will be used for illustrative purposes because of the extensive set of data that has been collected for new and second hand prices for different makes and models of vehicles over the period 1974 to 2012. A lengthy

[2] These markets are often online, or partially on-line.

[3] Extensive surveys of this kind have been carried out in Japan and Canada, but not yet in Australia. See: Nomura, K. & Futakami, T. 2005, 'Measuring Capital in Japan: Challenges and Future Directions', in *2005 OECD Working Party on National Accounts*, Paris, France. and Patry, A. 2007, 'Economic Depreciation and Retirement of Canadian Assets: A Comprehensive Empirical Study', Statistics Canada.

series is important if the influence of changes in inputs prices is to be identified. Japanese databases of asset disposal data from business accounts cover a wider set of assets but only over a shorter period at present.

3.2 Empirical methods for estimating age-price profiles

Several studies have sought to estimate age-price profiles econometrically, but none of those reviewed attempts to take into account, or test, determinants other than age, such as endogenous technical change or real wage rates. The age-price profile refers to the relative price of an asset of age a relative to a new asset, $R_t^{a,m} = P_t^{a,m} \big/ P_t^{0,m}$, as a function of the age of the asset (hereafter 'price relative'). Depending on the objectives of the analysis or the nature of the data, some of the studies have also estimated or assumed an asset survival function.

For example, Hulten & Wykoff (1981) is an analysis of actual transaction prices of used assets in the USA, in which the Box-Cox power transformation model was used to identify an appropriate functional form for the age-price profile. The Box-Cox model has the following general form:

$$y^{(\theta)} + \alpha_0 + \alpha_1 x_1^{(\lambda_1)} + \alpha_2 x_2^{(\lambda_2)} + \ldots \tag{30}$$

where:

$$y^{(\theta)} = \begin{cases} \dfrac{y^{\theta} - 1}{\lambda} & \text{if } \theta \neq 0 \\ \ln y & \text{if } \theta = 0 \end{cases} \tag{31}$$

$$x^{(\lambda)} = \begin{cases} \dfrac{x^{\lambda} - 1}{\lambda} & \text{if } \lambda \neq 0 \\ \ln x & \text{if } \lambda = 0 \end{cases} \tag{32}$$

Hulten & Wykoff used the asset price as the dependent variable using the model:

$$P_i^{(\theta)} = \alpha + \beta a_i^{(\lambda_1)} + \gamma t_i^{(\lambda_2)} + \varepsilon_i \qquad i = 1 \ldots N \text{ observations} \tag{33}$$

Using this specification, the age-price profile can take a geometric, linear or one-hoss-shay form, depending on the estimated values of λ and θ. The purpose of the time variable, t, was to capture the effects of asset price inflation, which as the authors noted, affects all assets equally. If the price relative to that of a new asset were used as the dependent variable, this term may not be needed. Hulten & Wykoff did not find that any particular age-price profile was fully supported, but observed that actual depreciation is accelerated relative to the straight-line profile and "on average the geometric profile provides a reasonably good approximation" (Hulten & Wykoff 1981 p.369).

Another study, Patry (2007), used a large sample of asset disposal data obtained by Statistics Canada, and assumed that the age-price function follows a Weibull distribution:

$$\tilde{P}_i^a = \exp[-(\varphi . a_i)^\sigma] \quad (34)$$

The variable $\tilde{P}$ is the transaction price of the asset adjusted for capitalized improvements and deflated by the asset price deflator. Equation (34) is transformed into a linear expression for estimation:

$$y_i = \ln[-\ln(\tilde{P}_i)] = \alpha + \sigma . \ln a_i \quad (35)$$

Where $\alpha = \sigma \ln \varphi$. This study found that for buildings, the age-price profile "follows a straight-line pattern for the first 60% of value loss and then changes to a convex pattern", while the majority of machinery and equipment assets "follow a convex depreciation pattern that is well approximated by a geometric rate", although in some categories a linear profile performs equally as well (Patry 2007 p.25).[4]

Other studies have tested other functional forms (Biorn 1998; Doms 1996). Biorn shows that concave age-efficiency functions can be consistent with convex age-price functions.

3.3 'Lemons' problems

There are two 'lemons' problems that become relevant when using a set of data on used asset prices to estimate the age-price function and the age-efficiency function. The population of each type of asset of a given age will have a distribution of better and worse quality. The first 'lemons' problem is that for a given type of older assets, the worst examples may be retired and the observed prices in second-hand markets would reflect only those that survived to that age. The average prices of older assets would therefore provide a biased over-estimate

[4] Straight-line depreciation is equivalent to a one-hoss-shay age-efficiency profile.

of the average value of assets of that age, because it would exclude the zero values of those retired.

The second type of 'lemons' problem is that firms may only choose to sell poorer assets of a given type and age, and retain the better examples. This is the classical lemons problem of Akerlof (1970) in which buyers in the second-hand asset market cannot perceive the differences in quality of similar goods, so the owner of a better quality capital good cannot realise its value in the second-hand market and would be more likely to retain it. Because used assets of better quality are less likely to come onto the market, the second-hand prices may provide a biased under-estimate of the average value of assets of a given age. Therefore, these two effects work in opposite directions.

3.4 Proposed econometric specification

In this study we propose to broadly follow the approach of Hulten & Wykoff, but with some differences aimed to take into account embodied technical change and the effect of real wages. Using the price of the capital goods as the dependent variable, the Box-Cox method can be specified as:

$$P^{(\theta)}_{a,m,t} = \alpha_0 + \alpha_1 a^{(\lambda_1)} + \alpha_2 m^{(\lambda_2)} + \alpha_3 w_t^{(\lambda_3)} + \alpha_4 \left(w_t a\right)^{(\lambda_3)} + \alpha_5 t^{(\lambda_4)} + \sum_j \beta_j z_{j,m,t} \qquad (36)$$

In this model: P is the deflated asset price; t is the year of the price observation; a is the age of the asset; and m is the year in which that model was first released; w_t is the real input price in period t — including real wages and real fuel costs; and the z variables are vehicle attributes such as horsepower, fuel economy etc. The multiplicative term ($w_t a$) has been included to allow for the possibility that the real wage effect is stronger for older assets.

In this specification: coefficient α_1 provides information on the age-price function; coefficient α_2 provides information on embodied technical change; coefficients α_3 and α_4 provide information on the influence of real input prices on the age-price function. If vehicle survival data is available, alternative specifications may be feasible.

4 Conclusion

This paper has outlined the theoretical motivation and approach to empirically estimating the effects of embodied technical change and induced obsolescence in capital goods. To test this theory, a panel data for new and second-hand assets of different ages will be used — initially motor vehicles in Japan of several kinds including vans, passenger vehicles and different types of trucks. The econometric method involves estimating age-price, or depreciation, profiles that have both cross sectional and time series characteristics.[5] The aim is to test whether these profiles are influenced by changes in real input prices, as the theory of induced obsolescence would imply. It would be desirable to have data on asset retirement to analyse the effect of real input price movements on retirement rates.

The ultimate aim of this project is to produce alternative estimates of MFP movements based on the new capital services measures for selected industries. The paper presents a method of indexing capital stock measures to enable induced obsolescence to taken into account. The research project aims to draw conclusions about possible influences on observed MFP trends of factors such as real input prices and embodied technical progress.

[5] Diewert provides expressions for cross-sectional and time series depreciation and shows how these are related under different functional forms. Noting different views, Diewert argued that time series depreciation is the most appropriate in the vintage capital model. Given the functional form of the vintage production functions and assumptions about the process of expectations formation, it is possible to derive time series depreciation from cross-sectional depreciation.

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