The Impact of Supply Chain Disruptions: Evidence from the Japanese Tsunami*

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Abstract

Despite attention in the media concerning the increasing number of international supply chain disruptions due to major natural disasters, little empirical evidence is available. Using, as a natural experiment, the sharp drop in Japanese exports of motor vehicles and parts to the USA after the Great Tohoku Earthquake and Tsunami 2011, the impact of the supply chain disruption on labour inputs adjustment in the US auto industry is estimated. Exploiting state-level variation in numbers of direct employment by Japanese auto makers and location of auto manufacturing factories, this paper identifies the adjustment among Japanese companies, their suppliers as well as their competitors based on the CPS and QWI data. Notwithstanding significant losses of the Japanese firms' market share, I find that the disaster negatively affects only average monthly earnings of workers in Japanese assembly plants whereas their competitors do not seem to significantly increase any labour inputs in their assembly plants. Regarding changes in motor vehicle parts and accessories manufacturing, only production adjustment detected is in the counties where factories from the same auto companies are located. Moreover, other than a slight change in inventory management and sales incentive, there is no evidence of any adjustments on other margins of factors such as import substitution, or spikes in prices. These results suggest that the overall impact of this disaster on the US economy through the auto industry is rather small.

Keywords: international supply shock, firm behaviour (empirical), labour inputs adjustment, automobile industry

JEL Classification: D22, F16, J23, L62, Q54

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1 Introduction

International supply chain has enhanced its role in the manufacturing sector during the last two decades. Advancement in Information and Communication Technology (ICT) as well as trade and investment liberalization both reduces costs of coordination in production process and makes geographical separation of manufacturing stages driven by scale economies and comparative advantage become more viable (Humphrey, 2003 and Baldwin, 2011). This growing interdependence of the supply chain could, however, make output and price more vulnerable. Either demand or supply shock in one country could potentially jeopardize other countries manufacturing industries along its global production chain. For example in 2011, the media expressed their concerns about supply chain disruption of electrical components and motor vehicles after the destruction of Japan′s Great Tohoku Earthquake and Tsunami in March (New York Times, 2011, March 19) and hard disk drives shortage made a headline during Thai floods around the last quarter of the year (BBC, 2011, November 1 and The Guardian, 2011, October 25). Yet, there is little evidence of the impacts of such disruptions on production or other possible adjustments among producers and suppliers in countries on the downstream. While the expected negative outcomes on severely affected firms are obvious, the reaction of competitors and domestic suppliers are ambiguous, especially, when the shock is abrupt and massive but potentially involves uncertainty on the exact time of recovery.

There are several challenges to empirical research on the impacts of shock on the international supply chain. First, the literature on economic impacts of natural or man-made disasters tends to overlook the role of trade and the global value chain as a channel for shock transmission across countries. They mostly emphasize, for instance, estimation techniques for national or regional economies (Cochrane, 2004, and Hallegatte, 2008), volume of trade (Martin Gassebner and Teh, 2010), local labour markets (Belasen and Polachek, 2009, and Lopamudra, 2007) or local business survival, such as in Sri Lanka (Dickson and Kangaraarachchi ,2006). In addition, major supply shocks to one group of companies but not their counterpart in the same industry are rare events. There is a paucity of economic papers discussing impact on producers as well as dealers and their adjustment to demand shock(s) in an oligopoly market like the auto industry (Copeland, Dunn, and Hall, 2005, and Albuquerque and Bronnenberg, 2012) but none on a supply shock. This paper simultaneously estimates impacts of international supply shock on businesses through alteration in labour inputs, price and other margins using the Great Tohoku Earthquake and Tsunami 2011 as a natural experiment.

According to Figure 1, the Great Tohoku Earthquake and Tsunami has potential to cause disruption on infrastructure and production capacity of Japan. This shock reflects through an abrupt drop in Japanese exports to the USA. More specifically to the auto industry, there are two channels of supply

