Durable Goods Oligopoly
and the Tokyo Condominium Market in the 1990s*

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Abstract

This paper investigates an explanation for a phenomenon observed in the Tokyo condominium market during the 1990s – a persistent price deflation and a spike in output associated with land price depreciation in the context of market structure. Though land price and condominium price were highly correlated throughout the 1990s, a divergence in the two series is observed from 1993 onwards. This divergence may be due to imperfect competition between condominium developers or to an appreciation of the construction cost relative to the land cost for the condominium production. In order to address this problem, a dynamic durable goods oligopoly model of the condominium market that incorporates time variant costs is developed and estimated. On the basis of estimates and counterfactual experiments using the estimated model, I get the following results. First, the data provides no evidence of the firms in the primary market having any substantial market power in this industry. Second, the inflation in production cost strengthens the market power of condominium producers; at the same time, its deflation exacerbates the erosion of the market power derived from its durability. Third, the deflation of condominium prices is explained by the increase in production of small firms rather than by cost variations.

Keywords: Durable Goods, Dynamic Oligopoly, Housing Market
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1 Introduction

Throughout the 1990s, the condominium market in Tokyo showed significant growth. The annual supply of condominium units surged in 1994 from 8,000 units to 20,200 units; it has maintained an increasing trend ever since. At the same time, prices declined by an average of 5.2%. A major cause of this deflationary price trend is considered to be land price depreciation such as has taken place since the burst of the asset price bubble in the Japanese market, inasmuch as land is the most expensive factor of condominium production. Indeed, the two price series have been highly correlated. However since 1993, the speeds of deflation in the two price indices have been diverging. Land prices have depreciated more rapidly than condominium prices; between 1995 and 2000, land prices have depreciated by an average of 5.26% while condominium prices have depreciated by an average of 3.12%.

This paper investigates the main factors underlying the divergence between the two price series in the context of the market structure— is this divergence due to imperfect competition between condominium developers or to an appreciation of the construction cost relative to the land cost for the condominium production? Since condominiums are durable goods, demand will be driven by consumers’ expectations as to prices and the possibility of engaging in intertemporal substitutions. It has been well-known since Coase (1972) that such substitutions can erode the market power of a durable good producer. In addition, the presence of a secondary market means that a producer can, through its current production decision, influence the current and future value of a product. This effect will, however, depend on the presence of competing suppliers, as one firm’s current production will impact the secondary market, which affects all firms. The observed increase in condominium production in the Tokyo market may be a consequence of strategic interaction among firms, rather than solely due to forces on the demand side.

Identifying the existence of market power in this particular industry has important policy implications. The results derived from a conventional housing economics model may not apply to a market like Tokyo’s, as the literature usually assumes competitive market.\(^1\) For instance, the hedonic price index, which is used to measure consumer welfare, may not be accurate if the market

\(^1\)See Dipasquale (1999) and Whitehead (1999) for a discussion of this topic.
power is disregarded in its construction. ²

This paper further examines the relationship between the cost variation across time and the time inconsistency problem. The persistent land price decline in the Tokyo market motivates an extension of this model to include intertemporal cost variation. Facing rising costs, producers have incentives to produce now rather than in the future. Correspondingly, consumers correctly believe that producers will not cut prices in the future. On the other hand, deflationary costs provide firms with incentives to postpone production in order to cut costs. This leads consumers to lower their willingness to pay for newly produced goods. Consequently, firms tend to have less market power during deflationary period. ³ In this paper, I identify the extent to which the cost depreciation trend reduces the market power of the producers of durable goods. In order to address these problems, I employ a dynamic oligopoly model of a durable goods market, one which incorporates a time-varying cost component. Exogenous production by small fringe firms is also accommodated in the model. Using market-level supply data, the structural parameters are recovered. Estimation is performed through the use of a nested GMM procedure, in which each oligopolist’s dynamic optimization problem is solved.

With the obtained parameter estimates, I perform several counterfactual experiments to study the properties of the equilibrium behavior of firms and the resulting market outcome. The results are summarized as follows: First, the data provides no evidence of the firms in the primary market having any substantial market power in this industry. Second, the inflation in production cost strengthens the market power of condominium producers; at the same time, its deflation exacerbates the erosion of the market power derived from its durability. Third, the deflation of condominium prices is explained by the increase in production of small firms rather than by cost variations.

This paper proceeds in the following manner. In the next section, the related literature is introduced. In section 3, descriptions of the market and the industry of interest are given. Section 4 introduces a dynamic oligopoly model of condominium suppliers. Section 5 explains

²Feenstra (1995) points out that since variables reflecting price-cost markups are omitted, a hedonic price regression does not give an accurate estimation of the marginal price for the characteristics of the goods.

³This intuition is similar to the Kahn’s work (1986). As Kahn suggests, increasing production costs mitigate the Coase problem, inasmuch as buyers believe correctly that producers benefit from spreading production over time, and thus will not cut prices in the near future.
the estimation method for the model. Section 6 reports the estimation results followed by the simulation results. The last section concludes.

2 Literature Review

Durability makes a market more competitive; this is due to two characteristics of durable goods consumption: intertemporal substitution and the presence of a secondary market.

For a durable goods seller, intertemporal substitution over consumption generates competition with one’s past self as well as one’s future self, since a buyer will not purchase a product if he or she expects its price to go down in the future, even if his or her valuation of the good is higher than the current price. Consequently, a monopolist is better off maintaining a high price indefinitely. A rational buyer, however, realizes that an incentive exists for producers to violate this strategy once the future arrives. Thus the rational expectation of consumers will eventually drive prices down to the level at which a producer can no longer make a profit unless he or she commits to a high price path over the future. This is the time inconsistency problem faced by monopolist sellers of durable goods. This problem was first conjectured by Coase’s seminal paper of 1972. Under extreme circumstances where the marginal cost of production is constant and the good is infinitely durable, a monopolist loses his or her market power completely as the time between adjustments gets closer to zero. This related stark conjecture, that the monopoly results in perfectly competitive outcome, was later formally proven by several researchers, among them Stokey (1981), Bulow (1982) and Gul, Sonnenschein, and Wilson (1986).

The presence of secondary market erodes the market power of a producer by providing additional substitutes for a new product both within and across time. Furthermore, the resale possibility through secondary markets will make the future prices (or production) a factor for consideration for the potential owners of durable goods when making purchasing decisions. Since they prefer those goods that will yield a higher value in the secondary market at a future date so as to minimize capital loss, additional production by a monopolist generally harms profitability by reducing a

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4Similar time inconsistency problems can be found in markets of storable goods due to intertemporal substitution. Dudine, Hendel, and Lizzeri (forthcoming) show, however, that a monopolist may be better off not committing if consumers have the ability to stockpile.
respective product’s future resale value and indirectly reducing its current price in the primary market. Firms therefore need to take such consumers’ expectations into account when making production decisions, by predicting the future value of their own products in the secondary market.

There are various studies on tactics that a durable goods monopolist might use in order to mitigate the time inconsistency problem. One of the most well-studied schemes involves leasing, whereby a producer offers consumers a flow of services instead of the actual good. With leasing, a producer fully internalizes the effects of flooding the market with goods with regard to future and current profits; the time inconsistency problem is thus completely eliminated, as shown, for instance, in Bulow (1982). Examples of such schemes, whereby a monopolist commits him or herself to a future price path, are those aimed at increasing cost, augmenting one’s reputation, utilizing contract agreements such as money-back guarantee, maintaining information asymmetry with buyers. The presence of high opportunity cost to stay in the industry and constant inflow of new customers may also help the commitment by producers.5 The most relevant literature from this strand with respect to this paper encompasses works concerned with decreasing return to scale technology. Kahn (1986) shows that the Coase result does not hold when the cost function exhibits a decreasing return to scale. If the marginal cost is upward sloping, rational buyers know that the monopolist can save cost by spreading out production over time; they thus believe that the monopolist will not flood the market in the near future. Consequently, the monopolist is able to extract positive profit.6 Karp and Perloff (1996) endogenize the technology choice made by a monopolist, thus showing that he or she is able to benefit from inferior technology as it allows him or her to credibly commit to low production. Kutsoati and Zabojnik (2005) also finds that there exists an incentive for durable good monopolist seller to adopt inferior technology using a model of technology selection where 'learning-by-doing’ is present. Given these intuition, I incorporate the cost trend into the model so as to investigate the effect of cost variation on market power.

In contrast to the rich literature on durable goods monopolists, there exist few studies on durable goods markets made up of several firms. In general, as the number of firms increases, sellers of

6Bulow (1982) points out that the capacity constraint might work similarly to increasing costs in an infinite horizon framework.
durable goods lose their market power more quickly than seller of non durable goods. This result is shown in Carlton and Gertner (1989), who study the effect of a merger in a durable goods market. They also find that durable goods oligopolists have an extra incentive to overproduce compared to monopolists because the harm caused by a current reduction in price over future periods would be shared with their rivals. Gul (1987) shows, however, that, using a durable goods model, an oligopoly can be less competitive than a monopoly, as there exist credible price-war threats and rational consumers who can anticipate a price wars. Using a vertically differentiated product framework, Esteban and Shum (2006) found that secondary markets allows firms to exploit their asymmetries. The producer of goods at the high end of the quality spectrum tends to produce more, as this can hurt the profit of low quality product producers without seriously hurting its own profit; this is because its product is going to act more as a substitute for newly produced low quality goods once they reach the secondary market.7

Many empirical works in IO study demand dynamics arising from intertemporal substitution. Berkovec (1985) modeled the primary and secondary car market using a multinomial logit framework. Hendel and Nevo (forthcoming) and Erdem, Imai, and Keane (2003) investigate the demand for storable goods using scanner data, and point out the danger of getting biased estimates in price elasticities by ignoring intertemporal substitution caused by consumers’ ability to stockpile. None of them, however, incorporate supply side dynamics. Esteban and Shum (2006), on the other hand, construct a model that explicitly incorporates the secondhand market with vertical intra- as well as intertemporally differentiation. They estimate the model using a nested GMM procedure, by imposing the equilibrium at each observation. My approach is closely related to theirs. Benkard (2004) studies industry pricing in and the performance of the wide-bodied commercial aircraft market. The durability of aircrafts is dealt with by assuming that purchases are as rentals. He recovers the structural parameter by not imposing the equilibrium, something which is feasible to do given data availability. While this approach is robust with a misspecification of the model, the estimate is not efficient if the model is correct.

7Porter and Sattler (1999) points out that there exists similar benefits of secondhand market for durable goods producers as in the differentiated product market. The number of units sold is increased by giving low valuation consumers a chance to obtain durable goods, and by reducing the incentive of producers to cut prices in order to sell to those low valuation consumers.
Durability is also considered an important characteristic in the literature on housing supply. In recent years, structural approaches have been grouped into two categories; one based on urban spatial theory, and the other on investment theory. The urban spatial approach considers the equilibrium where the stock of housing always equals the urban population. Under such conditions, the supply of housing is equal to the inflow of the population. Land is defined here as a distinct input and its price is endogenously determined by housing stock. With the investment approach, consumers consider the residential building as an investment good, whose price is determined by the present discount value of the rental price (i.e., the price of the service derived from the structure). The rental price is the function of the level of the existing housing stock. Consumers therefore do not explicitly make distinctions between vintages. Home builders maximize the present discount value of the profit by taking the price as given. Topel and Rosen (1988) consider the convex adjustment cost, where the production cost is increasing at the rate of the change in the production level. Thus dynamics arise in the supplier’s decision problem in connection with the cost structure. Rosenthal (1999) on the other hand considers the case of constant marginal costs, where firms are myopic. With both approaches, the rationale for a competitive market assumption is that new construction is a small part of the existing stock; consequently, builders do not have any control over it. In my application, as there seems to exist a distinction between newly constructed units and old units in the minds of consumers (additionally, the data suggest a possible presence of market power), I introduce into the model strategic interactions between firms. My approach is similar to the investment approach. To my knowledge this is the first attempt at considering the housing market in an oligopolistic framework using an investment-based approach.

