Investments in Response to Trade Policy: The Case of Japanese Firms during Voluntary Export Restraints*

Hyo-Youn Chu†

Current Version: January 13, 2012 (First Version: October 31, 2011)

Abstract

This paper develops a dynamic structural model of a single agent decision in order to analyze the effect of voluntary export restraints (VERs) on quality-upgrade and foreign direct investment (FDI) behavior. I estimate the model parameters using a variant of the two-step estimator developed by Bajari, Benkard and Levin (2007). Using panel data of Japanese firms in the U.S. automobile industry, both activities are found to have significant sunk costs, which introduces intertemporal interactions in decisions, and I also find that the entry costs for FDI are larger than fixed adjustment costs for quality-upgrade. I simulate counterfactuals based on the estimation of the structural model. In the absence of the VERs, both quality-upgrade and the probability of undertaking FDI decrease. The second simulation examines the substitution effect between the two investment activities. The proposal to restrict FDI policy causes a dramatic increase in the level of quality-upgrade. Similarly, the proposal to restrict quality-upgrade policy results in an increase in the probability of FDI.

Keywords: Voluntary Export Restraints (VERs), Quality-upgrade, Foreign Direct Investment (FDI), Japanese Automobiles, Dynamic Models of a Single Agent Decision

JEL classification: F13, L1, L62

*I am deeply indebted to my advisor Marc Rysman for his continued guidance and support. I wish to thank Simon Gilchrist, Stefania Garetto and Keith Hylton for their comments and suggestions. I have also benefited from conversations with John Rust, Kerem Cosar, Jonathan Eaton, Ali Hortacsu and Francesco Decarolis. I thank the participants of Boston University’s Empirical Micro Lunch Workshop. All errors are my own.

†Department of Economics, Boston University, 270 Bay State Rd., Boston, MA 02215 (hychu7@bu.edu)
1 Introduction

Restrictions on exports to a particular country often have the unintended consequence of affecting the investment choices of foreign firms that sell to that country. An interesting and very well-known narrative from the past involves the responses of Japanese auto producers when the U.S. and Japan placed bilateral voluntary export restraints (VERs) on exports of automobiles from Japan to the U.S. during the 1980s. First, they were likely to upgrade their product quality levels by adopting new technologies and shifting to higher quality auto exports, which gave them higher profit margins. Second, they tended to establish manufacturing plants in the U.S. via foreign direct investment (FDI) because Japanese automobile products made in the U.S. were excluded from export restraints. In so doing, they were able to raise profits despite the trade restrictions by increasing product prices as a result of quality-upgrade and/or by selling more cars made in the U.S. as a result of the capacity expansion. When Japanese firms decide to invest in quality-upgrade and/or to participate in FDI, they may incur significant sunk costs, which ultimately introduce inter-temporal linkages in the decisions. This implies that the firms have to consider how their current investment decisions would affect future investment plans as well as future market profits before these decisions are made. This paper represents the first attempt to investigate investment decisions for quality-upgrade and FDI in the context of a certain trade restriction by linking a dynamic analysis to real market data.

Despite the coexistence of quality-upgrade and FDI activities, together with their inter-temporal interactions, the previous literature that has examined the investment behavior of Japanese firms has largely focused on each channel in isolation. The approach that has been taken to date of examining these factors in themselves rather than in their interaction has prompted the following research questions for this study. First, how do Japanese firms make quality-upgrade and FDI decisions, as possible investment strategies to overcome the trade restriction? Understanding the investment behavior of firms is crucial in exploring the profound implications for trade restrictions on product quality and FDI entry of Japanese firms.
into the U.S. Second, what would have happened if the trade restrictions (VERs) had never been in place? Although trade restriction is the major factor driving investment decisions, other state characteristics may be important as well to encourage Japanese firms’ investment actions. For instance, most of the trade literature on exports and FDI explain that the firms that have a large enough scale (large market share because they are highly productive) find it optimal to perform FDI rather than export if a foreign production plant allows to save on the transportation cost of exports. This is known as the proximity-concentration trade-off. Thus, I am interested in how much both quality-upgrade and the probability of FDI will decrease in the market if the VERs are not allowed to operate and also if the VERs, combined with some state characteristics, are not allowed to operate, to capture the proximity-concentration trade-off effect. Third, what happens if one of the investment policies (quality-upgrade or capacity expansion via FDI) is restricted? If two investment decisions can be substituted for one another, restricting one of the investment activities will increase the other investment strategy. Or if the two investment decisions exhibit some complementarity, this mechanism will have a negative impact on the other investment strategy. Alternatively, it could be that quality-upgrade and FDI are not affected by each other.

The first step in answering the above questions is to structurally model investment decisions regarding quality-upgrade and capacity expansion via FDI. These investment decisions, however, involve a complicated optimal decision-making process because product quality and U.S. production are not exogenously given. To address this complexity, I develop a dynamic model of a single agent investment decision of quality-upgrade and FDI entry. The model contains four key features. First, it endogenizes firms’ quality-upgrade and capacity expansion (FDI) decisions. Both quality levels and U.S. production are not exogenously given; rather they are optimally chosen based on firms’ quality-upgrade and firm’s FDI entry, respectively. Second, the model employs both continuous and discrete choices of investment. That is, firms are able to choose quality-upgrade as a continuous choice and FDI entry as a discrete choice in each period. Third, it allows for different cost structures between quality-upgrade and FDI
decisions. Specifically, I allow the fixed quality adjustment cost depending on firms’ quality-upgrade level and the FDI entry cost depending on FDI entry choice. Finally, the model identifies various state characteristics that may encourage Japanese firms to invest in either quality-upgrade or capacity expansion via FDI because the trade restriction alone does not account for subsequent investment activities, since the nature of those activities vary, given firm heterogeneity. As the U.S. dollar depreciation against the Japanese yen in 1985 and 1986 could have catalyzed FDI decisions of Japanese producers given relatively cheaper costs, I consider the Japan/U.S. foreign exchange rates as one of the state characteristics. There was no specific enforcement mechanism for the VER limits, which implies that Japanese firms did not necessarily have to conform to the VERs.\footnote{See Berry, Levinsohn and Pakes (1999)} However, an ex-post penalty would have been imposed if exports had failed to meet the required limits, although this penalty was not explicitly announced. Accordingly, I use the difference between exports and the limits for each Japanese firm to capture the possibility of a penalty imposition. A firm’s higher relative quality level compared to the quality level of other Japanese firms might encourage the firm to invest in building production plants but discourage the firm from upgrading product quality because it knows that its products are already good enough to be marketable in terms of quality. Last, I account for past investment experiences (past quality-upgrade and past FDI) as state characteristics because the probability of upgrading quality is relatively low in a year following FDI and, similarly, the probability of participating FDI is relatively low in a similar length of time following quality-upgrade experience as shown in Figure 1. Thus, I use these lagged investment variables to examine whether or not the two investment decisions have inter-temporal substitution effects.

I assume that markets are segmented. To maximize the present discounted value of their expected stream of payoff-profits, firms can decide on their investment choices based on their current state characteristics. To estimate the model, my approach builds on a line of research, initiated by Hotz and Miller (1993) and Hotz, Miller, Sanders and Smith (1994), on the study
of a single agent dynamic optimization problem using a two-step approach. I employ a refine-
ment of this two-step algorithm of estimating dynamic decisions suggested by Bajari, Benkard
and Levin (2007) in order to handle both discrete and continuous investment decisions. I also
incorporate the technique that finds the optimal quality-upgrade as the continuous choice
variable by introducing the first order condition proposed by Stahl (2011). In the first step, I
recover marginal cost parameters from demand and supply estimations to estimate a market
profit equation as a function of observed state characteristics. I also estimate several state
transition equations and two investment policy equations as a function of these observed state
characteristics. In the second step, I use a method of moments estimator by matching the
model predictions to their empirical counterparts observed in the data to estimate dynamic
cost parameters. In doing so, I am able to substantially reduce simulation bias in dynamic
parameter estimates, particularly in small samples, such as the one considered in this paper.

My empirical results are summarized as follows. First, past quality-upgrade decision to
attain higher relative quality in the current period and past FDI activity to spur more U.S. car
sales in the current period increase current market profits. However, the export surplus has a
negative impact on the market profits, which implies that firms are penalized and subjected
to immediate reduction of their market profits if they fail to meet the VER quotas. Second,
VERs encourage both quality-upgrade and FDI activities for Japanese firms, and the U.S.
dollar depreciation makes FDI more profitable. Third, higher relative quality discourages
quality-upgrade decision but encourages an FDI one. This suggests that firms switch their
investment strategy to capacity expansion as long as they have products of sufficiently high
quality to attract consumers. Fourth, past FDI experience has a negative impact on the
current quality-upgrade decision and similarly, past quality-upgrade activity has a negative
impact on the current FDI choice, which supports the occurrence of dynamic substitutions
in investment decisions. Lastly, there are significant sunk costs for both quality-upgrade and
FDI activity, which supports inter-temporal linkages in decisions, and further the entry cost
of FDI is larger than the fixed adjustment cost of quality-upgrade. To be more specific, the
result indicates that a unit increase in quality level would cost about $1.9 billion and Japanese firms would spend about $4.8 billion for a production plant if they enter into the U.S to open the plant.

This paper also simulates three counterfactuals based on the estimation of the structural model. The first simulation predicts that the overall quality-upgrade level and probability of undertaking FDI decrease without the VERs. However, firms still invest in quality-upgrade and participate in FDI even when the VERs are not present. Interestingly, in the absence of the VERs, the probability of FDI dramatically decreases almost to zero when I control for the Japan/U.S. foreign exchange rates. This suggests that other factors, such as trade costs or entry costs, are also important in driving FDI decisions. The next two simulations examine the substitution effect between the two investment activities. The proposal to restrict the FDI policy causes a large increase in the level of quality-upgrade. Similarly, the proposal to restrict the quality-upgrade policy causes an increase in the probability of FDI, but one of a smaller magnitude in the sense that entry costs of undertaking FDI are more expensive than fixed adjustment costs of quality-upgrade. These results confirm that the two investment decisions are substitutes under the VERs in the sense that the alternative investment strategy may be the only way to overcome the trade restriction when one strategy is restricted.

The rest of this paper is organized as follows: Section 2 describes the related literature; Section 3 describes the background of voluntary export restraints in the U.S. automobile industry; Section 4 describes the dynamic structural model of a single agent decision; Section 5 describes the data and specifications; Section 6 explains the estimation strategy in detail; Section 7 discusses the results and Section 8 describes the counterfactual experiments. Section 9 concludes the paper.
2 Literature Review

There is a large body of empirical studies that provide insights into the effects of trade policy by linking micro-level studies. Tybout (1992) analyzes policy effects by connecting changes in trade regimes to intra-sectoral responses of productivity. Because the manufacturing sector’s response is heterogeneous to changes in trade regimes, firm-level or plant-level productivity may often be miscalculated and, moreover, may not accurately reflect important aspects of the sector’s response according to these changes. To explain the unpredictable responses of trade flows to changes in trade regime, Roberts and Tybout (1997) stress the fact that producers face sunk entry costs when entering into foreign markets. This implies that the changes in trade regime may induce entry into the export market if the expected future stream of operating profits covers the sunk costs of entering foreign markets. The fact that FDI also incurs a sunk entry cost as exports and firms are more likely to choose foreign direct investment (FDI) over exports if there are higher transportation costs of exports and trade barriers suggests that the existence of FDI entry cost is also an important factor to explain the responses of trade flows to changes in trade regime. As far as I know, this paper is the first paper to structurally estimate a sunk entry cost of FDI.\(^2\)

Several authors are particularly interested in examining how VER affects changes in product prices or country welfare in the U.S. automobile industry. Dinopoulous and Kreinin (1988) examine the spillover effect on the demand for non-restricted producers, such as European automakers, using a simple reduced form model. They conclude that the VERs generate price increases of European cars after adjusting for quality-upgrade. Feenstra (1988) finds substantial quality-upgrade of Japanese cars under VERs, and then, using a hedonic regression model, explains that some of the observed price increases in Japanese vehicles could be accounted for by corresponding quality improvement. More sophisticated empirical studies of the effect of VERs on the U.S. economy are Goldberg (1995) and Berry, Levinsohn and Pakes

(1999). Using both consumer-level data and product-level data from Consumer Expenditure Survey (CES), Goldberg estimates the structural parameters of the U.S. automobile industry in a static framework, and evaluates the welfare impact of different trade policies. She finds that the VERs were binding in 1983 and 1984, but had less of an effect in subsequent years. Berry, Levinsohn and Pakes also estimate a structural oligopoly model of the U.S. automobile industry, and then investigate the effect of VERs on U.S. economic welfare. Although Berry et al’s method is similar to that of Goldberg, their work differs in accounting for econometric price endogeneity and by using a different demand structure. However, both studies use quality-upgrade as a source of exogeneity so neither one models quality-upgrade as response for trade policy.\(^3\)

VERs in the automobile industry is an interesting topic that is equally important for both economists and policy makers and, as such, is the subject of many research studies, as discussed above. There is relatively little empirical work however, on the effect of VERs on FDI activities. An exception is the work of Co (1997), who examines the FDI decision of Japanese automobile producers during the VERs period and finds how trade barriers combined with other government regulations and source of Japanese competitive advantages lead to FDI decisions. Co does not take dynamics into consideration, however, which may lead to underestimating the effect of trade restriction on FDI activities. Ignoring the dynamic issue also prevents us from understanding inter-temporal linkages between quality-upgrade and FDI decisions.