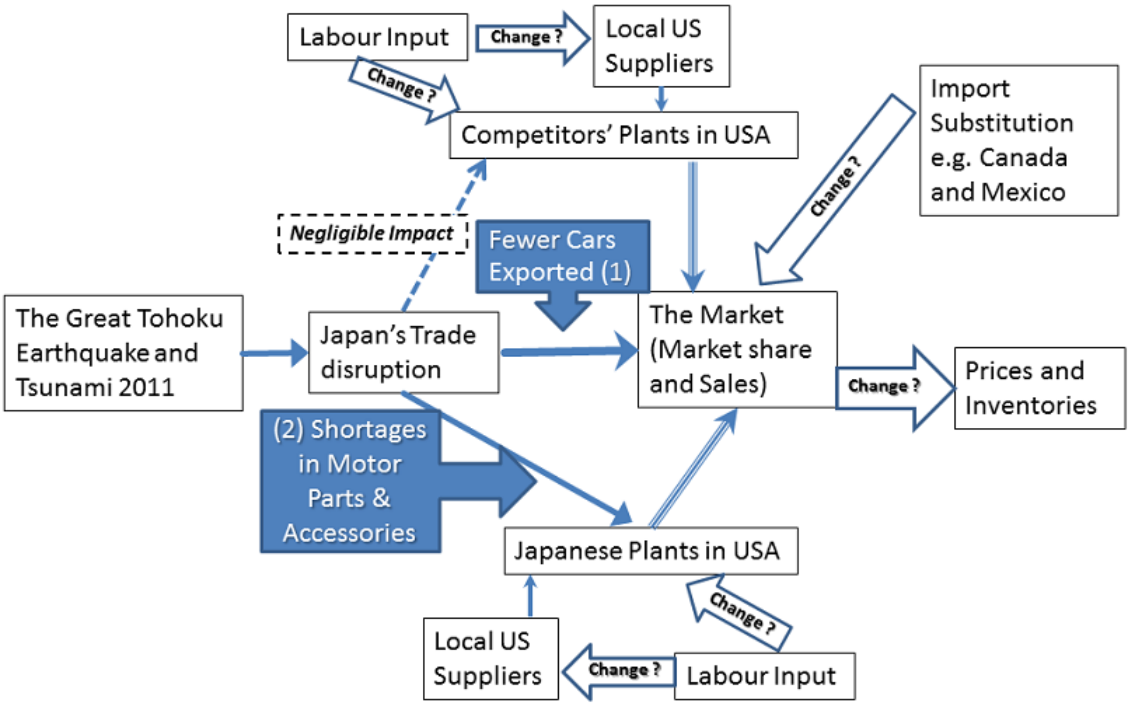

Figure 1: *Transmission Mechanism of the Shock and Potential Channels of Adjustment*

shock on Japanese auto companies in the US market. First, fewer cars can be imported from Japan. This shortfall offers other manufacturers an opportunity to grasp the Japanese market share through adjustment in production and inventory. The second mechanism is shortages in various motor vehicles parts and accessories which hampers production in plants inside the USA. The immediate direct effect of this mechanism reduces production among Japanese auto makers while the secondary effect amplifies the shortfall in finished cars available in the US market[1]. Moreover, Figure 1 suggests potential channels of adjustment, that is, a reduction in labour inputs[2] of Japanese auto makers and their suppliers, a possible increase in labour inputs among Japanese competitors and their suppliers, and other margins of adjustment such as spikes in price and import substitution.

I employ monthly Current Population Survey (CPS) data from January 2005 to April 2012 and Quarterly Workforce Indicators (QWI) from 1^{st} quarter of 2001 to 3^{rd} quarter of 2011 to estimate changes in labour inputs between Japanese auto makers and their counterparts. Since there is no information on nationality of firms in the CPS or QWI, the state-level variation in numbers of direct employment by Japanese auto companies is exploited to estimate the relationship between a share of Japanese employment and labour inputs alteration in those states. Only a small negative effect of the Japanese's

[1] Although it is plausible to assume that Japanese competitors do inevitably rely on some auto parts from Japan, most competitors such as GM and Hyundai claim that they can manage to get through the aftermath relatively unscratched.

[2] Since auto industry has enough spare capacity after the financial crisis, it is suffice to use an adjustment in labour inputs as a proxy for change in production

employment share on average monthly earnings of workers in motor vehicles manufacturing (chassis and assembly plants) is observed. Yet, this negative effect is not sustained under a broader classification of auto industry which includes not only motor vehicles manufacturing but also bodies, parts and engines manufacturing. Hence, the effect of intermediate inputs shortage on Japanese production in the US seems to be small and contained in just one sub-industry of auto manufacturing.