With respect to empirical housing supply analysis, there have been a few studies based on micro-level data concerning house builders. Dipasquale (1999) suggests that the major obstacle in understanding the housing supply mechanism has been data availability. In this respect, I have a great advantage, although I have to be careful in drawing conclusions about Tokyo’s general housing market from this analysis, inasmuch as my data only captures one segment of the housing market, namely condominium market.
3 The Tokyo Condominium Market

3.1 Definition of the Market

A condominium is defined as multi-unit housing consisting of 5 units or more, with three stories or more, and with a steel-reinforced concrete structure. In this paper, I only consider those units developed by private companies. 8

This paper studies the marketing of newly constructed condominiums in the Tokyo metropolitan area. I define the market as encompassing Tokyo’s 23 central districts. It is 621.45 square km in size and, as of 1995, consisted of about 3.5 million households. 9 Throughout the 1990s, population growth was moderate within this area, while the number of households grew at an annual rate of 1%. This growth is mostly accounted for by an increase in single-person households. Condominiums have become an increasingly common form of housing in the area-as of 1998, multi-unit housing owned by individuals accounted for 20% of all housing stock in the Tokyo Metropolitan Area. As of 2001, more than half of all households purchasing new housing chose a condominium unit rather than a single detached house. This ratio was about 45% on average throughout the 1990s.10

In terms of durability, and based on the national tax law since 1999, the statutory useful life of a condominium unit is 47 years. In reality, most existing condominiums are said to require either large scale repair or rebuilding after about 30 years. This suggests that the scrappage value – the value that an owner of a unit receives at the end of the life of a unit – can be thought of as being less dependent on future land prices. However, the physical (quality) depreciation of a condominium depends on the maintenance quality over the years. Thus, the vintage may not be the best proxy for quality. This fact motivates to incorporate other characteristics in the demand specification at

8The public entity known as Japan Public Housing Corporation (JPHC) has been the alternative seller of condominiums. JPHC had provided both rental housing and housing for sale since 1955. Their average annual national supply of housing units for sale of all types was approximately 13 thousand units. Those units are excluded from my analysis, as the influence of this entity on the Tokyo market is likely to be insignificant. Additionally, given the growing trend toward privatization and the abundance of housing in urban areas, it retreated from the sales business in 1999.
9The corresponding statistics for New York City in 2004 are as follows: an area of 785 square km (approximately 303 square miles), encompassing 3 million households and 8.1 million people.
the estimation stage, which will be described in section 5.  

3.2 The Market Environment

Figure 1 summarizes the various price indices relating to the housing market between 1984 and 2002, taking 1995 as a base year. The expansion of the economy started in 1986. During the subsequent four years, the real GDP growth in Japan was about 5%. The burst of land market bubble was gradually revealed in 1991, a year later than the stock market crash. By that time, land prices had risen by 122 % from its 1986 level. Since the burst, land prices have been consistently decreasing. The price of new condominiums in Tokyo showed almost identical movement to land prices through 1995, presumably because land was the most expensive factor in condominium production. Meanwhile, construction work price deflators reflecting the labor cost in the construction industry displayed a gradual increase, but the movement was very modest compared to the fluctuation in land related prices. The rental index (not shown in the figure) exhibited a slight decrease over time, but again, the change has been subtle compared to that for land prices, and might reflect the fact that land prices have not been fully adjusted for non-bubble prices. The prices of condominiums in the secondary market (not shown in the figure) also exhibited a downward trend, but the rate of decreasing was higher than that for new condominiums and land prices prior to 1995. After 1995, land price series and new condominium price series started to show a divergence: Land prices depreciated 1 to 5 % more rapidly than condominium prices between 1995 and 2000, which is the major phenomenon I focus on in this paper.

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11In 2002, stock older than 30 years old constituted 6% of total condominium stock in Tokyo. The increasing proportion of aged stock for condominiums is becoming a regulatory concern for safety reasons. In particular, condominiums built before 1981 were designed under a weaker regulation code, and thus do not satisfy current building standards. In many cases, the re-building of condominiums has proven difficult, as in many cases, the law requires an approval of re-building plans by four-fifths of a building’s owners.

12The greater part of condominium ownership included sectional ownership of land.

13In the simple setup, the theoretical price of an asset is the present discount value of the expected flow of income gain from the asset. Thus, the value of a house has to be equal to the present discount value of a future rental stream under perfect a market assumption. For example, if the expected rent is fixed to today’s level, the land price is proportional to the rent. This means that the land price and rental price indices have to be identical.
3.3 The Industry

Condominium construction involves at least two types of firms; developers and construction companies. Developers acquire land, plan condominium development projects and place the order for construction with the construction companies. Developers either sell the units directly to consumers or through dealer companies. In this study, developers are assumed to produce and sell condominium units directly to consumers and the role of construction companies is abstracted away.

One of the contributors to the surge in the supply in 1994 was new entrants to the market. The transition in market participants is summarized in Table 1. The number of active firms was 75 in 1993, increased to 166 in 1994, and stayed around 180 since then. For each year, about 15-52% of firms were one shot players that appeared in the data set only once over sample periods of nine years. Those firms or individuals seemed to take advantage of market expansion to sell their unused land. At the same time, the top 15 firms maintained more than 50% of the market share during the period of analysis, despite the large number of entries as summarized in Table 2.

On average, condominium construction takes 15 months. The average time lag in the sample between construction and sales is about 198 days and about 10% of the properties are sold before the completion of construction. It is common to divide the units from one project into groups and sell them at different phases. My dataset is organized by the sales phases. While the actual production decisions tend to be made well ahead of sales time, I assume that transaction and production choices occur at the same time.

3.4 The Secondary Markets

It is said that the resale housing market in Japan is less developed than its counterpart in North America. The trade volume in the secondary market has been estimated at 50 thousand units annually in the Tokyo metropolitan area alone. This accounts for 3% of the condominium stock in the area.

One of the reasons for the low volume of transactions in the secondary market may be infor-
mation asymmetry problems in the Japanese real estate market. Real estate brokers tend to be small scale and specialized in specific areas; they are thus inclined to monopolize local information. This leads to higher search costs for potential buyers and higher opportunity costs derived from vacancies for owners or potential sellers. Shimizu, Nishimura, and Asami (2004) focus on this point and find that there would be substantial cost savings if there were an information agency which provided relevant information to all (potential) market participants on all properties for resale for close to zero cost. Although this suggests that information asymmetry may be important in this market, this paper maintains the assumption of a perfectly competitive secondary market.

4 Model of the Condominium Market

This section gives a description of the dynamic oligopoly model for the primary market for condominiums. The model is constructed based on the discrete-time semi-durable goods oligopoly model of Esteban (2001), wherein both firms and consumers are forward looking. Consumers’ behavior is modeled using a multinomial Logit framework but the model incorporates the dynamics arising from durability. Firms are quantity setting oligopolists facing a decreasing return to scale technology with a macro cost shock and stochastically evolving fringe competitors.

4.1 The Environment and the Transition of the States

Condominiums are durable and are assumed to last for \( D \) periods. Newly constructed condominiums are traded in the oligopoly market, whereas older condominiums are traded in competitive secondary markets. Thus, the producers do not have direct control over the outcome in secondary markets. The condominium units are differentiated by vintage, implying that they are homogeneous within the same vintage. There are three types of state variables in this model: the stock of condominiums \((\vec{s}_t)\), the macro cost shock \((\vec{c}_t)\) and exogenous fringe competitors \((x_t)\).

In the market, there exist \( J \) firms producing and selling durable condominiums. Firms are indexed by \( j \) and are assumed to be homogenous. A typical firm \( j \) produces \( q_{jt} \) units of condominiums at time \( t \). Besides \( J \) firms, there are fringe competitors who take the price as a given.

\footnote{This modeling approach is employed by Berkovec (1985) with respect to car consumption.}
They collectively produce $x_t$ units at time $t$. It is assumed that $x_t$ evolves due to AR(1) process (i.e. $x_t = \bar{x} + \vartheta x_{t-1} + \xi_t$, where $\xi_t$ is distributed mean 0 and is finite variance $\sigma^2_{\xi,t}$).\footnote{This treatment of exogenous competitors is similar to that of exporters in The U.S. automaker model used by Esteban and Shum (2006). However, they assumed the stochastic process to be random walk without drift.} Therefore, $x_t$ eventually converges to the steady state level, $x^{ss}$. If current $x_t$ is below $x^{ss}$, it would be in a growth phase. The condominium market for each vintage clears for each period. Thus, all existing units are transacted in the secondary market of each vintage until they reach age $D$. A condominium unit depreciates at an annual rate of $1 - \delta$ before age $D$. Note that units above age $D$ stay in the market, but as part of an outside alternative. In other words, after age $D$, the specific links of used units with new or younger units are lost. The stock of age $d$ is expressed as

$$s^d_t = \delta \left( \sum_{j=1}^{J} q_{j,t-d} + x_{t-d} \right), d = 1\ldots D.$$  

Firm $j$ incurs cost to produce $q_{j,t}$ according to the quadratic cost function

$$C(q^{0}_{j,t}, c_t) = (\bar{c}_1 + \tilde{c}_t)q_{j,t} + \bar{c}_2q_{j,t}^2,$$

where $\bar{c}_1$ and $\bar{c}_2$ are constant, while $\tilde{c}_t$ is stochastic, following the AR(1) process to capture macro shocks to the market. Formally, it is expressed as $\tilde{c}_{t+1} = \rho \tilde{c}_t + \eta_{t+1}$, where $\rho \in (0, 1)$ is the persistence parameter and $\eta_{t+1}$ is white noise (independently identically distributed over time with mean zero and a finite variance ($\sigma^2_{\eta}$)). The cost function is common among $J$ firms, which observe $\tilde{c}_t$ when making production decisions.

Let $\vec{q}_t$ be a vector consisting of the production of $J$ firms. The above specifications on stock, exogenous production and cost determine the law of motion, as follows.
\[
\begin{bmatrix}
  s_{t+1}^1 \\
  s_{t+1}^2 \\
  \vdots \\
  s_{t+1}^D \\
x_{t+1} \\
\tilde{c}_{t+1}
\end{bmatrix} =
\begin{bmatrix}
  0 \\
  0 \\
  \vdots \\
  0 \\
  0 \\
  0
\end{bmatrix} + \begin{bmatrix}
  B_1 & 0_1 \\
  0_2 & B_2
\end{bmatrix} \begin{bmatrix}
  \delta \\
  \delta \\
  \vdots \\
  \vdots \\
  0 \\
  0
\end{bmatrix} q_t + \begin{bmatrix}
  0 \\
  \eta_{t+1} \\
  1 \\
  0
\end{bmatrix} .
\]

(2)

\begin{align*}
\text{Note } & B_1 = \\
& \begin{bmatrix}
  0 & \delta & 0 & \ldots & 0 \\
  0 & 0 & \delta & \ldots & 0 \\
  \vdots & \vdots & \vdots & \ddots & \vdots \\
  0 & 0 & 0 & \ldots & \delta \\
  0 & 0 & 0 & \ldots & 0
\end{bmatrix},
\quad B_2 = \begin{bmatrix}
  \vartheta & 0 \\
  0 & \rho
\end{bmatrix}.
\end{align*}

\(0_0\) is \(D \times 1\) vector of zero, \(0_1\) is \(D \times 2\) matrix of zero and and \(0_2\) is \(2 \times D\) matrix of zero. For notational convenience, I denote the vector of the state variables as \(\tilde{S}_t = [s_t, x_t, \tilde{c}_t]'\), where \(s_t\) is defined by \([s_t^1, s_t^2, \ldots, s_t^D]'\).

### 4.2 Consumers

Consumers’ decisions about condominium purchases are modeled using a discrete choice framework with Logit. There are \(M\) consumers in the market and they are indexed by \(i\). For each period, a typical consumer \(i\) purchases, at most, one unit from a set of condominiums, age 0, 1, \(\ldots\), \(D\). The age 0 product is traded in the primary market while older units are traded in a competitive secondary market. The owner of a new condominium unit can sell it in the secondary market after holding it for a year. The owner of condominium, age \(D\), receives a terminal value \(p\) at the end of the year. The product is indexed by its age, denoted by \(d\). The outside alternative is denoted by \(d = n\), and it includes the choice of purchasing single-unit housing, condominiums older than \(D\), or not buying any type of housing (i.e., renting). The flow utility of the consumer \(i\) from purchasing a good of
vintage $d$ at time $t$ is given as following quasi-linear form.

\[
    u_{it}(d) = \begin{cases} 
    g(d) - \alpha p^d_t + e^d_{it} & \text{if } d = 0, 1, ... D, \\
    e^d_{it} & \text{if } d = n,
    \end{cases}
\]  

(3)

where $g(.)$ is a function of the age of the product $(d)$, and measures the quality of the product; $p^d_t$ is the price of the product; and $e^d_{it}$ captures the heterogeneity of consumers that goes unobserved by the econometrician. These follow some zero mean finite variance distributions independently across time and age. Let $J = [1, ..., J]$ be a set of active firms in the market and $D = [0, 1, ... D]$ a set of available vintages for those products. Consumer $i$ maximizes the sum of his or her present discounted utility flow by making choice $(d)$ from set $D + 1$. Given the consumer’s time discount rate, $\beta$, the problem for the consumer $i$ is given by

\[
    \max \sum_{\tau = t}^{\infty} \beta^{\tau-t} u_{i\tau}(d).
\]  

(4)