3 Background: Voluntary Export Restraints in the U.S. Automobile Industry

The U.S. automobile industry began in the 1890s and rapidly grew into the largest automotive industry in the world. This industry started with hundreds of automakers, but became dom-\(^3\)Berry, Levinsohn and Pakes (1999) explain that including FDI do not substantively change their results in a static oligopoly structural model. I believe that this is due to the fact that their model is static.
inated by three big producers: General Motors, Ford and Chrysler. Of particular relevance here, the U.S. automobile industry was primarily isolated from foreign competition because of the horizontal specification of the automobile products. The U.S. consumers preferred full sized vehicles produced by domestic automakers because gasoline prices were relatively cheap and they often needed to drive long distances. Thus, the dominance of the domestic firms in the U.S. automobile industry along with the absence of competition with foreign automakers was enough to provide strong market power and high profits for the big three domestic producers. However, their dominant market power in the U.S. auto industry eventually led to several problems regarding price decisions and product strategy. They often joined forces to rig an increase in the automobile prices and thought about how to effectively block foreign entries. They often responded to the entries of foreign automakers into the U.S. market with auto price decreases, and then gradually raised their prices to more than pre-entry levels after foreign producers’ exits. In terms of product strategy, they put more importance on updating the body designs of cars than on improving product quality performance, which ultimately harmed consumer welfare by reducing the average period of owning a car and increasing the frequency of car replacement.

In the 1970s and 1980s, the structure of the U.S. automobile industry, however, was dramatically transformed by the oil crisis, combined with government regulations. Expensive gasoline prices were responsible for consumers’ switching their relative demands for automobiles from low fuel efficiency domestic cars to higher fuel efficiency Japanese cars, which led to increasing market shares of Japanese producers. Furthermore, safety and environmental issues required stricter regulations of automobiles, such as mandated shoulder belts for the front passenger, energy-absorbing steering columns and padded interiors. In response to these needs, the domestic producers immediately introduced new compact automobiles designed to follow these regulations. However, there were several serious manufacturing problems which

---

4 Ono (1993) explains that GM, Ford and Chrysler earned an average rate of return on net worth of 19.7%, 12.3% and 10.7% respectively, compared to all manufacturing average of 9.2% during the period between 1946 and 1973.
ultimately led to the producers’ losing market shares.\(^5\) Under the highly competitive pressure from foreign automakers, especially from Japanese producers, Chrysler slid into bankruptcy and the domestic auto producers petitioned the government for relief from imports. The U.S. government responded immediately by granting emergency loans to Chrysler and by negotiating bilateral voluntary export restraints (VERs) with the Japanese government.

In 1981, Japanese producers entered into a voluntary restraint agreement, which imposed on exports a limit of 1.68 million units per year. The VERs were renewed regularly and lasted until the early 1990s.\(^6\) Each Japanese producer was assigned a separate sub-quota, allegedly based on their past sales of automobiles in the U.S. market. In addition, the U.S. government started to purposely depreciate the U.S. dollar against foreign currency, including the Japanese yen, in early 1985. These combined policies eventually resulted in two primary investment strategies by Japanese automakers. First, the Japanese auto producers switched their emphasis to adopt new technology and export higher quality automobiles, which gave them higher profit margins. More specifically, they started adopting new engines and exporting better performing autos with stronger engine powers. In addition, three big Japanese automakers, Honda, Toyota and Nissan, began to launch luxury brand divisions in the second half of the VER period by developing new engine technology and by upgrading car designs. In 1986, after several years of research, Honda opened its Acura automobile division in the U.S. It was the first Japanese premium brand to be introduced and its success led to luxury brand ventures by other Japanese producers. In 1989, Toyota and Nissan began to launch their own premium brands, Lexus and Infiniti, respectively, in the U.S. Second, Japanese producers began to invest in building auto production plants in the U.S. in terms of FDI because Japanese vehicles made in the U.S. were excluded from export limits. As a leader, Honda opened a new production plant in Marysville Ohio in 1982, encouraging the entry of Toyota and Nissan into

---

\(^5\)The U.S. big three producers suffered from massive recalls and poor quality after introducing several compact automobiles. For example, Ford Pinto as the new compact car was found that it did not design any safeguards and its gas tank was very vulnerable to exploding when hit from behind.

\(^6\)The export limits was raised to 1.85 million autos in 1984 and to 2.30 million autos in 1985, until the program was terminated in the early 1990s.
the U.S. by 1985. By 1990, other Japanese automakers, such as Mazda, Mitsubishi and Subaru, joined in producing a substantial number of automobiles in the U.S.\(^7\) Their consolidation of investment strategies, combined with their “Just In Time” (JIT) system, completely succeeded in overcoming the VER limits. The JIT is a production and inventory control system in which materials are purchased and automobiles are produced only as needed to meet actual consumer demand. This process is very efficient for the automobile industry because it can reduce inventories to the minimum level and, in some cases, to zero. Ultimately, this great success caused the U.S. domestic producers to develop joint ventures with several Japanese automakers. More importantly, Japanese producers have become the largest foreign presence in the U.S. through an ongoing global expansion.

4 Model

I construct a model that captures the investment behavior of Japanese firms in the U.S. automobile industry in order to examine the effects of voluntary export restraints (VERs), combined with other state characteristics, on two types of investment decisions. The model focuses on exporting firms’ investment decisions regarding quality investment (quality-upgrade) and capacity investment (FDI) in the context where such firms are facing various state characteristics. In each period, a firm chooses its quality-upgrade level to increase its product quality for the next period. The firm also decides each period whether or not to open a new production plant to expand its capacity level the next period. Each firm’s market profit and these two investment policies are a function of its own state characteristics that are currently observed. Both quality-upgrade and FDI activities involve substantial adjustment costs and entry costs respectively, so the current period’s investment decisions affect future investment decisions as well as future market profits. The firm chooses its two types of investments to

maximize the present discounted value of its expected stream of payoff-profits as a function of its own states. I assume that markets are segmented so the firm maximizes the expected intertemporal payoff-profits earned from the U.S. automobile market.

4.1 State Characteristics
At period $t$, firm $f$’s state characteristics can be described by the vector of $S_{ft}^{\text{char}}$:

$$S_{ft}^{\text{char}} = \{\text{VER}_t, \text{EXC}_t, \text{LFDI}_{ft}, \text{LQUP}_{ft}, \text{QUAL}_{ft}, \text{DIFF}_{ft}\}$$

For each firm in each period, I construct various state characteristics that are likely to affect all payoff-relevant features, such as market profit, quality investment and capacity investment decisions.

All firms can observe the same exogenous states $\text{VER}_t$ and $\text{EXC}_t$. I call them exogenous aggregate state variables because they are not controlled by firms but determined exogenously in the world. The variable $\text{VER}_t$ is a dummy variable denoted as below:

$$\text{VER}_t = \begin{cases} 
1, & \text{if VERs occurs in period } t \\
0, & \text{otherwise}
\end{cases}$$

The variable $\text{EXC}_t$ is defined as the logarithm value of the U.S. dollar in terms of Japanese yen (JPYY/US$) determined in the foreign exchange market.

Firm $f$ can observe firm-specific endogenous states $\text{LFDI}_{ft}, \text{LQUP}_{ft}, \text{QUAL}_{ft}$ and $\text{DIFF}_{ft}$. I call them endogenous state variables because each firm can adjust these state variables by choosing quality investment and/or capacity investment. So I add the subscript $f$ in them to identify each firm. The variable $\text{LFDI}_{ft}$ is a binary variable as below:

$$\text{LFDI}_{ft} = \begin{cases} 
1, & \text{if capacity investment occurred in period } t - 1 \\
0, & \text{otherwise}
\end{cases}$$

---

*The vector of state characteristics is a part of the state vector. The state vector is described in Section 4.4.*
The variable $LQUP_{ft}$ is also a binary variable as below:

$$LQUP_{ft} = \begin{cases} 
1, & \text{if quality investment occurred in period } t - 1 \\
0, & \text{otherwise} 
\end{cases}$$

I include these lagged investment variables as state variables because the current quality-upgrade decision is likely to be negatively affected by the last period’s FDI experience and similarly the current FDI decision is likely to be negatively affected by the last period’s quality-upgrade in the data (Figure 1). So I want to capture the dynamic substitution effect in two investment decisions by including these state variables, $LFDI_{ft}$ and $LQUP_{ft}$. The variable $QUAL_{ft}$ represents the firm $f$’s relative quality level compared to the average quality level available among other firms. The value of $QUAL_{ft}$ below one corresponds to a case that the firm $f$ produces relatively low quality products among others, while the value of $QUAL_{ft}$ above one indicates that the firm $f$ produces relatively high quality products among others. The variable $DIFF_{ft}$ captures a shortage or a surplus between exports and trade limits implying that the positive value of $DIFF_{ft}$ corresponds to a case that the firm $f$’s exports exceed the trade limits, while the negative value of $DIFF_{ft}$ indicates that the firm $f$’s exports are below the trade limits.

### 4.2 Timing of Decisions

Each decision period is one year. In each period, the sequence of events unfolds as follows:

- Firms observe states $S_{ft}$ and decide on product prices\(^9\);
- Consumers decide which product to buy based on product characteristics and prices. Firms accrue market profits from product sales;

---

\(^9\) The details of the demand model are described in Appendix.
• Firms receive private draws on the cost of quality investment $\varepsilon_{ft}^\delta$ and observe a fixed adjustment cost of quality-upgrade, and make their continuous decision to upgrade quality level.

• Firms receive private draws on the cost of capacity investment $\varepsilon_{ft}^\gamma$ and observe a sunk entry cost of FDI, and make their discrete decision to participate in FDI.

• Observed states $S_{ft}$ are updated for the following period according to the state transitions described below.

### 4.3 Quality and Capacity Investment Costs

Let time be assumed discrete with an infinite horizon and indexed by $t \in 1, 2, \ldots, \infty$. At the beginning of period $t$, firm $f$ decides to choose quality investment level to increase its product quality. This decision can be summarized by quality-upgrade variable $\Delta q_{ft}$, which is defined as the increase on median quality level of available products produced by the firm $f$ in period $t$ (i.e., $\Delta q_{ft} = q_{ft} - q_{ft-1}$). The adjustment cost for upgrading quality in period $t$ is assumed to be proportional to upgrade quality level as follows:

$$C^q \left( S^\text{char}_{ft}, t; c^q, \sigma^\delta, \delta, \eta^\delta_f \right) = \left( c^q + \varepsilon^\delta_{ft} \right) \Delta q \left( S^\text{char}_{ft}, t; \delta, \eta^\delta_f \right)$$

(1)

where $\Delta q (\cdot)$ is a reduced-form function of a state characteristics vector $S^\text{char}_{ft}$ and a time trend $t$, parameterized by a vector of quality investment decision coefficients $\delta$ and $\eta^\delta_f$ is a firm specific quality investment constant (a firm fixed effect), described in Section 6. The variable $\varepsilon^\delta_{ft}$ is a shock to quality investment cost distributed $N(0, \sigma^\delta)$. This shock will capture the difference between the observed quality-upgrade level and the optimal quality-upgrade level predicted by the model, explained in Section 6.2.2.

At the beginning of each period, the firm $f$ also decides whether or not to open a new production plant in the foreign country through FDI. The firm’s entry cost for FDI in period
is assumed to depend on the firm’s FDI entry choice $\chi_{ft}$ as follows:

$$C^c\left(S_{\text{char}}^{\text{ft}}, t; c^c, \sigma^\gamma, \gamma, \eta_f^\gamma\right) = \left(c^c + \varepsilon_{ft}^\gamma\right) \chi\left(S_{\text{char}}^{\text{ft}}, t; \gamma, \eta_f^\gamma\right)$$

(2)

where $\chi(\cdot)$ is a reduced-form function of a state characteristics vector $S_{\text{char}}^{\text{ft}}$ and a time-trend $t$, parameterized by a vector of capacity investment decision coefficients $\gamma$ and $\eta_f^\gamma$ is a firm specific capacity investment constant (a firm fixed effect), described in Section 6. The variable $\varepsilon_{ft}^\gamma$ is a shock to capacity investment cost distributed $N(0, \sigma^\gamma)$.

Finally the firm $f$’s static payoff-profit at period $t$ is defined as follows:

$$\pi\left(S_{\text{char}}^{\text{ft}}, t; \theta\right) = \Pi\left(S_{\text{char}}^{\text{ft}}, t; \alpha, \eta_f^{\Pi}\right) - C^q\left(S_{\text{char}}^{\text{ft}}, t; c^q, \sigma^\delta, \delta, \eta_f^\delta\right) - C^c\left(S_{\text{char}}^{\text{ft}}, t; c^c, \sigma^\gamma, \gamma, \eta_f^\gamma\right)$$

(3)

where $\theta = \{c^q, \sigma^\delta, c^c, \sigma^\gamma, \alpha, \delta, \gamma, \eta_f^{\Pi}, \eta_f^q, \eta_f^c\}$. The firm’s market profit $\Pi(\cdot)$ is a reduced-form function of state characteristics $S_{\text{char}}^{\text{ft}}$ and a time trend $t$, parameterized by a vector of market profit coefficients $\alpha$ and $\eta_f^{\Pi}$ is a firm specific market profit constant (a firm fixed effect) described in Section 6.

4.4 States Space and Dynamic Programming

Firm $f$’s states in period $t$ can be fully described by a state vector $S_{\text{ft}}$:

$$S_{\text{ft}} = \{S_{\text{char}}^{\text{ft}}, \eta_f^{\Pi}, \eta_f^q, \eta_f^c, t\}$$

where $\eta_f^{\Pi}, \eta_f^q, \eta_f^c$ are firm $f$’s fixed-effects and $t$ is the time trend explained in Section 6.1.