In spite of a modest adjustment in Japanese production in the US, a sharp drop in imported cars still gave other companies an opportunity to gain market share and capitalize on the Japanese loss. I therefore employ various techniques to model trend and seasonality in the data for each groups of auto makers and I then identify the impacts of this shock as any significant deviation from underlying trend and seasonal effects during the second and third quarters of 2011. The findings based on CPS data suggest that auto companies and suppliers in the US production bases, that is, the states of Michigan and Illinois increase their hours of overtime per week, with significance level at 20%, while none of other auto groups shows any movement. However, the results based on QWI data depict different patterns of the adjustment. None of the counties that are the location of the US auto or parts manufacturing has any significant results, except for one outlier county in Indiana[3]. Meanwhile, the only significant change at 5% level comes from a rise in average monthly earnings of those counties with German owned parts and engines plants. Although this could be a sign of adjustment corresponding to a gain in market share from the Japanese, it must be interpreted with caution because there is no change detected among the German assembly plants.

In addition, this paper tests for any linkages between auto makers' assembly plants and suppliers for parts and engines around their locality during this shock. The results do not indicate any labour inputs adjustment in the counties where parts and engines plants are located alongside assembly plants. The exception is in two counties where both assembly and parts plants belong to the same auto companies. In sum, the overall labour inputs adjustments among Japanese firms and their competitors are modest.

Due to the difficulty of obtaining the data, some descriptive statistics are used to verify adjustment in other margins. As for import substitution, value of imports from Canada and Mexico does not illustrate any change due to the shock. Moreover, there is no evidence of any spikes in prices based on the CPI data. Yet, other indices depict a slight change in inventory management and sales incentive which could be important mechanisms used by auto companies to implicitly adjust their price and manage their output flow. Nevertheless, all available results suggest that the overall impact of this disaster on the US economy through the auto industry is surprisingly small.

The paper is structured as follows. Section 2 outlines the shock and US Auto industry. Section 3

[3]This result contrasts to the one from CPS. Yet, it can coincide because a small adjustment in overtime might not lead to a significant change in average monthly earnings, the only proxy for average hours of worked available in the QWI.

describes the data while Section 4 briefly discusses the theoretical background and empirical strategies. Section 5 presents the results and Section 6 examines other margins of adjustment.

2 The shock and US Auto industry

The disaster and Japanese exports

The scale of destruction caused by the Great Tohoku Earthquake and Tsunami 2011 is immense. It claimed 15,870 lives and 2,814 people missing across Japan. The economic damage is estimated to be 210 billion USD, the highest among all natural and unnatural disasters in decades (CRED, 2011). Yet, it is not straightforward how impacts of this disaster ranging from loss of human lives and demolition of physical capital to energy crisis involving a number of nuclear accidents can be identified. This paper primarily identifies a shock from Great Tohoku Earthquake and Tsunami 2011 as losses of production capacities in three prefectures, namely, Iwate, Miyagi and Fukushima, which are the most severely affected areas classified by number of casualties, missing persons and buildings damaged (National Police Agency of Japan, 2012).

According to the Japan Census of Manufactures 2009, the three prefectures are not highly industrialized. The total value of manufactured goods shipments from these prefectures accounts for only 3.6% of the whole country. However, there are some intermediate goods which are intensively produced in these prefectures; for example, 40.9% of country-wide production of metal / combined with non-metal packing and gaskets, 32.5% of parts, attachments and accessories of cameras and motion picture equipment, 22.66% of digital camera module and 33.6% of car heaters. Specifically, for auto companies like Toyota, their motor plants in these prefectures were closed for around a month and operated under restricted capacity during the second quarter of 2011[4].

This disruption in the supply chain and damage to the transportation system lead to a drastic drop in Japanese exports in manufacturing goods to USA and the world. Among these products, export value of motor vehicles (with the first two digits Harmonised System (HS) code 87) to USA was reduced the most comparing to its predicted trend. Within this category, export of motor cars and vehicles for transporting persons (HS 8703) dropped more than half, while a decrease in parts and accessories for motor vehicles (HS 8708) was less severe. Yet, investigating into sub-categories depicted sharp shortfalls in some auto parts and accessories such as safety seat belts, brakes, radiators and clutches as shown in Figure 14[5].

[4] Although the number of casualties are much smaller in nearby prefectures such as Aomori, Ibaraki and Chiba, high levels of destruction in these prefectures lead to several immediate disruptions in the auto industry especially in March and April. For example, thousands of Nissan cars to be exported to USA were wiped out in the port of Hitachi, Ibaraki (Automotive News March 12, 2011).