This problem involves cumbersome dynamic programming. However, it is known that the problem can be simplified to a static one by assuming that there is no transaction cost. Berkovec (1985) and Esteban and Shum (2006) show that the problem (4) can be replaced by following:

\[
    \max_{d \in D+1} UG_{it}(d),
\]

where the utility gain $UG_{it}(d)$ is defined by

\[
    UG_{it}(d) = \begin{cases} 
    g(d) - \alpha ECC^d_t + e^d_{it} & \text{if } d \leq D, \\
    e^d_{it} & \text{if } d = n.
    \end{cases}
\]

The expected capital cost $ECC^d_t$ is defined by

\[
    ECC^d_t = \begin{cases} 
    p^d_t - \beta p^d_{t+1} & \text{if } d < D, \\
    p^d_t - \bar{p} & \text{if } d = D,
    \end{cases}
\]
where $p$ is the terminal/scrappage value of the condominium when it reaches age $D$ in period $t + 1$. It implies that a consumer’s dynamic decision is equivalent to a comparison of the utility gains from the choices available in the period. The utility gain consists of terms $g(d)$, the benefit from the consumption of the goods for the given period and $p_t^d - \beta p_{t+1}^{d+1}$, the implicit rental price under the no transaction cost assumption. Here, consumers have perfect foresight, such that

\[ E_t(p_{t+k}^d) = p_{t+k}^d \]

for all $t$ and $k = 0, 1, D + 1$. This assumption is relaxed at the estimation stage.\(^{17}\)

The unobserved heterogeneity of consumers, $e_{it}^d$, is assumed to be identically and independently distributed with respect to the type I extreme value distribution across consumers $(i)$, the vintage $(d)$ and the time $(t)$. Integrating $e_{it}^d$ then yields a market share equation for each vintage as follows.

\[
\mu_t^d(p_t, p_{t+1}) = \begin{cases} 
\frac{\exp(g(d) - \alpha ECC_t^d)}{1 + \sum_{t = 0}^D \exp(g(d) - \alpha ECC_t^d)} & \text{for } d \leq D, \\
\frac{1}{1 + \sum_{t = 0}^D \exp(g(d) - \alpha ECC_t^d)} & \text{for } d = n .
\end{cases}
\]

(5)

Applying the transformation method of Berry (1994), the logarithm of $\mu_t^d$ and $\mu_t^n$ are taken and their differences given the following expression

\[
\ln \mu_t^d(p_t, p_{t+1}) - \ln \mu_t^n(p_t, p_{t+1}) = g(d) - \alpha ECC_t^d ,
\]

(6)

\[
= g(d) - \alpha p_t^d + \alpha \beta p_{t+1}^{d+1} ,
\]

(7)

for $t = 1, ...T, d = 0, 1, ...D$. Note that the market share of each type is defined by

\[
\mu_t^d = \begin{cases} 
\frac{x_t + \sum_j q_{jt}^d}{M} & \text{if } d = 0, \\
\frac{s_t^d}{M} & \text{if } d = 1, 2, ...D \\
1 - \left(\frac{\sum_j q_{jt}^d + \sum_d s_t^d + x_t}{M}\right) & \text{if } d = n.
\end{cases}
\]

(8)

Iterating over the future expected capital cost $ECC$, together with some manipulations, yields the

\(^{17}\)Berkovec (1985) considers stochastic breakdown and the scrappage possibility for automobiles. Correspondingly, the expected capital cost takes these possible events into consideration. In the case of condominiums, as a complete breakdown is seldom observed, I disregard this possibility.
following expression for the price of each new unit produced by firm j.

\[
p^0_t = \frac{1}{\alpha} \left[ \sum_{d=0}^{D} \beta^d (\ln \mu^n_{t+d} - \ln \mu^d_{t+d} + g(d)) \right] + \beta^{D+1} p_{t+D+1}, \tag{9}
\]

\[
= P^0(s_t, x_t, x_{t+1}, ..., x_{t+D}, \check{q}_t, \check{q}_{t+1}, ..., \check{q}_{t+D}). \tag{10}
\]

It shows that the price of each new product depends not only on today’s production \((\check{q}_t, x_t)\), but also on that of future \((\check{q}_{t+k}, x_{t+k}, k = 1, ..., D)\) and of the past \((\check{s}_t)\), through the outside market share \(\mu^n_{t+d}\).

The multinomial logit is notorious for imposing a very restrictive substitution pattern with regards to demand; the substitution of any two products depends only on the characteristics of those two products, and not on those of any other similar products. In this application, when the price of a new condominium goes up, substitution is allocated according to the ratio of the market share of other options, namely vintages younger than \(D\) years old and the outside option of not buying or of buying condominiums more than 3 years old. The alternative model that alleviate this problem is a nested logit model, wherein a tree structure is imposed on consumers’ preferences.

The resulting equation, corresponding to eq. (6), is given as follows.

\[
\ln \mu^d_t(p_t, p_{t+1}) - \ln \mu^n_t(p_t, p_{t+1}) = g(d) - \alpha ECC^d_t - \zeta \ln \mu^{d/g}_t(p_t, p_{t+1}), \tag{11}
\]

\[
= g(d) - \alpha p^d_t + \alpha / \beta p^{d+1}_{t+1} - \zeta \ln \mu^{d/g}_t(p_t, p_{t+1}), \tag{12}
\]

for \(t = 1, ..., T, d = 0, 1, ..., D\). \(\mu^{d/g}_t\) represents the market share of vintage \(d\) within the group and \(\zeta\) represents the correlation between consumers’ preferences on new condominiums versus older condominiums, and takes a value between 0 and 1. A value for \(\zeta\) closer to 1 implies a higher correlation between inside goods. \(^{18}\) In the results section, the estimates using the nested model, which allows for two groups-one inclusive of new units and units younger than \(D\) years old, and that the other inclusive of the outside alternative.

\(^{18}\)For a detailed assumption on errors and the derivation of this relationship, see McFadden (1978).
4.3 Firms

Firms are competing in a Cournot quantity setting game. Condominium development requires a long period of planning and it is difficult to make quick adjustments in terms of the number of units being supplied once a development plan is approved by the authorities. Thus, it is reasonable to consider the production level as a strategic variable of a firm. Given the inverse demand function of new product (9) and cost function (1), firm \( j \) chooses the level of production to maximize the present discounted profit:

\[
\sum_{\tau=t}^{\infty} \beta^{\tau-t} E_t \left[ p^0_{j\tau} q_{j\tau} - C(q_{j\tau}, \bar{c}_\tau) \right].
\] (13)

Because of the dependence of new condominium prices on the current, future and past production of the entire condominium stock (i.e., of all firms), any given firm’s production strategy may depend on the entire history of its production. The convenient assumption is to allow all firms’ production plans at time \( t \) to depend only on the stock of condominiums that is actively being traded in the market at any given time. This assumption corresponds to the concept of a Markov Perfect equilibrium, which is a subgame perfect equilibrium where actions are only functions of payoff-relevant state variables as defined in Maskin and Tirole (1988a, 1988b). In the current problem, the payoff relevant variables are the state variables (\( \vec{S}_t \)), as defined in the previous section.

Formally a firm’s problem is given by

\[
\max_{q_{jt}} \sum_{\tau=t}^{\infty} \beta^{\tau-t} E_t \left[ p^0_{j\tau} q_{j\tau} - C(q_{j\tau}, \bar{c}_\tau) \right],
\] (14)

subject to (2) and

\[
q_{jt} = h_j(\vec{S}_t),
\] (15)

and

\[
q_{jt} \leq M - \sum_{d'=1}^{d}\ s^{d'}_t - x_t - \sum_{j' \neq j} q_{j't},
\] (16)

given

\[
q_{j't} = h_{j'}(\vec{S}_t), \ j' = 1, 2, ... j - 1, j + 1, ... J,
\] (17)
where $h_l(\cdot)$ is the stationary policy function for firm $l$. The constraints (15) and (17) ensure that the solution is a Markov Perfect Nash Equilibrium. The expectation operator in the infinite sum in problem (14) is over the $\eta_s$ and $\xi_s$, $s = t, t + 1, \ldots$. The constraint (16) is there in order to restrict choice of production within the market size so that there is no oversupply. At the equilibrium, the policy functions that rational firms use to forecast future production, both their own and that of competitors, must coincide with the optimal policy for each. Note that in this case, the equilibrium strategy corresponds to a time consistent one.

The problem stated by equations from (14) to (17) gives the following Bellman equation

$$V_j(\vec{S}_t) = \max_{q_{jt}} E\pi_{jt}(\vec{S}_t, q_{jt}, \vec{q}_{-jt}, \vec{q}_{t+1}) + \beta EV_j(\vec{S}_{t+1}|\vec{q}_t),$$  \hspace{1cm} (18)

subject to (2) and (15) for $j = 1, \ldots, J$. $\vec{q}_{-jt}$ denotes a vector of production at time $t$, for all firms but $j$. It can be further simplified as follows:

$$V_j(\vec{S}_t) = \max_{q_{jt}} E\pi_{jt}(\vec{S}_t, q_{jt}, \vec{q}_{-jt}, H(\vec{S}_{t+1})) + \beta EV_j(\vec{S}_{t+1}),$$  \hspace{1cm} (19)

where the vector $H(\vec{S}_r) = [h_1(\vec{S}_r), \ldots, h_J(\vec{S}_r)]'$ stands for the vector of (expected) future production given the state $\vec{S}_r$. In order to obtain tractability and overcome computational burden, I focus only on the symmetric equilibrium, so that $h_j(\vec{S}_r) = h(\vec{S}_r)$ for all $j$.

4.4 Discussions about Some Assumptions

In this section, I discuss four assumptions that, while important in implementing the estimation, are certainly not innocuous. First, products are differentiated only by vintage. Thus, condominiums are homogeneous within the same vintage and the quality of the product in a given vintage is constant for each given time. Though the data suggests that each year there exists great variation in the characteristics of new condominiums, and that those characteristics change over time, this assumption is nonetheless maintained, as the focus of the current paper is on the durability of
condominiums.\textsuperscript{19} This simplification implies that firms take the quality of each rival’s product as a given; likewise, that they consider said quality as being the same as their own.

Second, firms are homogeneous. This restriction, together with the first assumption, greatly reduces the dimensionality of the problem by allowing a structure wherein the policy function only depends on common variables (i.e. total stock, exogenous production and macro cost shock), rather than also on firm-specific variables. It also enables me to impose a symmetric equilibrium when solving the model. If firm-specific variables are included in the set of state variables, the dimension of the problem grows with the number of the firms, and the problem quickly becomes intractable. The gain from these assumptions is that we are only required to solve the problem for a single agent. A drawback from this restriction is that the model does not explain the variation in the production level across firms, something which is observed in the data. Instead, this is dealt with using idiosyncratic production errors, as described in the estimation section.

Third, the terminal value of the condominium unit is fixed. This assumption permits us to obtain an analytical expression for the inverse demand function in a very simple manner. There are two shortcomings however; first, we get a high price elasticity of demand and a low sensitivity of price to output, inasmuch as the terminal value does not depend on the stock or production. Second, it is likely that $\tilde{c}$ is correlated with $\bar{p}$, because of the certainty that the value of the physical building will depreciate over time; thus, the price gets much closer to the land price as it ages. Nevertheless, it is difficult to infer the relationship between these variables unless I impose further structure on them, as I cannot directly observe $\tilde{c}$.

Fourth, $\tilde{c}$ is treated as being exogenous. Hence, the cost, mainly as reflected in the land price, is not allowed to be endogenous: if the project involves the development of a large community, large-scale condominium construction could raise the value of the land.

\textsuperscript{19}Treating the products of oligopolistic firms and the product of fringes is unlikely to be problematic. The estimation of probability that a unit is provided by a fringe firm controlling for characteristics and year effects by Probit indicates there are no substantial difference between products of two types of firms.
5 Estimation

The set of structural parameters in the model described above is $\Theta = [\bar{x}, \vartheta, \sigma^2_\xi, \alpha, \beta, \delta, \bar{p}, \{g(d)\}_{d = 0, 1, \ldots D}, c_1, c_2, \rho, \sigma^2_\eta]$. This section describes the estimation strategy of those parameters.

5.1 Data

The data for this study was obtained from two sources: primary market data for the years 1990 to 2000 was taken from the yearly publication "National Condominium Market Trend," as constructed by the Real Estate Economic Institute; secondary market data was taken from periodical advertisements entitled "Weekly Housing Information," for the years 1992 to 2002, as published by Recruit Co., Ltd. The first set of data is organized by sales phase and includes the names of buildings, their addresses, closest train stations, distances to stations, the names of developers, the names of builders, as well as other characteristic variables as shown in Table 3. The second set of data is organized by unit. Two datasets are merged using common information such as the names of buildings and addresses. However, for each given time, the majority of condominiums are not traded; furthermore, the "Weekly Housing Information" advertisements do not cover all the properties on the market. For these reasons, prices for unobserved units are imputed using a linear regression of prices for each age, and on characteristics variables using data on observed units. Appendix B describes the method in detail.