Firm $f$’s payoff-profit over possible sequences of states can be represented by payoff-profit functions $\sum_{\tau=0}^{\infty} \beta^\tau \pi(a_{ft+\tau}, S_{ft+\tau})$, where $\beta \in (0, 1)$ is a discount factor and $\pi(a_{ft}, S_{ft})$ is the payoff-profit function in period $t$. The firm $f$’s quality and capacity investment decisions in period $t$ affect transitions of state variables but the firm faces uncertainty about the future values of state variables. Its beliefs about these future states can be represented by a Markov
transition distribution function \( P(S_{ft+1} | a_{ft}, S_{ft}) \). The beliefs are rational because they are based on the true transition probabilities of state variables from the data. At period \( t \), the firm \( f \) chooses investment decisions denoted by \( \sigma_f \) to maximize the present discounted value of its expected stream of payoff-profits:

\[
E \left( \sum_{\tau=0}^{\infty} \beta^\tau \pi \left( a_{ft+\tau}, S_{ft+\tau} \right) | a_{ft}, S_{ft} \right)
\]

(4)

This is an agent’s dynamic programming problem. The firm’s strategy maps from its state vector in period \( t \) to a vector of actions in period \( t + 1 \):

\[
\sigma_f : S_{ft} \rightarrow a_{ft+1}
\]

(5)

In the context of the present model, \( \sigma (S_{ft}) \) is a set of policy functions which describes the firm’s investment behavior for quality-upgrade and capacity expansion as a function of the present state vector. Let \( V \left( S_{ft}, \varepsilon_{ft}^\delta, \varepsilon_{ft}^\gamma \right) \) be the value function associated with this problem. By Bellman’s principle of optimality the value function can be obtained as follows:

\[
V \left( S_{ft}, \varepsilon_{ft}^\delta, \varepsilon_{ft}^\gamma \right) = \max_{a_{ft}} \left( \pi(a_{ft}, S_{ft}) + \beta \int V \left( S_{ft+1}, \varepsilon_{ft+1}^\delta, \varepsilon_{ft+1}^\gamma \right) dP \left( S_{ft+1} | a_{ft}, S_{ft} \right) dF \left( \varepsilon_{ft+1}^\delta \right) dU \left( \varepsilon_{ft+1}^\gamma \right) \right)
\]

(6)

The optimal strategy \( \sigma_f^* \) that maximizes the value of states \( S_{ft} \) is defined as follows:

\[
\sigma_f^* = \arg \max_{a_{ft}} v \left( a_{ft}, S_{ft} \right)
\]

(7)

where \( v \left( a_{ft}, S_{ft} \right) = \pi(a_{ft}, S_{ft}) + \beta \int V \left( S_{ft+1}, \varepsilon_{ft+1}^\delta \right) dP \left( S_{ft+1} | a_{ft}, S_{ft} \right) dF \left( \varepsilon_{ft+1}^\delta \right) dU \left( \varepsilon_{ft+1}^\gamma \right) \) is a choice-specific value function.

5 Data and Specifications

I collected data from the U.S. automobile industry annually from 1977 to 1996. I used product-level data on prices, quantities and quality levels to estimate the demand equation for the
U.S. automobile market. Ward’s Automotive group collects product-level data for all the automakers including foreign producers in the U.S. automobile industry and provides the annual results in Ward’s Automotive Yearbook. In this Yearbook, each product’s list price, quantity and specific engineering attributes, such as horsepower and weight, that are available in the U.S. automobile market can be found. Each product quality level is measured by the ratio of the product’s horse power value to product’s weight.\textsuperscript{10}

I examine the effects of voluntary export restraints (VERs), combined with other state characteristics, on two types of investment decisions of Japanese firms: quality-upgrade and foreign direct investment (FDI). I also investigate inter-temporal substitutions between these two options. I separately collect Japanese product data on prices, quantities, horsepower and weights. The Japanese automotive firms studied in this paper are Honda, Toyota, Nissan, Mazda, Mitsubishi, Subaru and Isuzu. Because each product has numerous variants with different equipments and specifications I use the base model for each nameplate, which makes the number of products computationally manageable.\textsuperscript{11} I also calculate the sum of non-Japanese product quantities in order to compute the outside product option and total market size of the U.S. auto market.

Firm-level data on exports, sub-quotas of the VERs, years of entry into the U.S. for production plants, quality levels to estimate the market profit function, two investment policy functions and state transition functions for Japanese firms are necessary for this analysis. I use each firm’s total quantities sold in the U.S. automobile market in period $t$ as the firm’s total exports to the U.S. in the same period. This is probably an imperfect measure of the firm’s annual exports because automobiles can be inventoried and there is, in fact, a reported large inventory of Japanese cars in stock in 1981 (Berry, Levinsohn and Pakes 1999). However it is roughly consistent with the idea that the inventory of cars is likely to be small because

\textsuperscript{10}HP/Weight is in 100’s of HP divided by 1,000’s of lbs. The ratio of horse power value to weight captures firm’s quality level well in the sense that years of quality-upgrade are consistent with years of launching firm’s luxury divisions. 

\textsuperscript{11}For example, Honda Acura Integra Type-R is lighter (2600 lbs.) and less powerful (195 HP) than Honda Acura NSX (3069 lbs., 290HP) based on 1997 year model although they are under the same nameplate Acura.
most automobile firms produce slightly different models under the same nameplate every year, such as the 2011 Honda Civic being followed by the 2012 Honda Civic. More importantly, Japanese producers developed the “Just-In-Time” (JIT) manufacturing system in the early 1980s, which was extremely proficient in reducing auto inventories. The JIT system is a production and inventory control system in which materials are purchased and automobiles are produced only as needed to meet actual consumer demand. In so doing, inventories are reduced to the minimum and, in some cases, are zero. Accordingly, I treat the firm’s total quantities sold in the U.S. as the firm’s total exports to the U.S. in each period does not distort much my results. For each Japanese firm, I am able to observe a separate sub-quota of the VERs and years of its entry into the U.S. to open a production plant from Ward’s Automotive Yearbook. I identify years of FDI based on each firm’s reported dates of started production as binary 0/1 variables. Each firm’s quality level is measured by a sales weighted median quality level of all available products in the firm. While the mean quality level can move from year to year depending on sales distribution although firms do not invest in quality-upgrade, the median value of all available products in the firm are likely to be independent on sales distribution.

To express prices into real terms, I make use of consumer price deflators. All prices are adjusted to 1983 constant dollars. I also collected data on Japan/U.S. foreign exchange rate to use as a state variable because it is likely to affect investment decisions, especially for FDI activities. The consumer price deflators and Japan/U.S. foreign exchange rates were obtained from Bureau of Labor Statistics.\footnote{http://www.bls.gov/data/}

A look at the data confirms that Japanese automobile producers made significant quality-upgrades and started to enter into the U.S. to build production plants over the VER period. For the purpose of looking at investment incentives of the VERs, I examine their investment behavior over the sample period 1977-1996 by including both the VER (1981-1991) and non-VER period (1977-1980 and 1992-1996). A look at the magnitude of quality-upgrade and the
frequency of FDI by Japanese firms per year over the sample period suggests that Japanese firms responded to the changing trade policy by exporting higher quality cars with better engine performance and by establishing production plants in the U.S. to produce mass market vehicles.

Figure 1 shows the quality-upgrade levels and years of FDI entry into the U.S. by Japanese firms on a yearly basis from 1977 to 1996 by including both the VER and non-VER periods. The quality-upgrade level is measured by the difference between a firm’s quality level in the current period and the firm’s quality level in the previous period. Each firm’s quality level is measured by a sales weighted median quality level of all available products in the firm. I denote 1 if Japanese firms entered into the U.S. to build a production plant and 0 otherwise for the years of FDI entry. Since Japanese cars produced in the U.S. are excluded from VER limits, most Japanese firms began to participate in FDI during the period of VERs. Beginning with Honda’s Marysville plant in 1982, Japanese firms responded to VERs by opening U.S. production plants. By 1990, Nissan, Toyota, Mazda, and Mitsubishi had joined in producing substantial numbers of cars in the U.S. through FDI. The quality-upgrade levels also picked up dramatically over the VER period for most Japanese producers. Interestingly, I find that these two possible investment decisions were likely to be substitutes. For instance, the probability of upgrading quality is relatively low in a year following FDI and, similarly, the probability of entering into the U.S. to establish production plants is relatively low in a similar length of time following quality-upgrade experience.

Before the VERs were in effect, none of the Japanese firms had U.S. production plants. After the VERs were in place, they contributed greatly to FDI decisions of Japanese producers with some exceptions, such as Isuzu and Suzuki, whose number of exports were relatively small compared to their export limits. Figure 2 describes the difference between exports and trade limits. I exclude the non-VER period from Figure 2 because Japanese firms could export without any constraints when the VERs were not present. As shown in Figure 2, exports to the U.S. exceeded export limits for most Japanese firms in the beginning of the VER period,
while exports from Isuzu and Suzuki to the U.S. fell under their quota limits. This suggests that Isuzu and Suzuki did not have any incentives to participate in FDI.

Although export restraints greatly contributed to entries of Japanese firms into the U.S. to open production plants, it cannot fully explain their strategic investment activities. For instance, as leading Japanese producers, Honda and Toyota experienced more than one FDI: once in the early 1980s and another time in the late 1980s. Moreover, other firms tended to enter into the U.S. in the second half of the VER period. This was not a coincidence. In early 1985, the U.S. government purposely started to depreciate the U.S. dollar against foreign currency, including the Japanese yen. So I expect that the decreasing Japan/U.S. foreign exchange rates (U.S. dollar depreciation) fills the gap that is unexplained by the VERs. As shown in Figure 3, the U.S. dollar value against the Japanese yen depreciated dramatically in the middle of the 1980s (1985 and 1986), then gradually declined over the rest of sample period. This depreciation pattern suggests that Japanese firms might find profitable to do FDI in the U.S., especially after 1985.

With respect to quality-upgrades, the vast majority of quality-upgrade decisions occurred during the VER period (Figure 1). This suggests that Japanese producers began to switch a large majority of exports to higher quality vehicles when they faced limits on the number of cars exported because exporting higher quality products is more profitable than exporting lower or middle quality cars. Moreover, activities in quality-upgrade are observed more frequently than FDI experiences, which implies that the fixed adjustment cost of quality-upgrade is probably lower than the entry cost of FDI. However, the VERs cannot fully explain these quality-upgrade decisions of all Japanese producers. For instance, Suzuki and Mitsubishi were likely to increase their quality levels gradually over the sample period regardless of the VERs. To explain this investment pattern of quality-upgrade, I use the time trend dummy in estimation.

The goal of this paper is to examine the dynamic investment decisions of Japanese firms in quality-upgrade and FDI depending on the current state characteristics. I model each firm as
solving an independent individual problem in a reduced form, taking the choices of competitors as exogenous. Strategic interactions in investment choices is potentially interesting but not the focus of the paper.

I also take advantage of various state characteristics that may affect investment decisions of Japanese firms in order to estimate investment policy equations as a function of these state variables. For the state variables, I include VER states as binary 0/1 variables, lagged FDI choice and lagged quality-upgrade choice as binary 0/1 variables. I also add real Japan/U.S. foreign exchange rates, relative quality levels and differences between exports and quotas. Each firm’s relative quality level is measured by a ratio of a firm’s quality level over the average quality level of other Japanese firms. Each firm’s quality level is measured by a sales weighted median quality level of all available products in the firm. Each firm's difference is defined as the difference between the firm’s total exports to the U.S. and its sub-quotas, interacting with the VER binary variables \( VER_t \cdot (Export_{ft} - Quota_{ft}) \). This interaction captures the fact that there is no shortage or surplus of exports without the VERs. I also use time trend variables and firm-specific fixed effects to capture each firm’s heterogeneous characteristics.

In sum, the data required for the estimation of the model consist of the following variables: 1) product-level data - prices, units sold, quality levels, product market shares and market sizes; 2) firm-level data - relative quality levels, differences between exports and VER limits, quality-upgrade levels, years of FDI entry and firm market shares; and 3) macro-level data - consumer price deflators and Japan/U.S. foreign exchange rates. The prices, units sold, quality levels, product market shares and market size are observed in the product-level data. Each product market share is defined as the ratio of units sold to the market size. I define the annual market size by adding all number of vehicles being sold on a yearly basis in the U.S. automobile market. The relative quality levels, differences between exports and limits, quality-upgrade levels, years of FDI entry and firm market shares are obtained in the firm-level data for the dynamic model estimation associated with quality and capacity investment.
cost parameters.

Table 1 provides the summary statistics for all variables that I include in the estimation. As shown in Table 1, there is considerable homogeneity among Japanese firms, which allows me to look at their investment behavior in a single agent decision model. The variable which shows the greatest variation relative to its mean is the frequency of capacity investment (FDI). This suggests that the FDI decisions heavily depend on each firm’s specific characteristics or each firm’s specific environmental situations. For example, Toyota participated in FDI twice over the sample period because it was facing serious exports restraints whereas Isuzu never entered into the U.S. to open production plants because as written, this suggests that there were many quotas, not that it was not a problem limiting exports to the quota amount. The median value of relative quality levels is at 103% of the leading Japanese firms in terms of quality indicating that Japanese firms are on nearly the same quality level. This supports the fact that Japanese firms consolidated their technologies and strategic investment behavior to successfully overcome the unfavorable trade regime.