[5] There are examples of disruptions on Media. For instance, according to a Toyota News Release, there are approximately 150 parts affecting new-vehicle production, mainly electronic, rubber and paint-related. However, replacement parts for

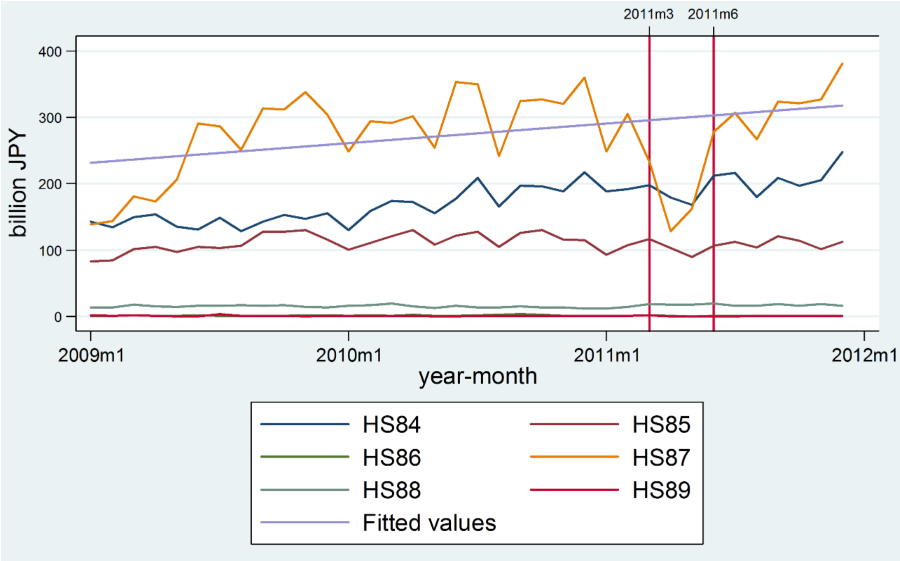

Figure 2: *Japan's Export Value to USA 2009-2011 by HS code industry 84-89*

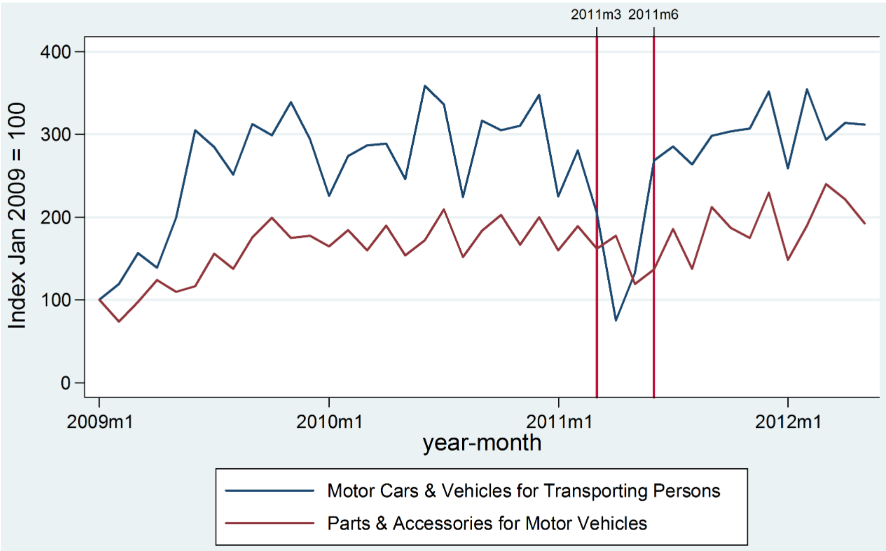

Figure 3: *Japan's Export Value to USA (Monthly Indices)*

Further, as for the relative importance of Japanese exports to USA in both cars & vehicles for transporting persons and parts and accessories, they constitute 28% and 17% of the total value of US imports in 2010 respectively. Therefore, an impact to the auto industry in US could be significant since they cannot easily offset any shortage in Japanese motor vehicles and parts by other trade partners.

I identify a supply shock on Japanese car makers in the US as either (1) a shortage of finished cars imported from Japan or (2) a production disruption in their US plants due to parts shortage (They are (1) and (2) in Figure 1). The main result on labour inputs for Japanese companies focuses on the second type of shock, whereas the first effect indirectly affects labour inputs of Japanese competitors if they increase their production in response to the shortage. Moreover, other margins of adjustment due to this supply shock are discussed in Section 6.