The last two sections in Table 3 report the summary statistics for imputed prices. Prices are adjusted for inflation using a GDP deflator. The base year is 1995. In order to obtain numerical stability in the nested algorithm, prices are re-scaled by 1 one millionth, and the units are rescaled by 1 one thousandth.

My model classifies firms into two types, oligopolistic firms and fringe firms. The firms that had been in the top 15 in terms of market share during these 9 consecutive years are classified as oligopolistic firms. \(^{20}\)

\(^{20}\)These are Mitsui, Daikyo, Town, Sumitomo and Recruit.
5.2 Predetermined Parameters

Some parameters that are predetermined in the estimation procedure are summarized in Table 4; these are predetermined in order to implement the estimation.

Two parameters that dictate durability in the model are fixed—the lifespan of a condominium unit $D$ and the depreciation factor $\delta$—for computational reasons. The value of $D$, representing the lifespan of a condominium unit, is fixed at one calendar year in order to reduce the dimensionality. Note that as $D$ increases, the number of vintages included in the state vector increases accordingly. In order to see the consequence of this treatment, the production paths of monopolists over a period of 25 years for $D = 1$ and $D = 2$ are simulated using the same parameter values. The results are shown in Figure 2. The diagram indicates that there are no substantial differences in the nature of the two series. Although the same parameter values are used, additions to the vintage increase the value of a steady state; thus, we see the difference in the levels of production. Since what is important for the estimation and for the purpose of this study is the property of the series, this treatment does not cause any substantial differences in the results.  

It is unlikely that a condominium unit physically depreciates over the first two years of its life. However, I set its annual depreciation rate $(1 - \delta)$ at .01 for two reasons. First, since the precise data of the stock of condominiums is unavailable, the parameter value cannot be estimated. Second, the numerical stability of the nested dynamic programming algorithm requires $1 - \delta$ to be strictly greater than 0.

The common discount factor for firms and consumers is fixed at $\beta = .975$, which reflects the interest rate during this period and follows the convention of dynamic found in the IO literature.

As discussed in the previous section, in order to obtain an analytical expression of the inverse demand function, the price of a two-year-old unit ($\bar{p}$) is considered constant. In the estimation, it is fixed at 42.3 million yen, which corresponds to the weighted average (imputed) price of a two-year-old unit between 1994 and 2002.  

---

21 For the initial value of this simulation, I used the value corresponding to the 1991 observations for stock and exogenous production, and the calibrated value for the macro cost shock. The method of calculation for the initial value of the macro cost shock is described in appendix C.

22 The simple average of the imputed unit price for the same period was 45.52 million yen, with a standard deviation of 29.18 million yen.
The cost parameter $c_1$ is set at 24.71 million yen. This parameter is thought of as constituting the steady state of the level of the constant portion of the marginal cost. For numerical optimization, I restrict the sum of $c_1$ and the macro shock ($\tilde{c}_t$) so that it is bounded below by 0. If this parameter is to be estimated, the range of $\tilde{c}_t$ has to be adjusted for each iteration, something which increases the computation time. The variance of the macro cost shock, $\sigma^2_{\eta}$ is normalized at 1, as the policy function is very insensitive to this parameter. The market size ($M$) is fixed at 3,514,000, which is equal to the number of households in the area in 1995, a figure obtained from the census data. Thus, outside alternatives include not only condominiums older than two years old but also all types of housing, inclusive of single unit ownership and "no purchase.” "No purchase” is equivalent to rental housing.

Given these fixed parameters, the set of structural parameters to be estimated is reduced to $\Theta = [\bar{x}, \vartheta, \sigma^2_\xi, \alpha, g(0), g(1), c_2, \rho]$. In the next subsection, structural errors are introduced. Subsequently the three-step estimation procedure is described.

### 5.3 Structural Errors

In order to carry out a statistic inference of the model, the structural errors - observed by the agents in the model but not by the econometrician - have to be introduced so that variations observed in the data will be generated by the model.

The key equations for the estimation are the market share equations (6) and the equilibrium production rule (15). For the demand side relationship, the assumption about a consumer’s expectation (i.e., perfect foresight) is relaxed, and a rational expectation is assumed instead. Specifically, the price of product age $d+1$ at time $t+1$ can be written as follows:

$$p_{t+1}^{d+1} = E_t(p_{t+1}^{d+1}|\Omega_t) + \nu_{t,t+1}^{d+1},$$

where $\Omega_t$ is the information available at time $t$ and $\nu_{t,t+1}^{d+1}$ is the forecast error for vintage $d$.

For the supply side, a structural error $\lambda_{jt}$ for firm $j$ at time $t$ is introduced; thus, the relation

\footnote{Note that the actual price of product age $d$ at time $t$ in the next period when the product’s age is $d+1$}
between the observed data and the optimal production rule can be written as:

\[ q_{jt} = h(S_t) + \lambda_{jt}, j = 1, ..., J, \]  

(21)

where it is assumed that \( \lambda_{jt} \) is unobserved by any firm when making a decision, and that it is identically independently distributed with respect to \( N(0, \sigma^2_\lambda) \) across firms and time. This implies that a producer integrates out, not only its own structural errors, but also those of its rivals when solving the problem (19). This change in the assumption adds one more parameter to estimate, \( \sigma^2_\lambda \). The assumption that there may be unexpected adjustments in the production at the time of planning may sound restrictive. However, it is observed that, in some cases, condominium developers purchase condominium buildings from other developers. Hence \( \lambda_{jt} \) can be thought of as constituting such adjustments.

Additionally, the forecast error \( \nu_{t,t+1} \) and \( \lambda_{jt} \) are assumed to be independent across time, firms and vintages. With this assumption, the introduction of \( \nu_{t,t+1} \) does not change the problem for the producer.

Using forecast errors as the basis for an estimation is not a common approach in the empirical discrete choice literature, which assumes the existence of unobserved heterogeneity. In this model, the time invariant heterogeneity is captured by the term \( \gamma_d \), while time variant heterogeneity cannot be introduced, as it will not be consistent with the dynamic problem solved by the producers unless \( \nu_{t,t+1} \) is treated as another state variable. This is not feasible because of computational difficulties.

An alternative structure is the introduction of measurement errors. However, as the equilibrium production rule (21) is not linear for state variables measured using past errors, the construction of the GMM objective function requires an integration of all past errors. This is not available, however, given the current computational ability.

24One of the advantages of the GMM over other methods, such as the maximum likelihood estimation, is that it does not require a parametric assumption of the error term. However, in this model, a parametric assumption is required, as the current price and profit depends on \( \omega_{jt} \), and each firm solves its own profit maximization problem with regard to expectation.

25It is because the forecast errors are entered additively to the expected price function that the expected current period profit function is identical to the one without \( \nu_{t,t+1} \), so long as it is independent of \( q \) or \( \lambda \).
The First Step - Estimation of $x_t$ Process

The evolution of $x_t$, the production level of fringe competitors, is estimated using the data from 1985 to 2000, by regressing it for its lagged variable (i.e. $x_{t-1}$). From the residuals, I recover the estimate for $\sigma^2_\xi$.

The Second Step – Estimation of the Demand Parameters $(\alpha, g(0), g(1))$

Since the model treats all condominiums of the same vintage as homogenous, the corresponding data is aggregated by year. Inasmuch as the aggregation makes the number of observation too few for a reasonable estimation, I employ firm-level data to estimate the parameters $\alpha$, $g(0)$ and $g(1)$. Let the variables that vary across firms be indexed by $j$. To capture quality variations across products as produced by different firms, a characteristic vector, $\vec{x}_{j,t}$, is introduced.

The introduction of forecast error $\nu_{t,t+1}^{d+1}$ and the use of firm-level data modify the equation (6) as follows:

$$
\ln \mu_{jt}^d - \ln \mu_t^n = \vec{x}_{j,t}^d \Gamma - \alpha (p_{jt}^d - \beta Ep_{jt+1}^{d+1}),
$$

$$
= \vec{x}_{j,t}^d \Gamma - \alpha (p_{jt}^d - \beta p_{jt+1}^{d+1} - \beta \nu_{jt+1}^{d+1}),
$$

$$
= \vec{x}_{j,t}^d \Gamma - \alpha CC_{jt}^d + \omega_{jt+1}^{d+1}, j = 1, ..., \tilde{J}, d = 0, 1, t = 1, ..., T, \quad (22)
$$

where $CC_{jt}^d (= p_{jt}^d - \beta p_{jt+1}^{d+1})$ denotes the realized capital cost of a product produced by $j$, of age $d$ at time $t$.

As the disturbance ($\omega_{jt+1}^{d+1} = \alpha / \beta \nu_{jt+1}^{d+1}$) is due to a forecast error, its definition gives the orthogonality condition as follows. (i.e., given the information set at time $t$, the expected error on the forecast is 0.)

$$
E(\omega_{jt+1}^{d+1} | \Omega_t) = 0
$$

$$
E(y_{jt} \cdot \omega_{jt+1}^{d+1}) = 0, \quad (23)
$$

where $y_{jt}$ consists of variables that are known at time $t$, yet which vary across time and vintages. Note that $\Omega_t$ cannot include $q_{jt}$, as it is not known when consumers make their choices. $y_{jt}$ includes
constant and lagged realized capital costs \( CC^{d}_{jt-1} \), as well as some characteristic variables. The consistent estimates for the demand parameters \((\alpha, \Gamma)\) can be obtained using a two-stage least-square estimator. The parameters for the next estimation step, \(g(0)\) and \(g(1)\), are obtained by calculating the mean characteristic vector for each vintage across \( j \) and \( t \) \( \vec{x}^{d} = \sum \sum \vec{x}^{d}_{j,t} \), and by evaluating \( \hat{g}(d) = \vec{x}^{d} \hat{\Gamma} \) for \( d = 0, 1 \). By doing this, \( g(d) \) becomes fixed to the mean of the quality for vintage \( d \) across time.

**The Third Step – Estimation of the Supply Parameters**

Given the estimates from the previous steps, I recover the cost related parameters \((\rho, \sigma^{2}_{\lambda}, \sigma_{2})\) by estimating eq. (21), using the nested GMM procedure as per Esteban and Shum (2006). In this model, where the parametric form of the policy function is unknown, my data matching procedure utilizes a function approximation technique. Given the variables \( \tilde{z}_{jt} \), which are orthogonal to \( \lambda_{jt} \), I am able to obtain the moment condition:

\[
E(\tilde{z}_{jt} \cdot \lambda_{jt}) = 0. 
\]  

(24)

Under the assumption \( \lambda_{jt} \), the instruments are constant, lagged production for two periods with the exception of its own, exogenous production (i.e. \( z_{jt} = [1, q_{-j,t-1}, q_{-j,t-2}, x_{t}] \)). The distribution assumption for \( \lambda_{jt} \) gives another moment restriction, based on the second moment for \( \lambda_{jt} \), namely,

\[
E \left[ (\tilde{z}_{jt}^{'} \lambda^{2}_{jt} - \sigma^{2}_{\lambda}) \right] = 0. 
\]  

(25)

The stacking conditions (24) and (25), together yield \( E(Z_{jt} \ast \Lambda_{jt}) = 0 \), where \( Z_{jt} \) is the block diagonal matrix. Its sample analogue is given by

\[
Y_{s} = \frac{1}{TJ} \sum_{t=1}^{T} \sum_{j=1}^{J} Z_{jt} \ast \Lambda_{jt}. 
\]  

(26)

For each evaluation of the set of parameter values, the firms’ dynamic programming problem has to be solved, as the function \( h(\cdot) \) is a function of parameters \((\rho, \sigma^{2}_{\lambda}, \sigma_{2})\).
The GMM criteria function (26) is, however, not available due to an initial condition problem – one of the state variables, \( \tilde{c} \), is unobservable and serially correlated. The feasible objective function is obtained by integrating out sequence of \( \tilde{c} \) from (26) using density of \( \tilde{c} \). Nevertheless, as any of \( \tilde{c} \) is observable, serial dependence of \( \tilde{c} \) requires further assumption on its initial value (or terminal value). In this application, the terminal value \( \tilde{c}_T \) is assumed to be non stochastic and fixed to the value based on informal information on the cost of condominium production in the late 1990s. See appendix C for how I calibrated this value. The feasible moment condition is thus given by

\[
\Upsilon_{si} = \frac{1}{J} \sum_{j=1}^{J} \int \cdots \int Z_{jt} \ast A_{jt}(\tilde{c}) f(\tilde{c} | c_T) d\tilde{c}. \tag{27}
\]

Given a positive definite weighting matrix \( \hat{\Xi}_s \), the GMM estimator minimizes \( \Upsilon_{si}^{-\frac{1}{2}} \hat{\Xi}_s \Upsilon_{si} \). In the first stage estimation, I used inverse of squared instrument matrix as \( \hat{\Xi}_s \). The results reported in this paper is the optimal GMM estimator, which uses a consistent estimate of \( E(\Upsilon_{si} \ast \Upsilon_{si}') \) as a weighting matrix.