6 Estimation

6.1 First-Step Estimation

6.1.1 Market Profit Estimation

I estimate the market profit equation as a function of state variables. The dependent variable is the total market profit generated by firm $f$ in period $t$. The regressors are the state variables that were discussed in Section 4.1. I include a time trend to see whether the market profit is largely the result of growth in production or industry earnings. Firm fixed-effects are also included. Thus the firm $f$’s market profit in period $t$ is as follows:

$$
\Pi \left(S_{f,t}^{\text{char}}, t; \alpha, \eta_f^\Pi \right) = \alpha^c + \Gamma^\Pi \left(S_{f,t}^{\text{char}}; \alpha^S \right) + \alpha^t t + \eta^\Pi_f + \omega^\alpha_{f,t}
$$

(8)

where $\Gamma^\Pi (\cdot)$ is a reduced-form function of the state characteristics vector $S_{f,t}^{\text{char}}$, parameterized
by the vector of market profit coefficients $\alpha^S$ and $t$ is the time trend, $\eta^\Pi_f$ is the firm f’s fixed-effect, and $\omega^\alpha_{ft}$ is a shock to the market profit distributed $N (0, \kappa^\alpha)$ . The standard error of the market profit shock $\kappa^\alpha$ is estimated by the standard error of the regression residual across all observations. The details of the demand estimation and computation of the market profit are described in Appendix.\footnote{The market profits of firms are computed from prices and marginal costs of products. Since I cannot observe the product marginal costs from the data I need to recover them by using a simple logit demand estimation.}

### 6.1.2 Quality and Capacity Investment Estimation

The investment policy functions are optimal because they are all based on the actual investment policies that are actually played in the data. I estimate a reduced form for quality investment policy using a non-linear regression. The dependent variable is the quality-upgrade level generated by firm f in period $t$. The regressors are the state variables. I add the time trend to capture the fact that the data shows that quality-upgrade activity gradually increased for some Japanese firms even when voluntary export restraints (VERs) were not present. Firm fixed-effects are also included to account for firm-specific characteristics for the quality investment. For the dependent variable of quality investment, I consider the fact that a firm cannot downgrade its upgraded quality level once it achieves that level. Therefore I define the quality-upgrade level as follows:

$$
\Delta q \left( S_{ft}^{\text{char}}, t; c^q, \sigma^\delta, \delta, \eta^\delta_f \right) = \max \left\{ 0, \left( \delta^c + \Gamma^q \left( S_{ft}^{\text{char}}; \delta^S \right) + \delta^t t + \eta^q_f + \omega^\delta_{ft} \right) \right\}
$$

(9)

where $\Gamma^q (\cdot)$ is a reduced-form function of the state characteristics vector $S_{ft}^{\text{char}}$, parameterized by the vector of quality investment coefficients $\delta^S$ and $t$ is the time trend, $\eta^q_f$ represents the firm f’s fixed-effect and $\omega^\delta_{ft}$ captures a shock to quality investment distributed $N (0, \kappa^\delta)$. The standard error of the quality investment shock $\kappa^\delta$ is estimated by the standard error of the regression residual across all observations.
In this paper, the capacity investment is associated with a discrete choice. I therefore estimate the capacity investment policy function $\chi_{ft}$ using a probit model with state variables as regressors:

$$\chi\left(S_{ft}^{char}, t; c^c, \sigma^\gamma, \gamma, \eta^\gamma_f\right) = \begin{cases} 
1, & \text{if } \gamma^c + \Gamma^c\left(S_{ft}^{char}, \gamma^S\right) + \gamma^t t + \eta^c_f + \omega^\gamma_{ft} > 0 \\
0, & \text{otherwise}
\end{cases}$$

(10)

where $\Gamma^c(\cdot)$ is a reduced-form function of the state characteristics vector $S_{ft}^{char}$, parameterized by the vector of capacity investment coefficients $\gamma^S$ and $t$ is the time trend, $\eta^c_f$ represents the firm $f$’s fixed effect and $\omega^\gamma_{ft}$ captures a shock to capacity investment distributed $N(0, \kappa^\gamma)$.

The standard error of the capacity investment shock $\kappa^\gamma$ is estimated as the standard error of the regression residual across all observations.

### 6.1.3 State Transitions Estimation

To complete the first step estimation, it is necessary to specify the causal effect of the current period’s state variables on the next period’s state variables. The state transition functions are rational because they are all based on the true transition probabilities of state variables that are actually played in the data.

The lagged FDI variable, $LFDI_{ft}$ and the lagged quality-upgrade variable $LQUP_{ft}$ are deterministic functions of last period’s choices, so no estimation of these transitions is necessary. Future beliefs about $LFDI_{ft+1}$ are therefore always equal to the current period’s FDI decision as shown in the following equation:

$$LFDI_{ft+1} = \chi_{ft}$$

(11)

Future beliefs about $LQUP_{ft+1}$ is also equal to the current period’s quality-upgrade decision with binary 0/1 variables as shown in equation (12):

---

Footnote 14: After model estimation, I exclude the firm fixed effect to avoid the incidental parameter problem.
\[ LQUP_{ft+1} = \Theta_{ft} \]  

where,

\[ \Theta_{ft} = \begin{cases} 
1, & \text{if } \Delta q_{ft} > 0 \\
0, & \text{otherwise} 
\end{cases} \]  

I take these binary lagged investment decision states into account for the state variables in the sense that the current quality-upgrade decision is likely to be affected by the past FDI experience and, similarly, the current FDI decision is likely to be affected by the past quality-upgrade experience observed in the data (Figure 1). More notably, I use only one lag for each variable because Japanese producers temporarily stopped upgrading quality levels and stopped entering into the U.S. to build production plants for about a year following FDI and quality-upgrades respectively.\(^{15}\)

I assume that the binary VER variable \( VER_t \) indicates 1 if the VER occurs in the current period and 0 otherwise as follows:

\[ \begin{align*}
VER_{t+1} &= \begin{cases} 
1, & \text{if } VER_t = 1 \\
0, & \text{otherwise}
\end{cases} 
\end{align*} \]  

This implies that Japanese producers believe that the VERs will be imposed for their entire lives if they observe the trade restriction in the first period.

The Japan/U.S. foreign exchange rate \( EXC_{t+1} \) is also assumed to follow a first-order autoregressive process AR(1) as below:

\[ EXC_{t+1} = \phi_0^{EXC} + \phi_1^{EXC} EXC_t + \nu_t^{EXC} \]  

where \( \nu_t^{EXC} \) is a shock to the exchange rate distributed \( N(0, \sigma^{EXC}) \). I simply use the OLS regression to estimate the state transition function of foreign exchange rates. The standard

\(^{15}\)The use of only one lag was determined after much experimentation by including more lagged variables. I found that the only one lagged investment variables give a much more significant result.
error of the exchange rate shock $\sigma^{EXC}$ is estimated by the standard error of the regression residual across all observations.

I assume that two endogenous state variables $QUAL_{ft+1}$ and $DIFF_{ft+1}$ are always proportional to the current period’s own state and the current period’s two investment decisions in the following equations:

$$QUAL_{ft+1} = \phi_0^{QUAL} + \phi_1^{QUAL} QUAL_{ft} + \phi_2^{QUAL} \Delta q_{ft} + \phi_3^{QUAL} \chi_{ft} + \nu^{QUAL}_{ft} \tag{15}$$

$$DIFF_{ft+1} = \phi_0^{DIFF} + \phi_1^{DIFF} DIFF_{ft} + \phi_2^{DIFF} \Delta q_{ft} + \phi_3^{DIFF} \chi_{ft} + \nu^{DIFF}_{ft} \tag{16}$$

where $\nu^{QUAL}_{ft}$ and $\nu^{DIFF}_{ft}$ are a shock distributed $N(0, \sigma^{QUAL})$ and $N(0, \sigma^{DIFF})$ respectively. The standard error of each state shock $\sigma^{QUAL}$ and $\sigma^{DIFF}$ is estimated by the standard error of the regression residual across all observations respectively. I estimate state transition functions for both quality investment and capacity investment using maximum likelihood estimation.

### 6.2 Second Step Estimation

The first step recovers all parameters that describe market profits at each state, how the state vector affects investment decisions in each period, and how the state characteristics evolve over time. The second step is concerned with finding cost parameters that make both quality and capacity investment functions optimal. To recover these parameters, I use a method of moments estimator to minimize the distance between observed investments at each state and those predicted by the model suggested by Bajari, Benkard and Levin (2007). In particular, I find the cost coefficients that satisfy the first order condition for the optimal quality investment level as a continuous choice as proposed by Stahl (2011).

A firm incurs significant fixed adjustment costs and entry costs when it determines to choose quality investment and capacity investment respectively. More notably, the present period’s capacity investment is likely to prevent the firm from embarking on the next period’s
quality investment and, similarly, the present period’s quality investment is likely to prevent
the firm from undertaking the next period’s capacity investment. In other words, its invest-
ment decisions today affect all future market profits as well as future investment decisions.
Therefore, a firm chooses its investment decisions for quality investment and capacity invest-
ment so as to maximize its stream of payoff-profits, not just its static profits. I follow the
forward simulation approach of Bajari, Benkard and Levin (2007) (hereafter BBL) to form
both ex-ante partial derivatives of value function for the optimal quality investment decision
(continuous choice) and value function for the optimal capacity investment decision (discrete
choice).

6.2.1 Quality Investment Cost

Firm $f$ can choose quality-upgrade level $\Delta q_{ft}$ to maximize the expected discounted value of
payoff-profits in period $t$. The quality investment decision $\Delta q_{ft}$ is viewed as a continuous
choice so I use the first order condition for the optimal quality investment level. To avoid
corner solutions I assume that the firm chooses positive quality-upgrade level at each period\(^{16}\):

$$\frac{\partial \pi_{ft}}{\partial \Delta q_{ft}} + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \frac{\partial \pi_{ft+\tau}}{\partial \Delta q_{ft}} | S_{ft} \right] = 0 \ \forall \ f, \ t \quad (17)$$

where the discount factor $\beta$ is set to 0.925 for the empirical analysis. The equation (17) says
that the marginal cost of the quality investment decision $\Delta q_{ft}$ on the current profit must be
equal to the marginal benefit of the quality investment decision $\Delta q_{ft}$ on the present discounted
value of the firm’s expected stream of payoff-profits. That is, the quality investment decision
today $\Delta q_{ft}$ affects the sequence of expected future payoff-profits because it affects expected
future endogenous states, such as future relative quality levels and differences between exports

\(^{16}\)I observe zero quality-upgrade levels in the data but I assume that the firm chooses only positive quality-
upgrade levels to manage the first order condition in the model. So the quality-upgrade shock $\varepsilon^\delta$ is able to
capture the difference between observed quality-upgrade levels and the optimal quality-upgrade levels predicted
by the model.
and VER limits. Thus, I can write the first order condition as follows:

\[-c^q - \varepsilon_{ft}^\delta + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \pi_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \frac{\partial S_{ft+\tau}}{\partial \Delta q_{ft}} \mid S_{ft} \right] = 0 \quad \forall \ f, \ t \quad (18)\]

The effect of present quality investment decision on the future states works through the firm’s strategies. The next period’s states depend on the current investment decisions and on the current states. The future profit in period \( t + \tau \) is a function of the \( t + \tau \) period’s states. So the first order condition can be transformed as follows:

\[-c^q - \varepsilon_{ft}^\delta + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \pi_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \frac{\partial S_{ft+\tau}}{\partial \Delta q_{ft}} \mid S_{ft} \right] = 0 \quad \forall \ f, \ t \quad (19)\]

Recall from Section 6.1.3 that I specify linear state transition functions so \( \partial S' / \partial S \) and \( \partial S' / \partial \Delta q \) are a vector of constants with respect to the current state \( S \) and the quality investment choice \( \Delta q \). Therefore, the first order condition can be written as follows:

\[-c^q - \varepsilon_{ft}^\delta + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \pi_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \frac{\partial S_{ft+\tau}}{\partial S_{ft+\tau-1}} \cdots \frac{\partial S_{ft+\tau+1}}{\partial S_{ft+\tau} \partial \Delta q_{ft}} \mid S_{ft} \right] = 0 \quad \forall \ f, \ t \quad (20)\]

where \( P \) are state transition functions discussed in Section 6.2.4. The next step is to find, for each state \( S_{ft} \) observed in the data, the expectation in the present discounted value of the stream of future marginal payoff-profits \( E_t \left( \sum_{\tau=0}^{\infty} \beta^\tau \partial \pi_{ft+\tau} / \partial S_{ft+\tau} \mid S_{ft} \right) \). The marginal effects of state variables on the payoff-profit \( \partial \pi / \partial S \) is more complicated because some state variables enter non-linearly into the payoff-profit.\(^\text{17}\) So the marginal effects of state variables on the payoff-profit is defined as a function of the current state variables as long as those

\(^\text{17}\) To be more specific, I add the interaction term which is associated with the relative quality variable derived from the past quality investment experience and the lagged capacity investment variable to capture the substitution effect of two investment decisions on the market profits. Moreover, the market profit and two investment costs have a quadratic term of the difference variable and/or the relative quality variable interacted with the VER dummy in estimation. The use of quadratic and interaction terms was determined after much experimentation by including and excluding various quadratic and interaction variables of state characteristics. I found that these variables give a much more significant result.
state variables enter into the market profit or two investment cost functions non-linearly and $E_t \left( \sum_{\tau=0}^{\infty} \beta^\tau \partial \pi_{ft+\tau} / \partial S_{ft+\tau} \mid S_{ft} \right)$ is evaluated at $E_t \left( S_{ft+\tau} \mid S_{ft} \right)$ for each period $t + \tau$.