US Auto industry and the market aftermath

Motor vehicle manufacturing industry is one of the biggest employers in USA. Apart from the Detroit 3 (GM, Ford, and Chrysler LLC), foreign auto-makers have been investing in several assembly plants such as German and Japanese from the 80s and South Korean since 2005. These foreign-owned Original Equipment Manufacturers (OEMs) recently become important employers for manufacturing workers in states like Alabama, Georgia, Kentucky, Mississippi, and South Carolina.

Although the industry has experienced a series of declines in employment since 2000, in 2008, it still employed approximately 6.6% of the U.S. manufacturing workforce (Platzer and Harrison, 2009). During and after the financial crisis, the auto industry suffered a sharp drop in demand forcing auto makers to cut their capacity utilization from 73.7% in 2007 to a trough of 44.8% in the recession-led 2009. Then, the utilization gradually rebounded to 65.1% and 70.7% in 2010 and 2011 respectively (WardsAuto, 2012).

In terms of market share, the Detroit 3 domestic share decreased from 64.5% in 2001 to 47.5% in 2008. After the restructuring and bankruptcy of Chrysler and General Motors in 2009 until early 2011, the US auto makers retained the share of around 45% while the Japanese sales accounted for 35-40%. Yet, the disaster caused a major setback for Japanese firms. According to Figure 4, their market share dropped sharply from 40% in March to just over 30% in July before they regained their position in early 2012 (see Figure 15 for the detailed movement in sales among major auto companies). The magnitude and length of loss in market share by Japanese companies illustrates the severe but transitory effects of this shock on these firms' supply chain and performance. This is, however, consistent with a reduction in Japan's export in Figure 2. In the following section, labour market data is used to shed some light on a reaction to a temporary supply shock by Japanese producers and their competitors.

sales service and repair are available.

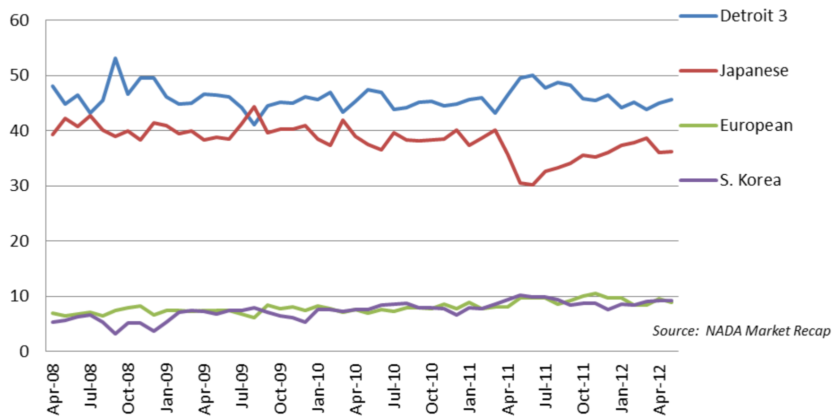

Figure 4: *Market Share of Auto Industry by firms' nationality*

3 Data

Two sets of data are employed to estimate impacts of the shock on labour inputs adjustment in the auto industry. They are the Current Population Survey (CPS) conducted by the Bureau of Census for the Bureau of Labor Statistics (BLS) and the Quarterly Workforce Indicators (QWI) published by the Longitudinal Employer-Household Dynamics (LEHD) Program at the U.S. Census Bureau[6]. First, I analyse monthly data of the CPS from January 2005 to April 2012. The starting point of this data is chosen arbitrarily to achieve a balanced representation between pre and post financial crisis. Moreover, it might be misleading to include CPS data during the 90s or early 2000s because the auto industry had experienced different trends and turning points due to shocks and changes, for instance, oil price hikes or a dot-com bubble burst.

The sample consists of individuals aged sixteen and over who had their primary jobs in selected industries during the CPS survey week and for whom data are available for weekly hours of work and overtime. Then, I aggregate the data to state-level for total employment, average hours of work and overtime per week in motor vehicles and motor vehicle equipment manufacturing and other related industries[7].

Further, analyses in this paper rely on an external shock on Japanese auto makers but there is no information concerning nationality of employers in CPS. I therefore exploit state-level variation in employment among groups of motor vehicles manufacturers. Specifically, the number of direct employment by Auto companies in each state[8] is used to compute the share of Japanese firms' direct employment in those states. Moreover, to compare the impacts between Japanese auto makers and their competitors,

[6]The data I used are compiled from public-use data files by the Cornell Virtual RDC version R2012Q3

[7]I ignore hourly earnings data because only one-fourth of CPS samples answer questions on earning. Thus, sample sizes of any specific groups in each month are small and unrepresentative.