5.4 Identification

As explained in the first and the second estimation steps, identifications of parameters for the process of production by fringe competitors and the demand system are obtained using cross-sectional and time series variations of observables – market shares, observed capital costs, and aggregate production by fringe competitors. However, the identification in the third step is not trivial. Although the model in this paper fully specifies the parametric form in the return function, those assumptions alone do not guarantee identification. Stated more formally, the objective function for the estimation (optimally weighted quadratic form of the GMM conditions) has to be reasonably sensitive to the change in parameter values.

In order to gain some ideas about its sensitivity to the parameter values in which we are interested, I present simulated production paths of a monopolist for different values of \( \bar{c}_2 \) and \( \rho \) in Figure 3. The initial value of each simulation is set at the observed value for 1991, and each run

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\( ^{26} \)For a more precise discussion of non-parametrical identification of the dynamic Markov decision problem, see Rust (1994).
consists of 10,000 simulations over 9 periods. The panel on the left shows that the increase in \( \bar{c}_2 \), the coefficient of the quadratic term in the cost function, decreases the production at each period but does not greatly change the shape of the path. Thus it determines the level of the optimal production. The panel on the right indicates that low value of \( \rho \), which imply the smaller persistence of the macro cost shock (\( \tilde{c} \)), generates a hump-shaped path by making \( \tilde{c} \) reach steady state faster. Hence, the peak of the production shifts later, as \( \rho \) increases. At higher level of \( \rho \), the peak does not realize within 9 periods. Therefore, observed variations of the level of production can identify \( \tilde{c} \) and observed shapes of the production paths can identify \( \rho \). The variance of idiosyncratic production shock, \( \sigma^2 \), can be identified by cross-sectional variations in production as all heterogeneity among the firms are summarized in \( \lambda_{jt} \) in the model. \(^{27}\)

6 Results

6.1 The Parameter Estimates

The estimation results are reported in Tables 5, 6 and 7 for each estimation step. The process for \( x_t \) is estimated with a positive and significant AR(1) coefficient, \( \vartheta \), and is less than one, as seen in Table 5. The constant term is positive, but not significant, however. Those parameter estimates imply that the process of \( x_t \) is gradually converging toward a positive steady state value, \( x^{ss} \), which is estimated to be 31,613.3 units.

The demand system is estimated using demand data aggregated at the firm level for the period 1993 to 1998. The period includes the year of change in consumption tax rate. It is likely to have large impact to consumption. Nevertheless I assume that all consumers and firms anticipated this change in the beginning of the period in this paper. \(^{28}\) There are 449 firms over the estimation period, leading to 624 firm-year observations. Selected results for the demand parameters are reported in Table 6. Columns (i) and (ii) report the estimates for the multinomial Logit(MNL) model by OLS and GMM respectively, while columns (iii) and (iv) show the estimates for the

\(^{27}\)There are 45 samples with a mean of 1.25 thousand, and a standard deviation of 1.024.

\(^{28}\)The consumption tax was raised from 3 to 5 percent in April 1997, in order to compensate for fiscal loss from the income tax cut plan determined in 1994. Note that the consumption tax is imposed on any consumption expenditure, inclusive of residential buildings while the value of the land is not subject to it.
nested Logit model by OLS and GMM respectively. Since imputed prices are used as values of condominium stock, standard errors must be adjusted for the noise from imputation. The correction is conducted by bootstrap method.

The value of $\zeta$, which represents a correlation of preference within the condominium group, is significant and very close to 1. It indicates that condominiums closer in age (new and one year old condominiums in this case) substitute more highly with each other, and the data supports the nested Logit model over the MNL model.

Possible endogeneity for expected capital cost is dealt with using its own lag and the log of its height. The coefficient for expected capital cost, $\alpha$ is estimated to be negative and significant for all specifications, though the magnitude’s absolute value is larger when instruments are used, indicating that the forecast error $\omega_{jt}$ causes a bias toward zero. The negative value of $\alpha$ suggests that consumers prefer a good with a lower capital cost, as was expected. Table 6 also reports that the test statistics for instrument relevance (the canonical correlations likelihood-ratio test), endogeneity and overidentification restriction for each model in the GMM estimation.

Dummy variables for age, which measure the quality of each vintage after controlling for other characteristic variables, are negative and significant for all ages and for all specifications, implying that, relative to the outside alternative, consumers value new and one-year old condominium units less. Among condominiums, new condominiums are valued more highly than old condominiums, as is shown by the larger estimated coefficient of the age 0 dummy relative to the age 1 dummy.

Having obtained estimated parameters for the age dummies and the other characteristic variables, the vintage quality parameters $g(d), d = 0, 1$ are calculated using the mean value for each characteristic variable; these are reported in Table 6. They represent the average valuations of consumers on condominium units for each vintage relative to outside goods. In each specification, the ranking of these two parameters by age stays the same as that for the age dummies. Due to the complexity of computing a dynamic programming problem for the nested Logit demand specification, I use the results for specification (ii) as the basis for the remaining results reported in the paper. The remaining results should be understood as being preliminary but indicative of the results that could be obtained using this model. Updated results using a more sensible specification
(iv) will be reported in the next version of this paper.

The cost parameters estimated in the third step are reported in Table 7. Firm-level data for five oligopolist firms over six periods (from 1993 to 1998) were used. Note that standard errors reported here are not adjusted for errors from the second step estimation. The estimates for $\rho$ indicate that the macro cost shock is a stationary process. $c_2$ is positive and significant, which confirms that the technology in this industry has a decreasing return to scale. This implies that condominium developers have an incentive to spread production across time, as indicated in Kahn (1986); thus, they have some ability to commit to a future production plan.

6.2 The Numerical Solution of the Model

In this section, the solution of the producers’ problem with the estimated parameters is presented. The solution of the model is obtained by the policy function iteration algorithm utilizing function approximation technique called collocation method that is described in appendix A.

The panels in Figure 4 display the resulting policy function corresponding to eq. (21), the value function, and the price of a new condominium as a function of the macro cost shock ($\tilde{c}_t$) and production by fringe competitors ($x_t$) at the steady-state stock level ($s^{**} = 38.11$).

Both the policy and value functions are decreasing for all the state variables: the age 1 stock ($s_t$), the fringe competitors ($x_t$) and the macro cost shock ($\tilde{c}_t$). To understand the nature of the optimal production policy, it is useful to break down the states based on the values of the exogenous state variables, $\tilde{c}_t$ and $x_t$, relative to their steady states. For instance, if $\tilde{c}_t$ is above 0, the process shows a decreasing trend; thus, the state describes a deflationary period for $\tilde{c}_t$. If $x_t$ is below the steady state value (=31.61), the process shows an increasing trend and the state describes a growth period. Table 8 reports the elasticities of policy function with respect to each state variable for different exogenous state phases. For example, when the macro cost shock is deflationary and the exogenous competitor is growing, 1% changes for the 1 year old stock results, with a .02 % change in production. From this analysis, three more properties of the policy function are derived.

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29In order to obtain correct standard errors, one needs to perform bootstrap sampling for the second stage (demand data) and conduct the third step estimation for each subsample. Nevertheless, the third step estimation is computationally burdensome for even once as described above. Thus the correction has not been made in this paper.
First, as measured by elasticities, the policy is more responsive to production by the fringe competitors \( x_t \) than to the one-year-old stock \( s_t \); this is true for all states. For example, a 1% increase in \( x_t \) leads to somewhere between a .08% and .38% decrease in production, while a 1% increase in \( s_t \) leads to roughly a .02 % decrease in production. The intuition behind this result is that \( x_t \) influences the market longer through future stock than one year old stock, since \( x_t \) is part of current production.

Second, production is more responsive to the exogenous state variables when the cost is in a deflationary period, \( (\tilde{c} > 0) \), and exogenous production is contracting \( (x > 38.11) \). Conversely, production is less responsive when the macro cost shock is appreciating and exogenous production is growing. This reflects the effect of consumers expectations; since the policy function is a decreasing function of both \( \tilde{c} \) and \( x \), inflation in the cost and growth in exogenous production imply lower production in the future. As a result, consumers are convinced that there will not be a drastic price cut in the future; consequently, producers do not have to respond to changes in the market environment so much. As a result, adjustment towards the steady state is slower. With the opposite scenario where cost depreciates and fringe competitors contract producers have to respond relatively more, as consumers expect greater production and lower prices. Therefore, the convergence to the steady state occurs more rapidly than in the inflationary phase. This property corresponds to the result in Kahn (1986), whereby a decreasing return to scale cost function helps firms to credibly implement a low production plan, though in this case, the cost is variant over time. Furthermore, in the deflationary phase of the macro cost shock, consumers correctly expect a future price cut, on account of which, producers quickly lose the market power.

Third, the response to the stock of one-year olds does not vary very much with respect to the exogenous variables. This is partly due to the fact that the stock will move from the market to outside alternative the next period; thus, the stock does not have a direct impact on the future market.
6.3 Simulations

In this section, several simulation results are presented to show the dynamics in the market. All simulations are over 10,000 independent nine-period simulations of the dynamic model, unless otherwise noted. For the initial condition of $s_t$ and $x_t$, the actual observations for 1991 are used.

For $\tilde{c}_t$, which cannot be observed directly, I impose $\tilde{c}_{2000} = 1.68$, which is the calibrated value of $\tilde{c}$, based on industry information and the estimated parameter value. The calculation method is described in appendix C.

Predictive Power of the Model

Table 9 compares the simulated statistics and the observations for total production, new condominium prices and the production by fringe competitors. The mean predictions and mean observations are quite close for all variables. The performance is especially good for the prices. The last rows in the table report the percentages of time within which the predictions fall within the 10% intervals from observations. The percentage for prices is 53 % and for production, is on average, 38%. One possible explanation for this performance has to do with the realization of the unobserved state variable, $\tilde{c}$. In 1991, land prices dropped dramatically – by 12 % – possibly causing a sharp decline in $\tilde{c}$. However, my specification only allows for a smooth depreciation on average, inasmuch as I obtain a conjecture on the initial value of $\tilde{c}$, based on the information at the end of the observation period using the estimated smooth process of $\tilde{c}$. Naturally, this leads to a lower value for $\tilde{c}$ than that for the actual realization.

Market Power and Profits

The mean prediction of markup, evaluated at the marginal cost, is reported in the last column of Table 9. The markups are between 0.6% and 0.9%, which are small values and indicate that firms may not possess substantial market power. 3132

31 In general, the model with the estimated parameter values yields a low level of markup across all range of states where the problem is solved. Using simulations, I assess to what extent an assumption that firms produce differentiated products can lead to higher markups. The results are reported in the next version of this paper.
32 I estimate the model with a competitive assumption, in which five oligopolistic firms act as price takers. The estimated parameters are reported in the last column of 7. The Vuong test statistic is -.58, suggesting that both models explain the data equally well.
Given my quadratic production costs specification, however, markups evaluated at the marginal costs for firms are not indicative of profits. The profit margin measured using the average cost is 22.9% on average in the simulated data. This level of profit margin is comparable to the profit margins reported in the financial statements of several leading firms during the later 1990s, which suggests that the condominium business yield profit margin is about 15%.

The Role of Cost Variations

The role of the cost regime (i.e., the inflationary or deflationary phase) with respect to firms commitment abilities is examined using simulations where all the conditions of the previous simulation are maintained with the exception of the setting of the last value of the macro shock, \( \tilde{c}_{2000} = -1.68 \). This value takes the opposite sign as in the first simulation; thus, the distance from the steady state is exactly the same but the cost is in an inflationary phase. Figure 5 plots the mean data for this simulation against that from the previous simulation. Overall production, inclusive of exogenous production, increases, while the production by oligopolistic firms decreases throughout the simulation periods. Consequently, the price also decreases over time, reflecting the transition in aggregated production.

The price-cost margin during the cost inflation phase is significantly higher than that during the deflationary phase. This indicates that firms have more market power during the inflationary phase. On average, the markup with inflation is 39% higher relative to that under deflation. In terms of market share, it is, on average, 26% higher under inflation than under deflation. Underlying these results is the change in the incentive of producers compared to that under the time invariant cost structure. When cost is appreciating, a firm has an incentive to produce more now rather than later, since it is more costly to produce in the future. On the other hand, when cost is depreciating, a firm has an incentive to postpone production, as it can save on the cost by accruing a lower marginal cost tomorrow. Forward looking consumers are aware of these incentive to firms. Therefore, cost inflation makes consumers believe that firms will not flood the market in the future; thus, their willingness to pay does not decrease. Cost deflation leads to a reduction in willingness to pay. Hence, the time inconsistency problem of firms becomes less serious during the cost appreciation.