The expectation in $E_t \left( \sum_{\tau=0}^{\infty} \beta^\tau \left( \partial \pi_{ft+\tau} / \partial S_{ft+\tau} \right)' \mid S_{ft} \right)$ is over shocks to state transitions ($\nu$). Here, I use the assumption that the dynamic cost parameters that are unknown enter linearly into the market profits and into both quality and capacity investment cost functions in the current period and all future period as in BBL. In order to estimate expectation of the partial derivatives of the value function, I use the forward simulation approach suggested by BBL:

\[
0 = -e^\delta - \epsilon_{ft}^\delta + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \Pi_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft} \right] \\
- c^\delta E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \Delta q_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft} \right] \\
- \sigma^\delta E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial Pr (\chi_{ft+\tau} = 1)}{\partial S_{ft+\tau}} \right)' \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft} \right] \\
- \sigma^\gamma E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial Pr (\chi_{ft+\tau} = 1)}{\partial S_{ft+\tau}} \right)' \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft} \right] \forall f, t
\]

where:

$\epsilon_{ft+\tau}^\delta \sim \sigma^\delta N (0, 1), \epsilon_{ft+\tau}^\gamma \sim \sigma^\gamma N (0, 1)$ and $\epsilon_{0ft+\tau} \sim N (0, 1), \epsilon_{1ft+\tau} \sim N (0, 1)$

\[
\frac{\partial Pr (\chi_{ft+\tau} = 1)}{\partial S_{ft+\tau}} = \Phi \left( - \left( \gamma^c + \Gamma_c \left( S_{ftchar} ; \gamma^S \right) + \gamma^i t + \eta_j + \omega_{ft}^S \right) \right) \gamma^S
\]

and $\Phi(\cdot)$ is the standard normal distribution.

For the given state $S_{ft}$, a simulated path of play can be obtained by using the partial derivatives of estimated market profit function, quality and capacity investment policy func-
tions and a set of shocks drawn from the estimated distributions of endogenous state transition shocks. I simulate the evolution of each state variable based on the transition function with many periods (100) until the discount factor will contribute sufficiently small present value of marginal market profits and two investment policies. Given a set of coefficients on the market profit and investment costs, and draws of shocks, I can calculate the present value of marginal payoff-profits associated with this path of play. I repeat this step many times (1000) and compute the present value of marginal payoff-profits over all of simulated paths of play which finally yields an estimated ex-ante stream of marginal payoff-profits given this state.

6.2.2 Search for Quality Investment Cost Estimates

In this section, I discuss the search for quality investment cost parameters that sets the average over all states of the divergence between observed quality investment and the optimal quality investment predicted by the model equal to zero. As explained above, for a given set of parameters of market profit and two investment costs, I can estimate the first order condition (21) applying the simulation method that BBL suggest to estimate the value function. Note that here I construct the difference between observed quality investment and optimal quality investment predicted by the model by substituting the actual quality investment observed in the data for $\Delta q_{ft}$ into the equation (21). So actual quality investment cost shock $\varepsilon^\delta_{ft}$ can fully account for the difference between observed quality investment and predicted optimal quality investment, which should be close to zero. I construct the first moment condition using the average over all states of the first order conditions evaluated at the observed quality investment. The first order condition at the observed quality investment $\Delta q^{observed}_{ft}$ is as follows:

$$
\varepsilon^\delta_{ft} = -c^a + E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \Pi_{ft+\tau}}{\partial S_{ft+\tau}} \right)' \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \bigg| S_{ft}, \Delta q^{observed}_{ft} \right]
$$
I then define the moment condition of quality investment as follows:

\[
G_1 \equiv \frac{1}{T S} \sum_{t=1}^{T} \sum_{s=1}^{S} \left\{ -c^q E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \Delta q_{ft+\tau}}{\partial S_{ft+\tau}} \right) \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft}, \Delta q_{ft}^{\text{observed}} \right] \right\}.
\]

\[
G_1 \equiv \frac{1}{T S} \sum_{t=1}^{T} \sum_{s=1}^{S} \left\{ -c^q E_t \left[ \sum_{\tau=1}^{\infty} \beta^\tau \left( \frac{\partial \Delta q_{ft+\tau}}{\partial S_{ft+\tau}} \right) \left( \frac{\partial P}{\partial S} \right)^{\tau-1} \frac{\partial S'}{\partial \Delta q} \mid S_{ft}, \Delta q_{ft}^{\text{observed}} \right] \right\}.
\]

\[
\forall f, t \quad (22)
\]

6.2.3 Capacity Investment Cost

Firm \( f \) can also determine whether or not it opens a new production plant \( \chi_{ft} \) in period \( t \) to maximize the expected discounted value of payoff-profits. The capacity investment decision \( \chi_{ft} \) is modeled as binary 0/1 choices. So I use the conditional logit model for the optimal probability of capacity investment as follows:

\[
\begin{cases}
V^*_1 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{1ft} \right) = V_1 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft} \right) + \varepsilon^\gamma_{1ft} & \text{if firm } f \text{ invests} \\
V^*_0 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft}, \varepsilon^\gamma_{0ft} \right) = V_0 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft} \right) + \varepsilon^\gamma_{0ft} & \text{if firm } f \text{ does not invest}
\end{cases}
\]

where \( V^*(\cdot) \) represents an indirect value function and both \( \varepsilon^\gamma_{1ft} \) and \( \varepsilon^\gamma_{0ft} \) capture errors following independent and identical extreme value distributions. The quality and capacity investment cost shocks are drawn from the estimated distribution of \( \varepsilon^\delta_{ft} \) with mean 0 and standard error \( \sigma^\delta \), and from the estimated distribution of \( \varepsilon^\gamma_{ft} \) with mean 0 and standard error \( \sigma^\gamma \), re-
spectively. Note that the standard errors $\sigma^\delta$ and $\sigma^\gamma$ are ones of cost parameters that have to be estimated. To estimate the ex-ante value of the state with two binary choices (invest or not invest), I simply follow the approach described below:

1. For a given observed state, I draw two shocks $\varepsilon_{0ft}$ and $\varepsilon_{1ft}$ from the standard normal distribution and generate the quality and capacity cost shocks $\varepsilon_{ft}^\delta \sim \sigma^\delta N(0, 1)$, $\varepsilon_{ft}^\gamma \sim \sigma^\gamma N(0, 1)$ and simulate a path of play using the estimated functions and a set of shocks $(\omega^\alpha, \omega^\delta, \omega^\gamma, \nu^{VER}, \nu^{EXC}, \nu^{QUAL}, \nu^{DIFF})$ drawn from the estimated distributions of the market profit shock, investment policies shocks and endogenous state transition shocks given the cost shock $\varepsilon_{ft}$.

2. I simulate the evolution of each state variable with a large time length (100) and compute the present value of payoff-profits associated with this path of play.

3. I repeat this step many times (1000) and calculate the average of the present value of payoff-profits over all of simulated paths of play.

4. This procedure yields an estimated ex-ante stream of payoff-profits associated with the quality investment cost shock. The linearity assumption of cost parameters are also used in here and so I can estimate $W_1$, $W_2$ and $W_3$ under two different capacity investment strategies $(\chi_{ft} = 1$ and $\chi_{ft} = 0)$ given the shock $\varepsilon_{ft} = (\varepsilon_{0ft}, \varepsilon_{1ft})$:

$$V_1(\chi_{ft} = 1, S_{ft}, \varepsilon_{ft}) = W_1^1(\chi_{ft} = 1, S_{ft}, \varepsilon_{ft}) - c^q W_1^2(\chi_{ft} = 1, S_{ft}, \varepsilon_{ft}) - c^c W_1^3(\chi_{ft} = 1, S_{ft}, \varepsilon_{ft})$$

$$V_0(\chi_{ft} = 0, S_{ft}, \varepsilon_{ft}) = W_0^1(\chi_{ft} = 0, S_{ft}, \varepsilon_{ft}) - c^q W_0^2(\chi_{ft} = 0, S_{ft}, \varepsilon_{ft}) - c^c W_0^3(\chi_{ft} = 0, S_{ft}, \varepsilon_{ft})$$

(25)

where,

$$W_1^1 = E \left( \sum_{\tau=0}^{\infty} \beta^\tau (\alpha^c + \Gamma^H (S_{ft}^{\text{char}}, \alpha^S) + \alpha^t + \eta^H + \omega_{ft}^2) \mid \chi_{ft} = 1, S_{ft}, \varepsilon_{ft} \right)$$

32
To estimate the probability of capacity investment I need to calculate a ratio of the equation (26) is transformed as below:

$$W^2_t = e^\delta E \left( \sum_{r=0}^{\infty} \beta^r \Delta q \left( S^\text{char}_{ft+r}, t; \delta, \eta_f^r \right) \mid \chi_{ft} = 1, S_{ft}, \varepsilon_{ft} \right) + \sigma^\delta E \left( \sum_{r=0}^{\infty} \beta^r \Delta q \left( S^\text{char}_{ft+r}, t; \delta, \eta_f^r \right) \varepsilon_{0ft+1} \mid \chi_{ft} = 1, S_{ft}, \varepsilon_{ft} \right)$$

$$W^3_t = e^\epsilon E \left( \sum_{r=0}^{\infty} \beta^r \chi \left( S^\text{char}_{ft+r}, t; \gamma, \eta_f^r \right) \mid \chi_{ft} = 1, S_{ft}, \varepsilon_{ft} \right) + \sigma^\gamma E \left( \sum_{r=0}^{\infty} \beta^r \chi \left( S^\text{char}_{ft+r}, t; \gamma, \eta_f^r \right) \varepsilon_{1ft+1} \mid \chi_{ft} = 1, S_{ft}, \varepsilon_{ft} \right)$$

and

$$W^1_t = E \left( \sum_{r=0}^{\infty} \beta^r \left( \alpha^c + \Gamma^\Pi \left( S^\text{char}^c_{ft}; \alpha^S \right) + \alpha^t + \eta_f^\Pi + \omega_{ft}^\Pi \right) \mid \chi_{ft} = 0, S_{ft}, \varepsilon_{ft} \right)$$

$$W^2_0 = e^\delta E \left( \sum_{r=0}^{\infty} \beta^r \Delta q \left( S^\text{char}_{ft+r}, t; \delta, \eta_f^r \right) \mid \chi_{ft} = 0, S_{ft}, \varepsilon_{ft} \right) + \sigma^\delta E \left( \sum_{r=0}^{\infty} \beta^r \Delta q \left( S^\text{char}_{ft+r}, t; \delta, \eta_f^r \right) \varepsilon_{0ft+1} \mid \chi_{ft} = 0, S_{ft}, \varepsilon_{ft} \right)$$

$$W^3_0 = e^\epsilon E \left( \sum_{r=0}^{\infty} \beta^r \chi \left( S^\text{char}_{ft+r}, t; \gamma, \eta_f^r \right) \mid \chi_{ft} = 0, S_{ft}, \varepsilon_{ft} \right) + \sigma^\gamma E \left( \sum_{r=0}^{\infty} \beta^r \chi \left( S^\text{char}_{ft+r}, t; \gamma, \eta_f^r \right) \varepsilon_{1ft+1} \mid \chi_{ft} = 0, S_{ft}, \varepsilon_{ft} \right)$$

where $W_1$ is the present discounted value of the expected stream of market profits, $W_2$ and $W_3$ are the present discounted value of the expected stream of quality investments and capacity investments respectively. The probability of capacity investment conducted by the firm $f$ can be written as follows:

$$Pr \left( \chi_{ft} = 1 \mid S_{ft} \right) = \int_{\varepsilon^\delta} \int_{\varepsilon^\gamma} \frac{\exp \left( V_1 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft} \right) \right)}{\exp \left( V_0 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft} \right) \right) + \exp \left( V_1 \left( S_{ft}, \varepsilon^\delta_{ft}, \varepsilon^\gamma_{ft} \right) \right)} \cdot h \left( \varepsilon^\delta \right) k \left( \varepsilon^\gamma \right) d\varepsilon^\delta d\varepsilon^\gamma$$

(26)

where $h \left( \cdot \right)$ is a distribution function of $\varepsilon^\delta$ with mean 0 and standard error $\sigma^\delta$ and $k \left( \cdot \right)$ is a distribution function of $\varepsilon^\gamma$ with mean 0 and standard error $\sigma^\gamma$. For the simulation, the equation (26) is transformed as below:

$$Pr \left( \chi_{ft} = 1 \mid S_{ft} \right) = \frac{1}{N} \sum_{\varepsilon_0^\delta}^{\varepsilon_N^\delta} \frac{1}{N} \sum_{\varepsilon_1^\gamma}^{\varepsilon_N^\gamma} \frac{\exp \left( V_1 \left( S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft} \right) \right)}{\exp \left( V_0 \left( S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft} \right) \right) + \exp \left( V_1 \left( S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft} \right) \right)}$$

(27)

5. To estimate the probability of capacity investment I need to calculate a ratio of the exponential value function with capacity investment over the sum of the exponential value function with capacity investment and the exponential value function without
capacity investment associated with the given cost shock:

\[
exp(V_1(S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft})) / (exp(V_0(S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft})) + exp(V_1(S_{ft}, \varepsilon_{0ft}, \varepsilon_{1ft})))
\]  

(28)

6. Repeating this procedure many times (1000) by drawing several cost shocks and averaging them over all of these paths gives me an estimated probability of capacity investment with the given state.