[8]This data comes from various sources compiled by the Alliance of Automobile Manufacturers (Auto Alliance) which is an association of 12 new vehicle manufacturers in US.

Table 1: Descriptive Statistics of the CPS Sample

Variable	JP	USA	DE	Mix	Rest
Weekly hours	40.98	42.51	42.38	42.28	41.66
	(2.23)	(1.03)	(2.55)	(1.39)	(1.15)
Overtime	0.88	1.17	1.15	1.58	1.27
	(0.74)	(0.41)	(1.01)	(0.55)	(0.42)
Employment	66,019.8	360,012.3	55,307.1	384,780.4	261,167.9
	(19,782.7)	(71,621.31)	(17,559.4)	(60,537)	(60,859)
Sample size	21.25	115.51	19.51	131.67	136.81

All numbers are mean of variables in each group-month while standard errors are in parentheses.

I use these numbers to classify such states according to employment share by firms' nationality. Consequently, five groups of states are categorized, that is, US intensive states (Illinois and Michigan), Japan (California and Mississippi), Germany (North Carolina and South Carolina), Mixed states (Indiana, Kentucky, Ohio, Tennessee, Alabama, and Texas) and the rest (share of Japanese employment in each of these states which have more than 400 direct employees is presented in Table 9).

Table 1 shows descriptive statistics for employment, weekly hours of work and overtime as well as sample sizes of the first three categories in each group-month. The CPS sampling weights are used in the aggregation process but all of the statistical calculations reported here are unweighted estimates among sampling periods. In general, Japanese intensive states seem to have lower average hours of work and overtime than their US and German counterparts. A main concern is the relatively low number of respondents used to compute aggregate level data for Japanese and German intensive states. Thus, the QWI data is also employed for crosschecking the estimation.

The QWI offers some advantages over the CPS. Firstly, the QWI is estimated from administrative data[9], so it does not severely suffer from a small sample bias, as in CPS. Moreover, QWI provides detailed estimates of employment and earnings data at county level by detail industry (4-digit North American Industry Classification System; NAICS), gender and age groups of workers. Nevertheless, owing to disclosure-proofing methods used to protect the confidentiality of individuals and businesses that contribute to the underlying data, employment and earnings for specific industries in most counties are either suppressed or distorted[10].

I use both state and county level QWI data for all workers in auto manufacturing or related industries from 2001Q1 to 2011Q3. The choice of starting and ending point is mainly restricted by data availability. Unlike the CPS, 2005 is not chosen as a starting point because longer series are needed for properly modelling trend and seasonality of the data. In terms of identification strategy, other than applying the share of Japanese direct employment with state level data, I use the location of each manufacturer's

[9]such as wage records from state unemployment insurance (UI) system and Quarterly Census of Employment and Wages (QCEW) reported to the BLS

[10]These disclosure-proofing methods are noise infusion into micro data, weighting procedure and suppression of data based on fewer than three persons or establishments when the combination of noise infusion and weighting may not distort the publication data with a high enough probability to meet the criteria. See Abowd, *et. al.* (2005) for further discussion.

Table 2: Descriptive Statistics of the QWI Sample

Variable	JP	USA	DE
LogEmpEnd	8.485	8.668	8.250
	(2.775)	(2.836)	(2.297)
	[1,767]	[3,810]	[505]
LogEarnEnd	8.084	8.207	7.882
	(0.403)	(0.411)	(0.474)
	[2,321]	[4,832]	[869]
LogPayroll	16.648	16.891	15.428
	(3.256)	(3.596)	(3.235)
	[2,369]	[4,967]	[898]

All numbers are mean of variables in each group-month.
Standard errors are in parentheses while number of observations are in square blankets.

plants to classify counties into three groups. There are 25 counties categorized as Japanese, 36 as the US and 12 as German[11]. Three variables are employed from the QWI as indicators for adjustment in labour inputs, that is, number of employment on the last day of the quarter (EmpEnd), average monthly earnings of employees who worked on the last day of the reference quarter (EarnEnd) and total quarterly payroll (Payroll)[12]. Table 2 presents descriptive statistics of natural logarithm of these variables by group of firms' nationality.