\(^{33}\)For example, Daikyo, the largest developer in the market, reports a 17.2% profit margin for 2001.
phase, but worsens during the cost depreciation phase.

Given that factor prices are still in a deflationary trend on average in the Tokyo market, this result suggests that condominium developers had more difficulty making profits during the 1990s relative to prior decades.

**Durability and Speed of Price Change**

To see the relationship between durability and the speed of condominium price deflation, I perform a simulation of price paths with different values of $\delta$, which measures the degree of the annual depreciation of a condominium unit. A comparison of these simulated paths implies that the more durable the good (the higher the value of $\delta$), the faster the prices deflation rate, given the same rate of cost deflation. For example, the nine-year average deflation rate is -9.23% at $\delta = .99$, whereas it is -7.54% at $\delta = .1$. A higher $\delta$ means a stronger link between the primary market and the secondary market. Since the effect of flooding the market is much larger with higher durability, a producer cannot avoid producing more under deflation, something which leads to faster deflation. This simulation thus confirms that the price deflation caused by macro cost depreciation is accelerated by the durability of the product.

**Factors of Price Depreciation in the 1990s**

For the purpose of decomposing contributors to the price deflation during the 1990s, I obtain the following simulated price paths: (i) the benchmark price path reported in the beginning of this section, (ii) the price path fixed at $\tilde{c}$, and $x_t$ at the initial level for all simulation periods, and (iii) the price path with actual values of $x_t$ and a fixed $\tilde{c}$. By comparing these series, I am able to obtain how much of variation in price is accounted for by increased exogenous competition. Table 10 presents the result of the simulation. On average, 83% of the price variation is accounted for by increased competition due to exogenous fringe competitors. Other factors in particular, cost deflation account for more in 1995 and 1998. The shift in 1998 is likely due to the effect of the change in the tax preferential system, expected to go into effect in 1999. Assuming this law is implemented, potential buyers have a strong incentive to postpone their purchases so as to benefit from the new system. Thus, the price had to go down. However, this component is not accommodated for in the
model. 34

It is thus concluded that the increased competition coming from the entry of small developers is the main factor driving the price decline in the primary market for Tokyo condominiums. One thing to note, however, is the possibility that $x_t$ is correlated with cost factors. It is likely that, in general, competition intensifies as the cost declines. However, this is beyond the scope of the current paper, and is thus left for future research.

**Experiments on Alternative Market Structure**

Up to now, I maintain the assumption that there are five oligopolistic firms and that all other firms are fringe competitors. In order to explore the alternative explanation for the spike in output corresponding to the drop in price, I simulate the path of variables under the assumption that exogenous production ($x_t$) follows a random walk instead of an AR(1) process, with a different number of firms, ($n$), after the third period. This replicates the situation where oligopolistic firms enter or exit the market after the third period while holding the growth of exogenous production at a very low level.

Table 11 reports the summary statistics for this simulation. The first row shows the benchmark values of selected variables. The total annual production was, on average, 28.1 thousand units from the third period onwards.

The later rows show the means of the variables under each value of $n$. It indicates that if the increase in production after 1993 is accounted for entirely by the entrance of oligopolistic firms, there must be 13 firms in total. If this prediction is correct, the aggregate market share of 13 firms will be more than 79%. Yet 15 firms account for only 50% of the market in the observations, as seen in Table 2. Therefore, this experiment rejects the possibility that the increase in the output level is mainly explained by the entrance of firms with market power.

34As a part of the economic stimulus package, the government extended the existing tax preferential system to include mortgage payments on housing loans in 1999. The change, which did go into effect in 1999 as planned, increased the maximum tax benefit from 1.7 million yen to 5.87 million yen, a 245% increase.
7 Conclusion

This paper examines the market phenomenon of the primary market for condominiums in the Tokyo metropolitan area during the 1990s. During this decade, a persistent price decline and increased output were observed.

I focused on the durability of the condominiums in connection with various product characteristics and developed a dynamic oligopoly model based on Esteban (2001). The model incorporates an important feature of this industry; the persistent factor price variations that affect the dynamics of the market on account of the expectations of all agents.

The structural parameters of the proposed model are recovered using a three step estimation procedure, one which includes a nested GMM in which the algorithm solves the dynamic programming problem of producers for each evaluation of the GMM objective function.

At each estimated set of parameter values, the model yields an optimal policy for oligopolists as a decreasing function for all state variables (i.e., condominium stock, exogenous production and macro shock). The optimal policy is the most responsive to the macro shock, followed by exogenous competitors measured by elasticities. Furthermore, the model shows that firms respond to changes in the market environment more drastically during the deflationary phase than during the inflationary phase. This result may call for caution on the part of policymakers when considering the effects of policy instruments, such as modifications in the tax codes.

In the estimation and counterfactual experiments, I found five results. First, the data provides no evidence of the firms in the primary market having any substantial market power in this industry. Second, the inflation in production cost strengthens the market power of condominium producers; at the same time, its deflation exacerbates the erosion of the market power derived from its durability. Third, the deflation of condominium prices is explained by the increase in production of small firms rather than by cost variations.

There are two areas that could be improved upon in future studies. The first concerns the assumption of a transaction cost. In order to simplify the demand dynamics, the current model assumes that there is no transaction cost associated with sales and purchases in the secondary
market. However, the real estate market is known to have various transaction costs, both implicitly and explicitly. Thus, to give more explanatory power to the model, it is necessary to incorporate this component. The second is to allow for a differentiation of condominiums within a particular vintage. In order to do this, it is necessary to simultaneously solve the problems of multiple players; as such, it will be computationally complex. Nevertheless, it would improve the explanatory power of the model given the variations in the observed production of oligopolistic firms.

References


APPENDIX

A Solution Algorithm – the Collocation Method

With few exceptions, the Markov decision problems have no analytical solutions. In such cases, one needs to rely on the numerical solution which is an approximation of the true solution in order to understand the dynamics of the model. We describe here in this note one of the solution methods for a discrete time continuous Markov decision problem, the collocation method. Among the difficulties in solving such problems is the fact that the unknown of the dynamic programming is not a particular variable, but rather consists of two functions, usually known as the value function and the optimal policy function. In collocation methods, this difficulty will be overcome by approximating the value function by using a linear combination of pre-specified functions, called a basis function, and evaluating it at pre-determined state nodes. For details, see Miranda and Fackler (2002).

To simplify the notation, \( s \) denotes a vector of state variables and \( q \) denotes the choice variable. \( g(s, q) \) is the function that describes the transition of a state vector, given the choice of a firm, in the previous period. The problem can be expressed in the following form:

\[
v(s) = \max_q [\pi(s, q) + \beta E v(g(s, q))].
\]

The collocation method suggests an approximation of this value function \( V(\cdot) \), with a linear combination of \( n \) pre-specified functions; these functions are evaluated only at the pre-specified \( n \) state nodes. More specifically, the function \( V \) can be expressed as follows:

\[
v(s) \approx \sum_{j=1}^{n} c_j \phi_j(s),
\]

where \( c_j \) is the scalar and \( \phi_j(s) \) is a/the nonlinear function. The numerical analysis theory offers several choices of functional form for \( \phi_j(s) \) and the associated state nodes, such as the Chebychev polynomial basis and node, and the piecewise polynomial spline and nodes. Based on this approximation, we can rewrite the problem as follows:

\[
\sum_{j=1}^{n} c_j \phi_j(s) = \max_{x} \pi(s, q, h(g(s, q)))... + \beta \sum_{j=1}^{n} c_j \phi_j(g(s, q)).
\]

The task then is to obtain optimal policy function \( h(\cdot) \) and coefficient \( c_j, j = 1, 2, ..., n \).

Once \( \phi_j(\cdot) \)s and \( s \) are selected, the optimal policy and value function can be obtained using the algorithm below. Before describing the algorithm, several notations need to be introduced. Let \( s \) be the vector (or matrix if \( s \) is a vector) of interpolation nodes \([s_1, s_2, ..., s_n]\). Using \( \phi_j(\cdot) \)s and \( s \), I can construct a matrix, \( \Phi \), in which the \( ij \) th element is \( \phi_j(s_k) \), where \( s_k \) is \( k \)th, the interpolation node. Note that this matrix will not change over the solution algorithm. Let \( c = [c_1, c_2, ..., c_n]^\prime \), a vector of the approximation coefficients. Let \( v \) be column vector \([v(s_1), v(s_2), ..., v(s_n)]^\prime\), where \( s_k \) denotes each interpolation node. I can then write (28) as a vector notation:

\[v = \Phi c.\]

The outer loop solves for the value function approximation (obtaining coefficient value \( c_j^*, j = 1, 2, ..., n \)) while the inner loop solves for the optimal policy and the associated value function.
Note that the superscript for $c$ and $h$ stands for the number of iteration steps involved/ found in the outer loop in the description below.

**Step 1** At the beginning of the program, both the initial guess for the coefficient vector, $c^0$ (which approximates the value function), and the initial guess for the optimal policy, $h^0(\cdot)$, are determined.

**Step 2** Given $c^i$, the inner loop solves the Bellman equation and the return policy function and the value at the interpolation nodes, $s$. More specifically, for each interpolation node, $s$ I obtain $q$, thus satisfying the Karush-Kuhn-Tucker condition: \[
\frac{\partial \pi}{\partial q} + \beta \sum_{j=1}^{n} c_j^i \phi_j'(g(s, q)) \frac{\partial g}{\partial q} = 0,
\] where $\phi_j'$ is the first derivative of $\phi_j$. To evaluate this condition, $h_i$ has to be approximated with $\Phi c^*$. This allows me to gain the expected future production. Note that $\Phi$ is the same matrix for the approximation of $v$. This step yields $q = h^{i+1}(s)$ and the optimal value $v^{i+1}(s)$.

**Step 3** Given $v^{i+1}$, $c^i$ can be updated by the following rule: $c^{i+1} = \Phi^{-1} v^{i+1}$. Alternatively, it can be updated using Newton’s method, which uses the iteration rule, $c^{i+1} = c^i + [\Phi - v^{i+1}']^{-1} [\Phi c^i - v^{i+1}]$, where $v^{i+1}'$ is the Jacobian of $v^i$. It will go back to step 2 until $\|c^{i+1} - c^i\|$ reaches a particular level of tolerance.

Note that Miranda and Fackler (2002) provides the MATLAB toolkit, which constructs a vector from the basis function and the corresponding interpolations nodes with the users type of choice.

**B Imputing Future Prices in the Secondary Market**

In this section, I describe the method used for imputing future prices in the secondary market in detail. As mentioned in section 5.1, not all condominium units are traded every year, and not all of the data for those that were traded are available. Thus, future prices ($p_{jt+n}^*$) have to be imputed from the observed data. I followed two steps, as described in the sequel.

First, the secondary market data from the classified magazines documented above is matched with the primary market data by name and address. Out of the entire primary market sample, about 27% of the entries correspond to at least one secondary market entry between 1992 and 2002. The frequencies of correspondence by construction cohort and transaction year in the secondary market are given in Table B. It shows that there are relatively more observations in the birth cohorts between 1994 to 1996 than in other cohorts after 1996. This may be because there are more units in those cohorts than in earlier cohorts, or because the secondary market became more active after 1994, and thus it became more common for relatively young buildings to be sold in the secondary market.

Second, I estimate an imputation equation in the following specification. Note that I use prices per square meter instead of unit prices so as to control for size differences:

\[
\log(p_{jt+n}^*) = a_0 + a_1 \log(p_{jt}^*) + a_3 x + u_{jt},
\] (29)

, where $p_{jt}^*$ is the price of the property when it was sold as new, $x$ is a vector of the characteristics of the condominiums, inclusive of cohort dummies and transaction year dummies, and $u_{jt}$ is an error
term. Note that the OLS estimation of (29) is inclined to be biased, as the error term \( u_{jt} \) is likely to be correlated with (a) regressor(s) due to selection bias. There are at least two potential sources of selection bias. First, prices in the secondary market are only observed if properties are on the market (i.e., if there is incidental truncation). Second, as the sample is drawn from weekly classified magazines, only the subgroup for secondary market transactions is included. In order to correct these biases, Heckman’s two step method is applied. Table 12 reports the estimation of the equation (29) for selected variables from the OLS and selection model. For vector \( x \), I include the log of total units sold initially in the same phase, the log of the distance from the nearest train station, the log of the total area that was sold in the same phase, birth cohort dummies, transaction year dummies, vintage dummies, ward dummies, building height dummies, floor plan dummies, and railroad dummies. The selection of variables are based on Ono, Takatsuji, and Shimizu (2002), who study the hedonic price index using data from the same source as this paper. As my data misses some information, such as the detailed characteristics of each unit, an initial price \( p^*_jt \) is included in the regression to control for unobserved quality variation. In both models, the higher the price in the secondary market, the higher the initial price in the primary market. The negative and significant coefficient estimates on the distance from the nearest train station suggests that the future value of the unit is higher if it is closer to a train station. This is because, generally speaking, stores are concentrated around train stations. The estimates of the vintage dummies are all negative and significant, and the magnitude increases monotonically with the vintage, suggesting that older units are less expensive. The transaction year dummies are negative and monotonically decrease in the year. This implies that property has become less expensive in recent years, something which reflects the overall housing market trend. The birth cohort dummies are positive and increase for each year, up to 1996. There is no incident or event evident driving this result. A comparison of models (a) and (b) shows the direction of bias due to selection. The variables that are the most biased are the vintage and year dummies; the birth cohort dummies are underestimated in terms of magnitude. The vintage dummies are underestimated, while the transaction year dummies are overestimated.