6.2.4 Search for Capacity Investment Cost Estimates

In this section, I discuss the search for capacity investment cost parameters that sets the average over all states of the difference between the observed capacity investment decision and the probability of capacity investment predicted by the model equal to zero. Because capacity investment is the binary choice, the observed capacity decision is written as 1 if the firm decides to invest and 0 otherwise. For the moment condition of capacity investment, I use the average over all states of the differences. I then define the moment condition of capacity investment as follows:

\[
G_2 \equiv \frac{1}{TS} \sum_{t=1}^{T} \sum_{s=1}^{S} \left( \chi_{observed}(S_{ft}) - Pr(\chi_{ft} = 1 | S_{ft}) \right)
\]

(29)

The method that I used gives me only two moment conditions because I have two investment decisions (quality-upgrade and capacity expansion) in this paper. However, I need to identify three cost parameters \( c = \{ c^q, \sigma^\delta, c^c, \sigma^\gamma \} \). This can be solved by adding additional moment conditions based on the covariance between the difference between observed investments and state variables as follows:

\[
G_3 \equiv \frac{1}{TS} \sum_{t=1}^{T} \sum_{s=1}^{S} \left( \varepsilon_{ft}^\delta \cdot QUAL_{ft} \right)
\]

(30)
\[ G_4 = \frac{1}{TS} \sum_{t=1}^{T} \sum_{s=1}^{S} \left( \left( \chi_{\text{observed}} (S_{ft}) - Pr(\chi_{ft} = 1 | S_{ft}) \right) \cdot \text{DIFF}_{ft} \right) \] (31)

I finally estimate cost parameters by minimizing a quadratic form in these three moment conditions as follows:

\[ m \left( \sigma^q, \sigma^e, c, c^c \right) = \min_c G \cdot G' \text{ where } G \equiv [G_1 \ G_2 \ G_3 \ G_4] \] (32)

7 **Empirical Results**

I obtain the first set of demand parameter estimates simply by regressing the dependent variable on several regressors.\(^{18}\) This is possible because I include firm specific fixed-effects that create an error term in the logit demand model for a market specific deviation that is not correlated with prices, and therefore do not need to use any instrumental variables to account for correlations between prices and errors. For the dependent variable, I calculate the difference between the logarithm of each product market share and the logarithm of the market share of outside products available in the U.S. automobile market. I use the product quality level as an observed characteristic variable. In addition, I add a constant to ensure that the variable \( \xi_{jt} + \xi_f \) has a zero mean. All automobile prices are in thousands of 1983 dollars in this paper, and the results are presented in Table 2. The coefficients on the product quality levels and prices are intuitive and significant in the sense that I expect the marginal utility to be increasing in the observed quality levels and decreasing in the prices. This suggests that the firm fixed-effects capture well firm-specific features in prices. The price elasticity of demand is estimated to be 0.793, implying that a one percent increase in the price brings about less than a one percent decrease in the automobile purchased. This may explain investment behavior of Japanese firms which incurs significant sunk costs in the sense that they are able to invest in quality-upgrades and/or to participate in FDI by increasing prices. The anecdotal evidence

\(^{18}\)The demand model and estimation are explained in Appendix.
that Japanese firms increased product prices without losing any market shares in the early years of the VER period supports this possibility. The coefficient on product quality levels is 0.822, which also rationalizes firms behavior to upgrade quality by investing in R&D or adopting the new technology.

I use demand estimates and an assumption of Bertrand-Nash pricing to recover product marginal costs. I observe product prices and firm market shares from the data. I also have the estimated coefficient on prices from the demand estimation. The markup equation (40) thus allows me to recover the product marginal costs by substituting the observed values into the equation and then to compute market profit values. I am then able to estimate the market profit equation as a function of state variables. Note that as the state variables are used to estimate and simulate payoff-profits (market profits and two investment policies) for the dynamic model, all coefficients on state variables are important and are expected to be intuitive. The estimated effects of state variables on market profits are shown in Table 3.

The negative impact of the VERs on the market profit indicates that overall market profits decrease during the VER period because the VERs control Japanese car sales through the restricted numbers. The negative impact of the time trend on the market profit tends to reflect the fact that a recession began in the early 1990s in the U.S., which led to weak product sales and operation losses in the U.S. automobile industry. The positive impacts of past investment decisions on the market profit indicate that both past FDI and quality-upgrade experiences enable Japanese firms to increase market profits rationalizing their quality and capacity investment decisions for higher market profits. The positive impact of the foreign exchange rate on the market profit has the expected sign. This explains that the U.S. dollar depreciation makes consumers switch their relative demand to cheaper domestic cars, which leads to decrease market profits. The higher relative quality increases market profits as expected, which encourages firms to invest in quality-upgrade. I include a quadratic term of the difference between exports and limits to capture whether market profits decrease as
the square of the difference state variable.\textsuperscript{19} Interestingly, the market profits decrease as the square of the excess of exports, which suggests that there was a penalty mechanism to control Japanese exports if a firm exports beyond a threshold level.\textsuperscript{20} Thus, Japanese firms have to invest in quality-upgrade and/or participate in FDI to mitigate their penalty if their exports fail to meet the threshold level. The relative quality interacted with the last FDI decision captures the substitution effect of the two types of investment decisions on the market profit. The negative coefficient indicates that a firm who experienced FDI in the last period has a smaller marginal effect of relative quality on the market profit than the firm without past FDI experience, which implies that firms are unlikely to invest in a quality-upgrade following the FDI experience. This supports the hypothesis that firms consider the two investment decisions as inter-temporal substitutes.

In addition to the market profit estimation, both quality and capacity investment policy functions must be estimated in the first stage. The estimation results for the quality investment equation as a function of various state variables are presented in Table 4. As I expected, the VER state catalyzes quality-upgrade of Japanese firms although it is statistically insignificant. Interestingly, I find that the past FDI experience controls the current quality-upgrade decision. This suggests that the two investment activities are negatively correlated in a dynamic framework because firms are likely to consider the two types of investments as substitutes. The negative impact of foreign exchange rates on quality investment decisions suggests that the U.S. dollar depreciation stimulates quality-upgrade activities of Japanese firms in the U.S., such as launching premium divisions given relatively cheaper costs. However, the firms stop upgrading product quality once they have higher relative quality because they know that their products are already good enough to be marketable. I include a quadratic term of the difference between exports and limits to capture how fast an incentive of quality-

\textsuperscript{19}I only include a quadratic term of difference in the sense that it gives me the best fit after much experimentation by including and excluding various quadratic and interaction terms of state variables.

\textsuperscript{20}The threshold level is greater than zero in my result implying that if firms export more than trade limits within the threshold level they are still able to increase market profits without the penalty. However, they will get penalized if their exports exceed the threshold level.
upgrade increases as an excess of exports increases. I also add the relative quality variable interacted with the VER dummy to examine an incentive of quality-upgrade under the VER period. Interestingly, the marginal effect of the excess of exports on the quality-upgrade decision increases. The trade restriction alleviates the negative effect of higher relative quality on the quality-upgrade decision. This implies that the firms who are currently suffering from the trade restriction are more likely to upgrade quality than the firms without the trade restriction.

Table 5 shows the effects of various state variables on the capacity investment decision. The VERs catalyze FDI of Japanese firms in order to overcome the trade restriction as expected. The lagged FDI and quality-upgrade variables are not statistically significant but they have expected signs that the firms are unlikely to upgrade quality and to open production plants once they participated in FDI in the last period. These results provide the possibility that two investment activities incur significant sunk costs, which introduces inter-temporal interactions in investment decisions. Moreover, we can say that the two investment choices can be seen as substitutes in a dynamic framework because one investment decision is restricted by another investment experience occurred in the past period. The foreign exchange rates negatively affect FDI decisions: the U.S. dollar depreciation encourages Japanese firms to participate in FDI because it is cheaper to invest in the U.S. than before without the dollar depreciation. The higher relative quality level also positively affect the firms to enter into the U.S. through FDI, which suggests that they want to switch their investment strategy from quality-upgrades to FDI as long as they currently have a sufficient number of vehicles with high quality levels to attract consumers. I find that the marginal effect of an excess of exports on FDI decisions increases, implying that the firms strongly prefer participating in capacity expansion through FDI if their exports fail to meet the required trade limits.

Table 6, 7, 8 and 9 present estimation results of state variable transitions. These state transition functions are crucial to produce estimates of dynamic cost parameters in the second stage. Japanese firms are able to observe the current period’s two investment experiences for
the future state characteristics. As a result, I do not need to estimate the state transition functions of two past investment decisions because firms’ beliefs about the past quality-upgrade and FDI are always predetermined. I assume that the future VER variable depends on the first period of the VER state in my model. This implies that Japanese producers believe that the VER will be imposed for their entire lives if they observe the restriction in the first period. Other state variables are not predetermined so I construct each state transition function based on observed data to rationalize beliefs of Japanese firms.

I assume that state transition functions of foreign exchange rates follow a first-order Markov process. Although, an AR(1) process is not a perfect way to estimate foreign exchange rates between Japan and the U.S., it is, I believe, the best specification and it fits the few available data well. The coefficient on lagged exchange rates has a strong positive auto-correlation (0.9222) as shown in Table 7.

For relative quality levels and differences between exports and trade limits, I make transition functions conditional on two investment decisions as well as its own previous state because both future state variables are likely to be affected by current investment activities as well as its own current state variable. Table 8 presents the estimation results of the relative quality state transition. The future relative quality levels are positively affected by the current relative quality levels and current quality-upgrade activity. Interestingly, the current FDI experience has a negative impact on the future relative quality levels although it is not significant. This implies that Japanese cars produced in the U.S. through FDI are likely to be lower in quality as compared to the cars exported from Japan.21 Table 9 reports the estimation results of the state transition of the difference between exports and limits. Both current quality-upgrade and FDI experiences reduce the difference between exports and trade limits. This suggests that if Japanese firms participate in either quality-upgrades or FDI then they are able to meet trade limits (decrease quantities exported) by exporting high quality cars or

21Note that I use the sales weighted median value of all product quality levels available in a firm as the firm’s quality levels. If there are many Japanese cars produced in the U.S. after FDI and they are likely to be in lower quality as compared to Japanese cars exported from Japan then they can decrease relative quality levels as well as the firm’s quality levels.
selling more U.S. produced cars.

The results of the second stage estimation are described in Table 10. The dynamic parameter estimates regarding the quality-upgrade cost and FDI cost are both reported. I find that both quality-upgrades and FDI activities are associated with large sunk costs, which introduce inter-temporal linkages in investment decisions, and the entry costs of undertaking FDI are larger than the fixed adjustment costs of quality-upgrade. This implies that the start-up costs of entering into the U.S. to build a production plant are more substantial than the per-period costs of upgrading quality levels. The marginal cost of quality-upgrades and sunk costs of FDI have the expected sign and magnitudes of 1.856 and 4.779 respectively. The marginal quality-upgrade cost indicates that a unit increase (HP/Weight) in quality level would cost about $1.9 billion. This estimate is similar to the observed Japanese average R&D expenditures of $1.69 billion reported in Fuss and Waverman (1992). The FDI cost parameter suggests that if Japanese firms enter into the U.S. to open a production plant, they would spend about $4.8 billion for the plant. This estimate is in the same range as the actual capital investment of $4 billion for Honda’s Marysville auto-plant. The standard errors of investment cost shocks are estimated to be 0.001 and 0.014 respectively in a relatively small magnitude as compared to the two investment costs, indicating that the actual investment levels are close to the optimal investment levels predicted by the model. This implies that investment decisions conducted by Japanese firms are fairly stable and consistent with the model.


\footnote{The average annual production capacity of Japanese firms in the U.S. is 280,000 units and most plant sizes are in the similar range (250,000-300,000 units).

\footnote{Although I cannot collect all capital investment information for Japanese auto plants in the U.S., Honda reports its capital investments for three production plants in its official website. Honda’s capital investment in Marysville reported from http://ohio.honda.com/manufacturing/map.cfm}
8 Policy Experiments

The dynamic structural model developed above allows me to simulate various counterfactual policy experiments. My primary interest is to evaluate the effect of voluntary export restraints on investment decisions of Japanese firms. In addition, I want to examine the substitution effect between quality-upgrades and foreign direct investment (FDI). In light of these objectives, my policy experiments are divided into four different scenarios; 1) the difference of quality-upgrade decisions across trade regimes (including the VERs and excluding the VERs); 2) the difference of FDI decisions across trade regimes (including the VERs and excluding the VERs); 3) the difference of quality-upgrade decisions across FDI regimes (allowing FDI and restricting FDI); and 4) the difference of FDI decisions across quality-upgrade regimes (allowing quality-upgrade and restricting quality-upgrade).

As my interest in this paper is in looking at two types of investment behavior of Japanese firms rather than looking at social welfare, I do not compute the value function of the theoretical model with dynamic investment cost parameters in order to conduct various counterfactual regimes. More importantly, a comparison of payoff-profits under different trade regimes is meaningless here because Japanese firms are likely to start their investment activities after the VERs. Thus direct comparison between payoff-profits without investments under the non-VERs, and payoff-profits with investments under the VERs is not able to tell us about the effect of trade restrictions on producer welfare. I therefore only simulate quality and capacity investment as a function of state variables many times (1000) with different policy regimes to examine the effects of the trade restriction on investment incentives.

Several counterfactual exercises can be constructed by changing the values of the state variables associated with a specific regime. This comes from the fact that beliefs of Japanese producers about market states are always affected by industry policies. First, I examine the difference of quality-upgrade decisions between when the VERs occur over a period of several

---

25 Several application papers of Bajari, Benkard and Levin (2007) compute the Markov-perfect equilibrium of the theoretical model with dynamic cost parameters to conduct policy experiments. This procedure is necessary to evaluate the welfare.
years and when the VERs never occur. To achieve this, I assume that Japanese producers believe that the VERs will never be imposed for their entire lives if they do not observe the trade restriction in the first period. According to this assumption, I am able to take zeros for all VER dummy state variables. I then simulate a new optimal quality investment as a function of the new state vector, and also simulate several state transition functions based on the new VER states and new optimal quality investment. I do simulations with a large time length (30). Figure 4 shows the quality-upgrade levels of Japanese firms under an actual trade regime and a hypothetical trade regime, and Table 11 quantifies the average quality-upgrade levels in both regimes. Each point is computed by averaging each period’s optimal quality investment level over many simulated paths (1000) of play at the average state. I find that quality-upgrade levels would decrease by 50 percent in the absence of VERs. This implies that VERs are one of the main factors driving quality investment of Japanese firms.