4 Methodology

Considering the number of auto manufacturers and makes (models) sold in USA, the auto market can be viewed as an oligopoly with heterogeneous products. In this type of market, companies can choose to compete in either quantity (Cournot competition) or price (Bertrand competition). Singh and Vives (1984) show that if the goods are substitutes, larger profits can be obtained by deploying output over price competition. In particular, each car manufacturer can set sales target for its own dealers. Then, dealers will set monthly inventories and adjust prices to clear the market according to the sales goal (Tremblay, *et. al.*, 2010)[13]. Hence, this paper analyses effects of the shock in the auto industry through the framework of Cournot competition under an assumption that motor vehicles from different firms have certain degrees of substitution between each other.

Because of slackness in capital utilization during the recession, as well as a temporary nature of this shock[14], output adjustment through capital investment could be negligible. Thus, it is reasonable to

[11] I acquire these location from the Auto Alliance's data. Only counties with manufacturing plant(s) from the same group are included. This results in an exclusion of 2 counties in Michigan.

[12] As a result of disclosure-proofing methods, EmpEnd for many counties are suppressed while most of EarnEnd for specific industry at county level are distorted.

[13] However, according to Tremblay, *et. al.* (2010), it is optimal for firms to compete in price over output or a mix of both strategies provided that there are sufficient demand, cost, or strategic asymmetry between firms. They argue that in the small car market, Honda and Subaru use output strategy while Saturn and Scion (a nameplate of Toyota) first set prices and then fill consumers' demand at those prices.

[14] Although there was uncertainty in the first month after the disaster concerning energy shortage and whether the damage of Fukushima Daiichi Nuclear Plant could be contained, analysts in auto industry and stock market (such as Forbes, 2011) expected sales of Japanese auto makers to have recovered by the end of 2011.

assume that adjustment in level of outputs could be done by changes in labour and intermediate inputs. Therefore, production function for auto makers proposed by Copeland and Hall (2011) has been combined with perfect complementarity in materials. I specify production function for each manufacturing plant as follows:

$$q_t = Min(\frac{m_1}{a_1}, ..., \frac{m_i}{a_i}, ..., \frac{m_n}{a_n}, D_t \times S_t \times h_t \times LS) \tag{4.1}$$

where m_i is a quantity of material type i (i = 1,...,n) which requires a_i units to produce one unit of q_t. Meanwhile, each plant can operate in period t for D days with S shifts (either 1 or 2) per day and h hours per shift. Moreover, Copeland and Hall (2011) assume that number of employees per shift n and line speed LS are fixed. So, the production function is linear in hours[15] provided that there is no constraint on any materials m_i. Finally, total output of each firm at time t, Q_t, is a summation of output from all of its domestic plants (in the US) and its import (from Japan, Canada, Mexico, Germany, etc.).

However, the disaster could temporarily constrain levels of production through availability of intermediate inputs, m_i. With downward sloping best-response function (strategic substitutes) in the Cournot model for two sellers, this constraint would force firm $1'$s (suppose that it is a groups of Japanese companies) to produce less than the original equilibrium, that is, the former best-response function with a vertical kink at the constrained level of output[16]. Depending on the slope of their best-response function, firm 2 (Japanese competitors) might not increase their output enough to fulfill all supply shortage. Thus, the shock could lead to a lower equilibrium output but higher equilibrium price.

Due to limited data availability, the focus is mainly on adjustment in labour inputs. Nevertheless, I will present some descriptive statistics to infer any adjustment through import substitution, hikes in prices, and inventory management in section 6.

To identify the effect of this shock on demand for labour in auto industry, it is not obvious what the best strategy is. Since the main objective is to measure labour inputs adjustment due to the disaster among Japanese auto makers and their competitors, the first stage is to assess the direct effect of motor vehicles parts and accessories shortage on the choices of labour inputs among Japanese firms. I compute share of Japanese OEMs direct employment in every state as presented in Table 9 and use it as a proxy for exposure of the shock in each state. Then the CPS and QWI data are estimated with the following specifications:

$$y_{it} = \beta_0 + \beta_{1i} State_i + \beta_{2t} YM_t + \beta_3 Dis_t + \beta_4 ShareJP_i * Dis_t + e_{it} \tag{4.2}$$

[15] In their paper, Copeland and Hall (2011) also introduce several non-convexities in production costs through labour contract but it is beyond the scope of this paper.