C Calculation of the Terminal Condition for \( \tilde{c} \)

The terminal condition for \( \tilde{c} \) both for estimations and simulations is calibrated based on the costs and profit breakdown estimate for the unit price around 2000 performed by an industry analyst. First, from this information, I know that the average profit per unit was approximately 10% around 2000. Since the weighted average price of condominiums age 0 in the data for the year 2000, the average cost of production is set at 4.32 million yen (= 4.78 * .9).

Second, since the average cost corresponds to the expression in text, \( \tilde{c} + \tilde{c}_1 + \tilde{c}_2 * q \), and \( \tilde{c}_1 \) is fixed to 24.71, the value of \( \tilde{c}^{2000} \) is obtained using average production of five firms for \( q \). This calculation yields \( \tilde{c}^{2000} = 1.68 \), with estimated parameters.
### Table 1: Number of Firms

<table>
<thead>
<tr>
<th>Year</th>
<th>(A) number of active firms</th>
<th>(B) number of single appearance (^a)</th>
<th>(C) (= (B)/(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>89</td>
<td>35</td>
<td>0.393</td>
</tr>
<tr>
<td>1993</td>
<td>111</td>
<td>26</td>
<td>0.234</td>
</tr>
<tr>
<td>1994</td>
<td>205</td>
<td>56</td>
<td>0.273</td>
</tr>
<tr>
<td>1995</td>
<td>228</td>
<td>48</td>
<td>0.211</td>
</tr>
<tr>
<td>1996</td>
<td>227</td>
<td>29</td>
<td>0.128</td>
</tr>
<tr>
<td>1997</td>
<td>231</td>
<td>35</td>
<td>0.152</td>
</tr>
<tr>
<td>1998</td>
<td>221</td>
<td>32</td>
<td>0.145</td>
</tr>
<tr>
<td>1999</td>
<td>230</td>
<td>33</td>
<td>0.143</td>
</tr>
<tr>
<td>2000</td>
<td>231</td>
<td>44</td>
<td>0.190</td>
</tr>
<tr>
<td>Total</td>
<td>1,773</td>
<td>338</td>
<td>0.191</td>
</tr>
</tbody>
</table>

\(^a\)The number of firms that appeared in the dataset only once during the sample period.

### Table 2: Concentration Measures

<table>
<thead>
<tr>
<th>Year</th>
<th>5 -firm(^a)</th>
<th>10-firm(^a)</th>
<th>15-firm(^a)</th>
<th>HHI(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.383</td>
<td>0.523</td>
<td>0.614</td>
<td>0.046</td>
</tr>
<tr>
<td>1993</td>
<td>0.402</td>
<td>0.538</td>
<td>0.618</td>
<td>0.062</td>
</tr>
<tr>
<td>1994</td>
<td>0.309</td>
<td>0.442</td>
<td>0.540</td>
<td>0.032</td>
</tr>
<tr>
<td>1995</td>
<td>0.293</td>
<td>0.416</td>
<td>0.498</td>
<td>0.027</td>
</tr>
<tr>
<td>1996</td>
<td>0.297</td>
<td>0.412</td>
<td>0.501</td>
<td>0.037</td>
</tr>
<tr>
<td>1997</td>
<td>0.306</td>
<td>0.443</td>
<td>0.511</td>
<td>0.036</td>
</tr>
<tr>
<td>1998</td>
<td>0.259</td>
<td>0.385</td>
<td>0.480</td>
<td>0.026</td>
</tr>
<tr>
<td>1999</td>
<td>0.312</td>
<td>0.417</td>
<td>0.495</td>
<td>0.032</td>
</tr>
<tr>
<td>2000</td>
<td>0.317</td>
<td>0.433</td>
<td>0.516</td>
<td>0.030</td>
</tr>
<tr>
<td>Average</td>
<td>0.310</td>
<td>0.433</td>
<td>0.518</td>
<td>0.034</td>
</tr>
</tbody>
</table>

\(^a\)x-firm concentration ratio is the sum of the market share of the top x firms.  
\(^b\)Herfindahl Index.
Table 3: Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>Observations</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minutes from the NTS by car&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7100</td>
<td>0.21</td>
<td>1.52</td>
<td>0</td>
<td>25.00</td>
</tr>
<tr>
<td>Minutes from the NTS by walk&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7100</td>
<td>7.33</td>
<td>4.26</td>
<td>0</td>
<td>27.00</td>
</tr>
<tr>
<td>Distance form the NTS&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7100</td>
<td>711</td>
<td>931</td>
<td>0</td>
<td>15,240</td>
</tr>
<tr>
<td>Height of the building</td>
<td>7100</td>
<td>8.89</td>
<td>4.85</td>
<td>2.00</td>
<td>54.00</td>
</tr>
<tr>
<td>Total units for sale</td>
<td>7100</td>
<td>31.63</td>
<td>33.24</td>
<td>1.00</td>
<td>543.00</td>
</tr>
<tr>
<td>Total area size for the sale (sq. meter)</td>
<td>7100</td>
<td>2,157</td>
<td>2,660</td>
<td>39</td>
<td>46,913</td>
</tr>
<tr>
<td>Total sales</td>
<td>7100</td>
<td>163,650</td>
<td>263,719</td>
<td>2,980</td>
<td>6,006,590</td>
</tr>
<tr>
<td>Average size of the units</td>
<td>7100</td>
<td>69.58</td>
<td>51.90</td>
<td>21.32</td>
<td>1,346.00</td>
</tr>
<tr>
<td>Whether secondary market data is available</td>
<td>7101</td>
<td>0.27</td>
<td>0.44</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Number of developers</td>
<td>7100</td>
<td>1.24</td>
<td>0.58</td>
<td>1.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Price per square meter (0’000 yen)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary market (age0)</td>
<td>7100</td>
<td>77.45</td>
<td>23.54</td>
<td>9.29</td>
<td>833.58</td>
</tr>
<tr>
<td>Secondary market (age1)</td>
<td>7100</td>
<td>74.77</td>
<td>20.16</td>
<td>21.11</td>
<td>410.22</td>
</tr>
<tr>
<td>Secondary market (age2)</td>
<td>7100</td>
<td>71.95</td>
<td>17.97</td>
<td>17.62</td>
<td>342.31</td>
</tr>
<tr>
<td>Secondary market (age3)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5815</td>
<td>69.91</td>
<td>16.52</td>
<td>15.87</td>
<td>308.39</td>
</tr>
<tr>
<td>Unit price (0’000 yen)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary market (age0)</td>
<td>7100</td>
<td>5,460</td>
<td>5,283</td>
<td>1,713</td>
<td>143,688</td>
</tr>
<tr>
<td>Secondary market (age1)</td>
<td>7100</td>
<td>5,242</td>
<td>4,696</td>
<td>1,557</td>
<td>130.006</td>
</tr>
<tr>
<td>Secondary market (age2)</td>
<td>7100</td>
<td>5,044</td>
<td>4,395</td>
<td>1,387</td>
<td>119,616</td>
</tr>
<tr>
<td>Secondary market (age3)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5815</td>
<td>4,869</td>
<td>4,171</td>
<td>1,334</td>
<td>104,349</td>
</tr>
<tr>
<td>Production by a oligopolistic firm</td>
<td>45</td>
<td>1,250</td>
<td>1,024</td>
<td>125</td>
<td>4,054</td>
</tr>
</tbody>
</table>

<sup>a</sup>NTS stands for the “nearest train station.”
<sup>b</sup>The distance is calculated with the formula as follows: dist(meter)=walk*80+bus*600.
<sup>c</sup>They include only the imputed secondary market price in year 1994-2002.

Table 4: Predetermined Parameters

<table>
<thead>
<tr>
<th></th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common discount rate(β)</td>
<td>.975</td>
</tr>
<tr>
<td>1-period survival rate (δ)</td>
<td>.99</td>
</tr>
<tr>
<td>Scrappage price(ρ)</td>
<td>42.3 million(yen)</td>
</tr>
<tr>
<td>Market size(M)</td>
<td>3.514 million (households)</td>
</tr>
<tr>
<td>Number of firms(J)</td>
<td>5</td>
</tr>
<tr>
<td>Steady state cost (ρ&lt;sub&gt;1&lt;/sub&gt;)</td>
<td>24.71 million (yen)</td>
</tr>
<tr>
<td>Variance of macro cost shock (σ&lt;sub&gt;γ&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 5: Parameter Estimates for the process of $x_t$: the first step estimation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Explanation</th>
<th>Value$^a$$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>AR(1) coefficient</td>
<td>0.878 (.203)**</td>
</tr>
<tr>
<td>$\tau$</td>
<td>constant</td>
<td>3.846 (3.189)</td>
</tr>
<tr>
<td>$\sigma_\xi^2$</td>
<td>variance of $\xi$</td>
<td>3.363 (1.767)*</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td>.7692</td>
</tr>
<tr>
<td>Observations</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>$x^{ss}$$^c$</td>
<td>Steady State of $x_t$</td>
<td>31.613 (29.564)</td>
</tr>
</tbody>
</table>

$^a$Robust standard error is given in the parenthesis.
$^b$Stars refer to the significance level of a t-test.
$^*=$ significant at 10% level,$^**=$significant at 5% level,$^***=$significant at 1% level.
$^c$The standard error is obtained by delta method.

Figure 1: Key Variables in the Tokyo Condominium Market –1985-2000
Table 6: Demand Parameter Estimates: the second step estimation\textsuperscript{a,b,c}

<table>
<thead>
<tr>
<th></th>
<th>(i) MNL OLS</th>
<th>(ii) MNL GMM\textsuperscript{d}</th>
<th>(iii) NL OLS</th>
<th>(iv) NL GMM\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$ \text{ (coefficient for ECC)}</td>
<td>-.010 (.001)</td>
<td>-.171 (.096)*</td>
<td>-.010 (.002)**</td>
<td>-0.076 (0.038)**</td>
</tr>
<tr>
<td>1(age==0)</td>
<td>-10.382 (.082)**</td>
<td>-10.220 (.389)**</td>
<td>-4.460 (.075)**</td>
<td>-4.404 (.202)**</td>
</tr>
<tr>
<td>1(age==1)</td>
<td>-10.453 (.079)**</td>
<td>-10.417 (.413)**</td>
<td>-4.462 (.070)**</td>
<td>-4.457 (.206)**</td>
</tr>
<tr>
<td>$g(0)$</td>
<td>-10.382 (.074)**</td>
<td>-9.785 (.597)**</td>
<td>-4.4671 (.1927)**</td>
<td>-4.2304 (.242)**</td>
</tr>
<tr>
<td>$g(1)$</td>
<td>-10.436 (.0715)**</td>
<td>-10.021 (.434)**</td>
<td>-4.4789 (.1897)**</td>
<td>-4.3165 (.141)**</td>
</tr>
<tr>
<td>$\zeta$ \text{ (within group correlation)}</td>
<td>-.979 (.011)**</td>
<td>.978 (.017)**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instruments</th>
<th>–</th>
<th>$CC_{t-1}$ log of height</th>
<th>–</th>
<th>$CC_{t-1}$ log of height</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$R^2$</th>
<th>.9962</th>
<th>.9998</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR test for IV relevance</td>
<td>37.611</td>
<td>37.93</td>
</tr>
<tr>
<td>(p-value)</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Endogeneity test</td>
<td>14.064</td>
<td>24.464</td>
</tr>
<tr>
<td>(p-value)</td>
<td>.000</td>
<td>0.00</td>
</tr>
<tr>
<td>Overidentification test</td>
<td>.203</td>
<td>1.127</td>
</tr>
<tr>
<td>(p-value)</td>
<td>.9771</td>
<td>0.7705</td>
</tr>
<tr>
<td>Observations</td>
<td>624</td>
<td>624</td>
</tr>
</tbody>
</table>

\textsuperscript{a}All specifications include following characteristic variables: log of average unit size, firm dummies and ward dummies.