The second scenario is to examine the difference of FDI decisions between when the VERs are in place for a period of several years compared to when VERs were never in effect. I also examine the effect of the U.S. dollar depreciation on FDI decisions in the absence of VERs. To control for the dramatic dollar depreciation observed in 1985 and 1986, I use the value of the foreign exchange rate observed in 1977 for each initial state and simulate future foreign exchange rates based on the estimated state transition function. Figures 5 and 6 present the capacity investment decisions of Japanese producers under actual trade policy (including VERs with U.S. dollar depreciation) and hypothetical trade policies (excluding VERs with U.S. dollar depreciation, and excluding VERs without U.S. dollar depreciation), and Tables 12 and 13 quantify the average probabilities of FDI in several regimes. Each point is computed by averaging each period’s probability of capacity investment over many simulated paths (1000) of play at an average state. I find that the probability of FDI decreases by 52.4 percent when the VERs were never in effect and when the U.S. government still depreciates the U.S. dollar.

26By averaging the investment policy profile over many simulated paths of play and then averaging it again over all state variables yields an estimate of average optimal investment policy at each simulated period. Since my data span 1977 to 1996 and some of Japanese producers entered the U.S. auto market in the middle of 1980s, the VERs are associated with the early simulated period (T=30).
Interestingly, the probability of capacity investment dramatically decreases by 93 percent without U.S. dollar depreciation in the absence of VERs. These results imply that other factors, such as costs of exports and FDI entry costs, also drive FDI decisions.27

An interesting feature of Japanese investment behavior is that each investment decision is negatively affected by the past experience of another investment in terms of substitution effect. For instance, Japanese producers are likely to stop investing in quality-upgrade for a certain length of time (about a year) after FDI and, similarly, they tend to stop participating in FDI for a similar length of time after quality-upgrade. Thus it is worth considering how each investment decision would change when another investment is restricted. If two investment decisions are substitutes for each other, the mechanism for restricting one of investment activities will increase another investment strategy. Or, the mechanism will have a negative impact on another investment strategy if the two investment decisions are more likely to be complements of each other.

The third scenario is to evaluate the difference of quality-upgrade levels of Japanese firms when FDI is prohibited. To achieve this, Japanese producers are assumed to believe that they are not able to enter into the U.S. to build production plants. According to this assumption, I take zeros for all the past FDI state variables. Moreover, all capacity investment functions are set to zeros. I simulate a new optimal quality investment as a function of a new state vector and also simulate several state transition functions based on the new states and new optimal quality investment. I do simulations with a large time length (30). Figure 7 presents the quality investment decisions of Japanese producers with actual investment policy and hypothetical

27Most of the trade literature on exports and FDI explain that other things equal, when transportation cost of exports increases, it gets more and more costly to ship goods across between countries so it becomes more tempting to set up a subsidiary abroad to service the foreign market directly via FDI. Moreover, the larger the firm level returns to scale relative to the plant level to scale, the less costly in term of efficiency it is for a given firm to split up its production between different countries. Production plants in foreign countries benefit from the increasing returns to scale of the multinational firm, and there is little cost lost from building these new production plants. Hence, a firm has an incentive to become a multinational firm, and set up plants in foreign countries instead of exporting all its output. This is known as the proximity-concentration trade-off. I think that foreign exchange rates can capture the proximity-concentration trade-off in the sense that the transportation cost of exports cannot immediately reflect the dollar depreciation but FDI activities by purchasing the U.S. affiliates can take advantage of the dollar depreciation quickly.
FDI restriction and Table 14 quantifies the average quality-upgrade levels in both regimes. Each point is computed by averaging each period’s optimal quality investment over many simulated paths (1000) of play at the average state. In the absence of FDI, quality-upgrade levels dramatically increase by 129 percent, suggesting that Japanese producers would devote all attention to investing in quality upgrade as the substitute of FDI when it is prohibited because this is the only way to overcome the trade restriction.

The last scenario is to examine the difference of FDI decisions of Japanese firms when quality-upgrade are prohibited, such as the case of a ban on exporting higher quality automobiles. For this analysis, Japanese automakers are assumed to believe that they are not able to export any high quality cars so they do not invest in quality-upgrade. According to this assumption, I can take zeros for all quality investment functions. Moreover, to capture the pure substitution effect between quality-upgrade and FDI decisions when quality-upgrade is restricted, I need to control for relative quality levels because higher relative quality levels strongly encourage the firms to participate in FDI, which is observed in Table 5. I therefore use the relative quality levels simulated in the actual case (quality-upgrade allowed) to control the negative effect of decreasing relative quality on FDI incentives. I simulate a new optimal probability of FDI as a function of a new state vector and also simulate several state transition functions based on the new states and new optimal probability of FDI. I do simulations with a large time length (30). Figure 8 shows the effect of quality-upgrade restriction on the probability of FDI, and Table 15 quantifies the average probabilities of FDI in both regimes. I find that the probability of FDI increases by 11.1 percent in the absence of quality-upgrade, which implies that Japanese producers would increase their participation in FDI as the substitute for quality-upgrade when the quality-upgrade are not available. However, the absence of quality-upgrade does not dramatically encourage FDI participation of Japanese firms as compared to the effect of FDI restriction on the quality-upgrade level because entry costs of undertaking FDI are more expensive than fixed adjustment costs of quality-upgrade.
9 Conclusion

In this paper, I develop a dynamic structural model of a single agent decision in order to analyze the effect of voluntary export restraints (VERs), combined with other state characteristics, on two types of investment decisions of Japanese firms in the U.S. automobile industry: quality-upgrade and FDI. I find that the two types of investment decisions are substitutes in a dynamic framework. I also find that both investment activities are associated with substantial sunk costs, and that the entry costs of FDI are larger than the fixed adjustment costs of quality-upgrade. A static model may often miscalculate both investment costs, and it may not accurately reflect the important aspects of firms’ investment decisions according to the changes in trade regime because the substitutions of investment decisions occur in a dynamic framework and cannot be observed in a static analysis. Thus, a dynamic model provides a more appropriate framework to analyze the investment behavior.

An interesting extension of the paper would be to examine the effect of Japanese investment decisions due to the VERs on investment decisions of the U.S. domestic and European automakers within a dynamic competition framework. In this environment, investment decisions of Japanese producers may affect domestic and/or European producers’ investment strategies. There are several papers that have already studied the effect of VERs on quality-upgrade as well as on prices when there is competition and most of them find that VERs led to increases in both prices and product quality levels of the U.S. domestic and European producers in the U.S. automobile market. However, Japanese investment experiences due to VERs might have negatively affected the U.S. domestic capacity investment decisions due to decreasing domestic market shares. This appears true in an examination of the number of plant closures and start-ups in the U.S. during the VERs: many production plants of the big three domestic producers were likely to shut down or merge with each other, or convert from car to truck production. On the other hand, European producers may have had an opportunity to enter into the U.S. for production plants following successful Japanese FDI if they believed that they were likely to have export restrictions in the near future. The fact
that some European producers, such as BMW and Mercedes-Benz, actually began to open
their production facilities in the U.S. in the middle of the 1990s suggests that this would be
an interesting subject for future research.
References


49
Appendix A: Demand and Market Profit

Let time be assumed discrete with an infinite horizon and indexed by $t \in 1, 2, \cdots, \infty$. Consumer $i$’s utility from purchasing product $j$ at time $t$ is defined as follows:

$$u_{ijt} = \alpha^q Quality_{jt} - \alpha^p p_{jt} + \xi_{jt} + \xi_f + \epsilon_{ijt} \quad (33)$$

where $Quality_{jt}$ indexes product $j$’s quality level and $p_{jt}$ is the price of product $j$. The variable $\xi_{jt}$ represents unobserved characteristics of product $j$ and $\xi_f$ is the firm $f$’s specific dummy variable (firm fixed-effects) when the product $j$ is produced by the firm $f$. The variable $\epsilon_{ijt}$ is an idiosyncratic logit error term and it captures consumer specific heterogeneity. Outside products complete the demand system. The outside options are relatively large in my data because they allow consumers to choose non-Japanese products in the U.S. automobile market. The consumer $i$ chooses these outside options if the utility derived from purchasing outside products exceeds the utility derived from purchasing any inside options. The utility of outside products is given by:

$$u_{i0t} = \xi_0 + \epsilon_{i0t} \quad (34)$$

The mean utility of outside product is normalized to zero so that it anchors valuations of inside products.

There are $F$ firms in the automobile industry and each firm produces a subset of $J$ products. Firms are assumed to choose product prices each period in order to maximize their total market profits:

$$\Pi_{ft} = \sum_{j \in J_f} (p_{jt} - mc_{jt}) s_{jt} M_t \quad (35)$$

where $J_f$ denotes a set of products the firm $f$ produces, $M_t$ is a market size of the U.S. automobile industry in period $t$ and $mc_{jt}$ is a marginal cost of producing product $j$ in period $t$. The variable $s_{jt}$ denotes product $j$’s market share in period $t$ as follows:
\[ s_{jt} = \frac{\exp(\alpha^q \text{Quality}_{jt} - \alpha^p p_{jt} + \xi_{jt} + \xi_f)}{\left(1 + \sum_{r \in J} \exp(\alpha^q \text{Quality}_{rt} - \alpha^p p_{rt} + \xi_{rt} + \xi_f)\right)} \]  

(36)

Thus, each product price \( p_{jt} \) must satisfy the following first order condition as below:

\[ s(p_{jt}, \text{Quality}_{jt}, \xi_{jt}, \xi_f) + \sum_{r \in J_f} (p_{rt} - m_{cr}) \frac{\partial s(p_{rt}, \text{Quality}_{rt}, \xi_{rt}, \xi_f)}{\partial p_{jt}} = 0 \]  

(37)

By using equation (35), I find the derivatives of product market share as follows:

\[ -\frac{\partial s(p_{rt}, \text{Quality}_{rt}, \xi_{rt}, \xi_f)}{\partial p_{jt}} = \begin{cases} \alpha^p s_{jt} (1 - s_{jt}), & \text{if } r \text{ and } j \text{ are the same} \\ -\alpha^p s_{jt} s_{rt}, & \text{otherwise} \end{cases} \]  

(38)

**Appendix B: Demand Estimation and Computation of Marginal Cost**

I define product market share as \( s_{jt} \equiv Q_{jt}/M_t \) where \( Q_{jt} \) is product \( j \)’s quantity being sold and \( M_t \) is the market size of the U.S. automobile industry in period \( t \). I use a simple logit demand model to estimate the consumer demand:

\[ \ln(s_{jt}) - \ln(s_{0t}) = \alpha^q \text{Quality}_{jt} + \alpha^p p_{jt} + \xi_{jt} + \xi_f \]  

(39)

where \( s_{0t} \) denotes the market share of outside products, \( \text{Quality}_{jt} \) indexes product \( j \)’s quality level and \( p_{jt} \) is the price of product \( j \). The variable \( \xi_{jt} \) represents unobserved characteristics of product \( j \) and \( \xi_f \) is the firm \( f \)’s specific dummy variable (firm fixed-effect) when the product \( j \) is produced by the firm \( f \). The main problem of demand estimation is correlation between prices and unobserved characteristics \( \xi_{jt} \), which requires instrumental variables. Nevo (2000) explains that including brand fixed-effects in the demand model is able to solve this endogeneity problem without any instrumental variables. The brand-specific dummy variable captures both mean of observed characteristics \( \alpha^q \text{Quality}_{jt} \) that do not vary by markets and mean of unobserved components \( \xi_{jt} \). The error term is now market-specific deviation (\( \Delta \xi_{jt} = \xi_{jt} - \xi_f \)), which is not correlated with prices. Thus I use a simple OLS regression by including firm
(brand) fixed-effects to estimate the logit demand equation.

Marginal costs are not observed so I find a markup equation that satisfies the first order condition derived from the static model in which firm \( f \) chooses each product price to maximize the current value of market profit. To recover the marginal cost parameter for each product, I use the markup property

\[
\text{Markup}_{ft} = p_{jt} - mc_{jt} = p_{rt} - mc_{rt}, \forall j, r \in \mathcal{F},
\]

proposed by Anderson, De Palma and Thisse (1992). Then I am able to compute the simple markup equation as follows:

\[
\text{Markup}_{ft} = p_{jt} - mc_{jt} = \frac{1}{\alpha^p} \left( 1 - \sum_{j \in \mathcal{F}} s_{jt} \right)
\]  

(40)

where \( \sum_{j \in \mathcal{F}} s_{jt} \) is the total market share of firm \( f \).