\textsuperscript{b}Robust standard Error is given in the parenthesis.

\textsuperscript{c}Stars refer to the significance level of a t-test.

\textsuperscript{*} = significant at 10% level.,\textsuperscript{**} = significant at 5% level.,\textsuperscript{***} = significant at 1% level.

\textsuperscript{d}Standard errors are adjusted for the noise in imputed prices by bootstrap.
Table 7: Cost Parameter Estimates: the third step estimation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Explanation</th>
<th>Oligopoly Model $^{a,b}$</th>
<th>Competitive Model $^{a,b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>AR(1) Coefficient</td>
<td>0.7698</td>
<td>0.7532</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0194)$^{***}$</td>
<td>(0.0212)$^{***}$</td>
</tr>
<tr>
<td>$\bar{c}_2$</td>
<td>Cost Parameter</td>
<td>7.7666</td>
<td>7.9031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0472)$^{***}$</td>
<td>(0.0540)$^{***}$</td>
</tr>
<tr>
<td>$\sigma_\lambda$</td>
<td>Standard Deviation of</td>
<td>0.1667</td>
<td>0.1679</td>
</tr>
<tr>
<td></td>
<td>Idiosyncratic Production Shock</td>
<td>(1.4852)</td>
<td>(1.5104)</td>
</tr>
<tr>
<td>number of observations</td>
<td></td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Vuong Test Statistics</td>
<td></td>
<td>$-0.58$</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Robust Standard Error is given in the parenthesis.
$^b$Stars refer to the significance level of a t-test.
$^* =$ significant at 10% level,$^* * =$significant at 5% level,$^* * * =$significant at 1% level.
$^c$Standard Error is obtained by delta method.

Table 8: Responsiveness of Policy Functions to State Variables

<table>
<thead>
<tr>
<th></th>
<th>$\hat{c}$ Inflation $^a$</th>
<th>$\hat{c}$ Deflation $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$ Growth</td>
<td>$s_t$ 0.020 $s_t$ 0.019</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$x_t$ 0.089 $x_t$ 0.146</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{c}_t$ 0.029 $\bar{c}_t$ 0.875</td>
<td></td>
</tr>
<tr>
<td>$x$ Contraction</td>
<td>$s_t$ 0.022 $s_t$ 0.020</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$x_t$ 0.339 $x_t$ 0.380</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{c}_t$ 0.031 $\bar{c}_t$ 0.972</td>
<td></td>
</tr>
</tbody>
</table>

$^a$All figures are measured in elasticities in absolute value.

Table 9: The Model’s Performance

<table>
<thead>
<tr>
<th></th>
<th>$\sum q_{jt}$</th>
<th>$p_t^\beta$ $x_t$</th>
<th>Markup($%$) $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Observation</td>
<td>6.2524</td>
<td>52.5435</td>
<td>15.3028</td>
</tr>
<tr>
<td>(Standard Deviation)</td>
<td>(2.7513)</td>
<td>(7.3904)</td>
<td>(6.9625)</td>
</tr>
<tr>
<td>Mean Prediction</td>
<td>7.9617</td>
<td>55.8721</td>
<td>17.7908</td>
</tr>
<tr>
<td></td>
<td>7.9617</td>
<td>55.8721</td>
<td>17.7908</td>
</tr>
<tr>
<td>Mean Deviation from Observations $^b$</td>
<td>2.8911</td>
<td>4.4334</td>
<td>7.0442</td>
</tr>
<tr>
<td>Mean % of times that prediction falls in 10% interval $^c$</td>
<td>0.3752</td>
<td>0.5288</td>
<td>0.4334</td>
</tr>
</tbody>
</table>

$^a$The standard deviation is given in parenthesis.
$^b$Let $x_t$ and $\hat{x}_{tm}$ denote the observation in year $t$ and the prediction for year $t$ in $m$’th draw respectively. The deviation is calculated by following formula for $M$ simulation:$D = \frac{1}{\Pi \sum_m (x_t - \hat{x}_{tm})^2}$.
$^c$The mean is taken over time periods.
Table 10: Decomposition of Contributors to Price Deflation

<table>
<thead>
<tr>
<th>year</th>
<th>Fix ( \tilde{c} )</th>
<th>Fix ( \tilde{c} ) and ( x_t )</th>
<th>Benchmark contribution of ( x_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>61.5895</td>
<td>60.7993</td>
<td>60.1447</td>
</tr>
<tr>
<td>1994</td>
<td>61.5895</td>
<td>57.1870</td>
<td>56.6499</td>
</tr>
<tr>
<td>1995</td>
<td>61.5895</td>
<td>56.3555</td>
<td>55.7857</td>
</tr>
<tr>
<td>1996</td>
<td>61.5895</td>
<td>55.9040</td>
<td>55.1906</td>
</tr>
<tr>
<td>1997</td>
<td>61.5895</td>
<td>56.6347</td>
<td>55.7360</td>
</tr>
<tr>
<td>1998</td>
<td>61.5895</td>
<td>56.4984</td>
<td>55.5844</td>
</tr>
<tr>
<td>1999</td>
<td>61.5895</td>
<td>55.1316</td>
<td>54.2292</td>
</tr>
<tr>
<td>2000</td>
<td>61.5895</td>
<td>54.4853</td>
<td>53.6037</td>
</tr>
<tr>
<td>mean</td>
<td>61.5895</td>
<td>56.6245</td>
<td>55.8655</td>
</tr>
</tbody>
</table>

Table 11: Market Share Simulation - Mean of variables after period 3

| Benchmark | | | | | |
|-----------|---|---|---|---|
| N | \( q \) | \( \sum q + x \) | Price | Markup |
| 5 | 1.6562 | 28.0923 | 55.1117 | 0.0080 | 0.3149 |

| Random Walk | \( x_t \) | | | | |
|-------------|---|---|---|---|
| N | \( q \) | \( \sum q + x \) | Price | Markup | Market Share |
| 1 | 2.1342 | 8.4894 | 64.9259 | 0.0426 | 0.4342 |
| 2 | 2.0633 | 10.4576 | 62.7867 | 0.0288 | 0.5351 |
| 3 | 1.9942 | 12.3871 | 61.2998 | 0.0219 | 0.5924 |
| 4 | 1.9431 | 14.1108 | 60.2166 | 0.0181 | 0.6387 |
| 13 | **1.6565** | **27.9301** | **55.0909** | **0.0078** | **0.7966** |
| 14 | 1.6358 | 29.3534 | 54.7343 | 0.0071 | 0.8033 |
| 15 | 1.6174 | 30.6266 | 54.4237 | 0.0071 | 0.8132 |
| 16 | 1.5975 | 31.8700 | 54.1347 | 0.0070 | 0.8214 |
| 17 | 1.5811 | 33.1770 | 53.8554 | 0.0062 | 0.8282 |
| 18 | 1.5654 | 34.4576 | 53.5764 | 0.0061 | 0.8336 |
| 19 | 1.5485 | 35.8078 | 53.3038 | 0.0058 | 0.8366 |
| 20 | 1.5356 | 37.0299 | 53.0608 | 0.0058 | 0.8431 |
### Table 12: Estimation of Imputation Equation

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
<th>OLS</th>
<th>Model</th>
<th>(a)</th>
<th>(b)</th>
<th>OLS</th>
<th>Model</th>
<th>(a)</th>
<th>(b)</th>
<th>OLS</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OLS Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(price per sq. meter in the primary market)</td>
<td>0.604***</td>
<td>0.611***</td>
<td>(0.02)</td>
<td>(0.02)</td>
<td>-0.003</td>
<td>0.004</td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>-0.013***</td>
<td>-0.011***</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>log(total units for sale)</td>
<td>-0.003</td>
<td>0.004</td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>0.023***</td>
<td>0.022***</td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>1.893***</td>
<td>1.786***</td>
<td>(0.119)</td>
<td>(0.125)</td>
</tr>
<tr>
<td>constant</td>
<td>1.893***</td>
<td>1.786***</td>
<td>(0.119)</td>
<td>(0.125)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Birth cohort dummies:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age 2</th>
<th>Age 3</th>
<th>Age 4</th>
<th>Age 5</th>
<th>Age 6</th>
<th>Age 7</th>
<th>Age 8</th>
<th>Age 9</th>
<th>1993</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>0.051***</td>
<td>0.062***</td>
<td>(0.01)</td>
<td>(0.011)</td>
<td>-0.035**</td>
<td>-0.025*</td>
<td>(0.011)</td>
<td>(0.012)</td>
<td>0.056**</td>
<td>0.069***</td>
<td>(0.017)</td>
<td>(0.018)</td>
<td>-0.325***</td>
<td>-0.260***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.505***</td>
</tr>
<tr>
<td>1994</td>
<td>0.088***</td>
<td>0.101***</td>
<td>(0.01)</td>
<td>(0.011)</td>
<td>-0.094***</td>
<td>-0.073***</td>
<td>(0.012)</td>
<td>(0.014)</td>
<td>0.099***</td>
<td>0.116***</td>
<td>(0.013)</td>
<td>(0.014)</td>
<td>-0.215***</td>
<td>-0.172***</td>
<td>(0.015)</td>
<td>(0.018)</td>
<td>-0.398***</td>
</tr>
<tr>
<td>1995</td>
<td>0.093***</td>
<td>0.104***</td>
<td>(0.012)</td>
<td>(0.012)</td>
<td>-0.153***</td>
<td>-0.121***</td>
<td>(0.013)</td>
<td>(0.018)</td>
<td>0.104***</td>
<td>0.121***</td>
<td>(0.013)</td>
<td>(0.014)</td>
<td>-0.258***</td>
<td>-0.304***</td>
<td>(0.015)</td>
<td>(0.016)</td>
<td>-0.263***</td>
</tr>
<tr>
<td>1996</td>
<td>0.104***</td>
<td>0.121***</td>
<td>(0.013)</td>
<td>(0.014)</td>
<td>-0.215***</td>
<td>-0.172***</td>
<td>(0.013)</td>
<td>(0.018)</td>
<td>0.099***</td>
<td>0.116***</td>
<td>(0.015)</td>
<td>(0.016)</td>
<td>-0.258***</td>
<td>-0.304***</td>
<td>(0.015)</td>
<td>(0.018)</td>
<td>-0.263***</td>
</tr>
<tr>
<td>1997</td>
<td>0.099***</td>
<td>0.116***</td>
<td>(0.015)</td>
<td>(0.016)</td>
<td>-0.263***</td>
<td>-0.208***</td>
<td>(0.018)</td>
<td>(0.026)</td>
<td>0.056**</td>
<td>0.069***</td>
<td>(0.017)</td>
<td>(0.018)</td>
<td>-0.325***</td>
<td>-0.260***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.505***</td>
</tr>
<tr>
<td>1998</td>
<td>0.056**</td>
<td>0.069***</td>
<td>(0.017)</td>
<td>(0.018)</td>
<td>-0.325***</td>
<td>-0.260***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>0.031</td>
<td>0.035</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.398***</td>
<td>-0.322***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.505***</td>
</tr>
<tr>
<td>1999</td>
<td>0.031</td>
<td>0.035</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.398***</td>
<td>-0.322***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>0.056**</td>
<td>0.069***</td>
<td>(0.017)</td>
<td>(0.018)</td>
<td>-0.505***</td>
<td>-0.417***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.505***</td>
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<td>0.004</td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>-0.398***</td>
<td>-0.322***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>0.001</td>
<td>0.004</td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>-0.505***</td>
<td>-0.417***</td>
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<td>-0.505***</td>
</tr>
<tr>
<td>2001</td>
<td>0.160***</td>
<td>0.161***</td>
<td>(0.015)</td>
<td>(0.015)</td>
<td>-0.505***</td>
<td>-0.417***</td>
<td>(0.031)</td>
<td>(0.046)</td>
<td>0.001</td>
<td>0.004</td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>-0.505***</td>
<td>-0.417***</td>
<td>(0.021)</td>
<td>(0.024)</td>
<td>-0.505***</td>
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**Height dummies:**

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<th>10-19 stories</th>
<th>&gt; 20 stories</th>
<th>observations</th>
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<th>3119</th>
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<td>0.001</td>
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<td>0.004</td>
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<td>σ</td>
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<td>.377</td>
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<td>(0.008)</td>
<td>(.018)</td>
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</table>

*In both specification, ward dummies and railroad dummies are included.

Selection equation includes distance from the nearest station, total size of area, height of the building, maximum size of unit, year dummies, floor plan dummies, ward dummies, large firm dummies, dealer dummies.

Robust Standard errors in parentheses. ** significant at 1% level. * significant at 5% level.
Figure 2: Simulated Production at Different Product Lifespan

Figure 3: Simulated Production at Different Parameter Values
Figure 4: The Solution at $s_t = 38,110$

Figure 5: Inflation vs. Deflation