**Appendix C: Derivation of the Markup Equation**

In a matrix form:

\[
p - mc = \Omega^{-1} s(p, \text{Quality}, \xi, \xi_f)
\]  

(41)

where \( s(\cdot), p, \) and \( mc \) are \( J \times 1 \) vectors of product market shares, prices and marginal costs respectively. The variable \( \Omega \) is a \( J \times J \) matrix with the element:

\[
\Omega = \begin{bmatrix}
-\alpha^p s_1 (s_1 - 1) & -\alpha^p s_1 s_2 & \cdots & -\alpha^p s_1 s_{J-1} & -\alpha^p s_1 s_J \\
-\alpha^p s_2 s_1 & -\alpha^p s_2 (s_2 - 1) & \cdots & -\alpha^p s_2 s_{J-1} & -\alpha^p s_2 s_J \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
-\alpha^p s_{J-1} s_1 & -\alpha^p s_{J-1} s_2 & \cdots & -\alpha^p s_{J-1} (s_{J-1} - 1) & -\alpha^p s_{J-1} s_J \\
-\alpha^p s_J s_1 & -\alpha^p s_J s_2 & \cdots & -\alpha^p s_J s_{J-1} & -\alpha^p s_J (s_J - 1)
\end{bmatrix}
\]  

(42)

where,

\[
\Omega_{jr} = \begin{cases} 
-\frac{\partial s_{jr}}{\partial p_j}, & \text{if } j \text{ and } r \text{ are produced by the same firm} \\
0, & \text{otherwise}
\end{cases}
\]
I produce a simple example to derive the inverse matrix of $\Omega$; There are two firms (F1 and F2) in a market. The F1 produces P1 and P2. The F2 produces P3 and P4. The inverse matrix of $\Omega$ is as follows:

$$\Omega^{-1} = \begin{bmatrix}
\frac{s_2-1}{\alpha p s_1(1-s_1-s_2)} & \frac{-1}{\alpha p(1-s_1-s_2)} & 0 & 0 \\
\frac{-1}{\alpha p(1-s_1-s_2)} & \frac{1}{s_1-1} & 0 & 0 \\
0 & 0 & \frac{s_4-1}{\alpha p s_3(1-s_3-s_4)} & \frac{-1}{\alpha p(1-s_3-s_4)} \\
0 & 0 & \frac{-1}{\alpha p(1-s_3-s_4)} & \frac{s_4-1}{\alpha p s_4(1-s_3-s_4)} \\
0 & 0 & \frac{-1}{\alpha p(1-s_3-s_4)} & \frac{s_4-1}{\alpha p s_4(1-s_3-s_4)} 
\end{bmatrix} \quad (43)$$

By using (43), I am able to compute the markup equation in this example as below:

$$p - mc = \begin{bmatrix}
\frac{s_2-1}{\alpha p s_1(1-s_1-s_2)} & \frac{-1}{\alpha p(1-s_1-s_2)} & 0 & 0 \\
\frac{-1}{\alpha p(1-s_1-s_2)} & \frac{1}{s_1-1} & 0 & 0 \\
0 & 0 & \frac{s_4-1}{\alpha p s_3(1-s_3-s_4)} & \frac{-1}{\alpha p(1-s_3-s_4)} \\
0 & 0 & \frac{-1}{\alpha p(1-s_3-s_4)} & \frac{s_4-1}{\alpha p s_4(1-s_3-s_4)} \\
0 & 0 & \frac{-1}{\alpha p(1-s_3-s_4)} & \frac{s_4-1}{\alpha p s_4(1-s_3-s_4)} 
\end{bmatrix} \begin{bmatrix}
s_1 \\
s_2 \\
s_3 \\
s_4 
\end{bmatrix} = \begin{bmatrix}
\frac{1}{\alpha p(1-s_1-s_2)} \\
\frac{1}{\alpha p(1-s_1-s_2)} \\
\frac{1}{\alpha p(1-s_3-s_4)} \\
\frac{1}{\alpha p(1-s_3-s_4)} 
\end{bmatrix} \quad (44)$$

I finally have the general markup equation with product $j$ produced by firm $f$ from (44) as follows:

$$p_{jt} - mc_{jt} = \frac{1}{\alpha p \left(1 - \sum_{j \in f} s_{jt}\right)} \quad (45)$$
Figure 1: Quality and Capacity Investment Per Year
Figure 2: Difference Between Japanese Exports and VER Limits Per Year
Figure 3: Japan/U.S. Foreign Exchange Rates (Japanese Yen/U.S. Dollar)

Figure 4: Effect of VERs on Quality Investment
Figure 5: Effect of VERs on Capacity Investment with Dollar Depreciation

Figure 6: Effect of VERs on Capacity Investment without Dollar Depreciation
Figure 7: Effect of Capacity Investment Restriction on Quality Investment Policy

Figure 8: Effect of Quality Investment Restriction on Capacity Investment Policy
Table 1: Summary Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Std</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ($\times$000)</td>
<td>11.711</td>
<td>9.835</td>
<td>6.822</td>
<td>4.670</td>
<td>55.900</td>
</tr>
<tr>
<td>Unit Sold (1,000s)</td>
<td>52.828</td>
<td>29.106</td>
<td>6.834</td>
<td>0.001</td>
<td>1000.233</td>
</tr>
<tr>
<td>Product Quality Level</td>
<td>0.450</td>
<td>0.432</td>
<td>0.112</td>
<td>0.120</td>
<td>0.914</td>
</tr>
<tr>
<td>Product Market Share</td>
<td>0.006</td>
<td>0.003</td>
<td>0.007</td>
<td>0</td>
<td>0.105</td>
</tr>
<tr>
<td>VER Year</td>
<td>0.571</td>
<td>1</td>
<td>0.497</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Exchange Rate(Y/$)</td>
<td>168.460</td>
<td>144.600</td>
<td>56.117</td>
<td>93.960</td>
<td>268.620</td>
</tr>
<tr>
<td>Firm-Level Relative Quality</td>
<td>1.012</td>
<td>1.028</td>
<td>0.143</td>
<td>0.626</td>
<td>1.361</td>
</tr>
<tr>
<td>Difference (1,000,000s)</td>
<td>-0.017</td>
<td>0</td>
<td>0.054</td>
<td>-0.243</td>
<td>0.087</td>
</tr>
<tr>
<td>Quality Investment</td>
<td>0.011</td>
<td>0</td>
<td>0.022</td>
<td>0</td>
<td>0.136</td>
</tr>
<tr>
<td>Capacity Investment</td>
<td>0.071</td>
<td>0</td>
<td>0.259</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Firm Market Share</td>
<td>0.029</td>
<td>0.017</td>
<td>0.010</td>
<td>0</td>
<td>0.156</td>
</tr>
<tr>
<td>Market Size (1,000,000s)</td>
<td>9.519</td>
<td>9.751</td>
<td>1.073</td>
<td>7.765</td>
<td>11.318</td>
</tr>
</tbody>
</table>

Prices are adjusted in constant 1983 dollars.
Each product quality level is defined as HP/Weight (HP is divided by 10 s of lbs).
Quality Investment is measured as the difference between median value of current product quality levels and median value of past product quality levels.
Difference is measured as the difference between units exported and limits, interacted with the VER dummies.
Market size is total units sold in the U.S. automobile industry including Japanese automakers.

Table 2: Demand Estimates

| Dependent Variable: ln(Annual Firm Market Share)-ln(Annual Outside Market Share) |
|-------------------------------|-------------------|
| Variable                      | Coefficient       | Standard Error |
| Constant                      | -0.951            | 0.260          |
| ln(Price)                     | 0.793             | 0.085          |
| ln(Quality)                   | 0.822             | 0.214          |
| Firm (Brand) Fixed Effects    | Yes               |                |
| Adjusted R-Squared            | 0.7001            |                |
| Number of Observations        | 2012              |                |
Table 3: Effect of Firm’s State Variables on Annual Market Profit

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.141</td>
<td>1.324</td>
</tr>
<tr>
<td>Time Trend</td>
<td>-0.020</td>
<td>0.013</td>
</tr>
<tr>
<td>VER Dummy</td>
<td>-0.093</td>
<td>0.062</td>
</tr>
<tr>
<td>Lag FDI</td>
<td>0.329</td>
<td>0.079</td>
</tr>
<tr>
<td>Lag Quality-Upgrade</td>
<td>0.025</td>
<td>0.006</td>
</tr>
<tr>
<td>ln(Exchange Rate)</td>
<td>0.417</td>
<td>0.232</td>
</tr>
<tr>
<td>Relative Quality</td>
<td>1.603</td>
<td>0.196</td>
</tr>
<tr>
<td>Difference</td>
<td>1.988</td>
<td>1.030</td>
</tr>
<tr>
<td>Difference^2</td>
<td>-16.091</td>
<td>6.288</td>
</tr>
<tr>
<td>Lag FDI-Relative Quality</td>
<td>-0.041</td>
<td>0.079</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Adjusted R-Squared</td>
<td>0.743</td>
<td></td>
</tr>
<tr>
<td>Number of Observations</td>
<td>140</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Effect of State Variables on Quality Investment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.186</td>
<td>0.104</td>
</tr>
<tr>
<td>Time Trend</td>
<td>-0.003</td>
<td>0.010</td>
</tr>
<tr>
<td>VER Dummy</td>
<td>0.006</td>
<td>0.012</td>
</tr>
<tr>
<td>Lag FDI</td>
<td>-0.021</td>
<td>0.012</td>
</tr>
<tr>
<td>Lag Quality-Upgrade</td>
<td>-0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>ln(Exchange Rate)</td>
<td>-0.016</td>
<td>0.018</td>
</tr>
<tr>
<td>Relative Quality</td>
<td>-0.101</td>
<td>0.022</td>
</tr>
<tr>
<td>Difference</td>
<td>0.139</td>
<td>0.075</td>
</tr>
<tr>
<td>Difference^2</td>
<td>0.920</td>
<td>0.455</td>
</tr>
<tr>
<td>Relative Quality-VER Dummy</td>
<td>0.027</td>
<td>0.013</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Adjusted R-Squared</td>
<td>0.544</td>
<td></td>
</tr>
<tr>
<td>Number of Observations</td>
<td>132</td>
<td></td>
</tr>
</tbody>
</table>
Table 5: Effect of State Variables on Capacity Investment (Probit)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>24.203</td>
<td>12.681</td>
</tr>
<tr>
<td>Time Trend</td>
<td>-0.215</td>
<td>0.161</td>
</tr>
<tr>
<td>VER Dummy</td>
<td>2.376</td>
<td>0.916</td>
</tr>
<tr>
<td>Lag FDI</td>
<td>-0.201</td>
<td>0.884</td>
</tr>
<tr>
<td>Lag Quality-Upgrade</td>
<td>-0.105</td>
<td>0.502</td>
</tr>
<tr>
<td>ln(Exchange Rate)</td>
<td>-5.581</td>
<td>2.301</td>
</tr>
<tr>
<td>Relative Quality</td>
<td>3.419</td>
<td>2.254</td>
</tr>
<tr>
<td>Difference</td>
<td>47.600</td>
<td>21.587</td>
</tr>
<tr>
<td>Difference(^2)</td>
<td>854.166</td>
<td>479.880</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Prob\(>\chi^2\) 0.288
Number of Observations 132

Table 7: Exchange Rate Transition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.352</td>
<td>0.438</td>
</tr>
<tr>
<td>ln(Lag Exchange Rate)</td>
<td>0.922</td>
<td>0.085</td>
</tr>
</tbody>
</table>

Adjusted R-Squared 0.866
Observation 20

61
Table 8: Relative Quality Transition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.149</td>
<td>0.047</td>
</tr>
<tr>
<td>Lag Relative Quality</td>
<td>0.832</td>
<td>0.294</td>
</tr>
<tr>
<td>Quality Investment</td>
<td>2.138</td>
<td>0.294</td>
</tr>
<tr>
<td>Capacity Investment</td>
<td>-0.009</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Number of Observations: 132

Table 9: Difference between Exports and VER Limits Transition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Lag Difference</td>
<td>0.608</td>
<td>0.067</td>
</tr>
<tr>
<td>Quality Investment</td>
<td>-0.434</td>
<td>0.165</td>
</tr>
<tr>
<td>Capacity Investment</td>
<td>-0.021</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Number of Observations: 132

Table 10: Dynamic Parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Investment Cost</td>
<td>1.856</td>
</tr>
<tr>
<td>Capacity Investment Cost</td>
<td>4.779</td>
</tr>
<tr>
<td>Standard Error of Quality Cost Shock</td>
<td>0.001</td>
</tr>
<tr>
<td>Standard Error of Capacity Cost Shock</td>
<td>0.014</td>
</tr>
</tbody>
</table>

I simulate 1000 times and averaged to obtain expected values. Each simulation path has 100 year lifetimes.
Table 11: Average Quality-Upgrade levels with and without VERs

<table>
<thead>
<tr>
<th></th>
<th>Average Quality-Upgrade Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERs</td>
<td>0.0014</td>
</tr>
<tr>
<td>No VERs</td>
<td>0.0007</td>
</tr>
</tbody>
</table>

Table 12: Average Probabilities of FDI with and without VERs (Dollar Depreciation)

<table>
<thead>
<tr>
<th></th>
<th>Average Probability of FDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERs (Dollar Depreciation)</td>
<td>0.267</td>
</tr>
<tr>
<td>No VERs (Dollar Depreciation)</td>
<td>0.127</td>
</tr>
</tbody>
</table>

Table 13: Average Probabilities of FDI with and without VERs (No Dollar Depreciation)

<table>
<thead>
<tr>
<th></th>
<th>Average Probability of FDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERs (No Dollar Depreciation)</td>
<td>0.267</td>
</tr>
<tr>
<td>No VERs (No Dollar Depreciation)</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Table 14: Average Quality-Upgrade levels with and without FDI

<table>
<thead>
<tr>
<th></th>
<th>Average Quality-Upgrade Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDI</td>
<td>0.0014</td>
</tr>
<tr>
<td>No FDI</td>
<td>0.0032</td>
</tr>
</tbody>
</table>

Table 15: Average Probabilities of FDI with and without Quality-Upgrade

<table>
<thead>
<tr>
<th></th>
<th>Average Probability of FDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality-Upgrade</td>
<td>0.369</td>
</tr>
<tr>
<td>No Quality-Upgrade</td>
<td>0.410</td>
</tr>
</tbody>
</table>