[16] To be precise, this production constraint is resulted from shortages in both intermediate goods needed for production in USA and final products, that is, imported cars from Japan.

$$y_{it} = \beta_0 + \delta_{1i} State_i + \delta_{2c} Trend_t^c + \delta_{3s} Season_t^s + \delta_4 Dis_t + \delta_5 ShareJP_i * Dis_t + u_{it} \tag{4.3}$$

$$\begin{aligned} y_{it} = \theta_0 + \theta_{1i} State_i + \theta_{2ic} State_i * Trend_t^c + \theta_{3is} State_i * Season_t^s \\ + \theta_4 Dis_t + \theta_5 ShareJP_i * Dis_t + v_{it} \end{aligned} \tag{4.4}$$

where y_{it} are dependent variables of state i at time t. For CPS, they are average hours of work per week (HR), average overtime per week (OT) and natural logarithm of employment in the industry (LogEmp) (all are aggregated to state level using the CPS weight) whereas the dependent variables for QWI are natural logarithm of employment (LogEmpEnd), average monthly earnings (LogEarnEnd) and total quarterly payroll (LogPayroll). $State_i$ is a vector of dummy variables taking value 1 for state i and 0 for all other states. $ShareJP_i$ is a share of Japanese OEMs' direct employment (with value 0 - 1) computed from Auto Alliance's data[17] and Dis_t is a disaster dummy which is equal to 1 if t are April - July 2011 for CPS data and 2011 quarter 2 and 3 for the QWI[18].

The main difference between these specifications is how to model trend and seasonality. In equation 4.2, time dummies are used for each month-year, YM_t, in CPS (or quarter-year for QWI) while time trend and seasonal dummies are used in equation 4.3 where $Trend_t^c$ represents linear, quadratic as well as cubic time trend for period t[19] and $Season_t^s$ are monthly or quarterly dummies for season s in the CPS or QWI respectively. On the contrary, equation 4.4 explicitly models trend and seasonality for each state using $State_i * Trend_t^c$ and $State_i * Season_t^s$. In addition, I decide to allow for differences in states' fixed effect by using state dummies rather than relying on $ShareJP$ to pick up variations among states. Lastly, standard errors in all regressions are clustered at state level.

Nevertheless, the share of Japanese employment does not provide any information on adjustment by the competitors. With the CPS data, trend and seasonality of these series (HR, OT and LogEmp) are modeled separately for each group of states according to the firms' nationality categorized earlier. Allowing for stochastic rather than deterministic trend and seasonality, I employ Augmented DickeyFuller test (Said and Dickey, 1984) and HEGY test for monthly series (Hylleberg et al., 1990, Franses, 1990 and Beaulieu and Miron, 1993) to determine whether each series has unit root or seasonal unit root respectively. Then the multiplicative seasonal ARIMA model; $SARIMA(p,d,q)(P,D,Q)_S$ (Box, Jenkins and Reinsel, 1994) for each series is specified as follows:

$$\phi_p(B)\Phi_P(B^S)\Delta^d \Delta_S^D Y_t = \alpha + \theta_q(B)\Theta_Q(B^S)\epsilon_t \tag{4.5}$$

[17]This number reflects the share of Japanese employment around the end of 2010 to early 2011 when it is compiled by Auto Alliance. Hence, it is a constant for any state i

[18]The timing of this dummy is arbitrary but it corresponds to a sharp drop in Japanese's motor vehicles and parts export. The results are robust to a slight change in periods of the shock e.g. from Apr-Jul 2011 to Mar-Aug 2011.

[19]At the starting point of each data, t is set to be 1.

where Y_t is a series of dependent variable. B, B^S are backward shift operators for non-seasonal and seasonal component. d, p, and q (D, P, and Q) are number of differences required for (seasonal) stationarity, order of (seasonal) autoregressive and moving average component respectively. Δ^d, Δ_S^D are differences of order d and D. $\phi_p(B), \theta_q(B)[\Phi_P(B^S), \Theta_Q(B^S)]$ are polynomial of [seasonal] autoregressive and moving average component respectively. α is a constant and ϵ_t are white noise errors.

Moreover, SARIMA with intervention model (Box and Tiao, 1975) is employed to assess any adjustment owing to the shock. It can be specified as

$$Y_t = \zeta_t + N_t \tag{4.6}$$

where N_t is the Noise series from $SARIMA(p,d,q)(P,D,Q)_S$ and ζ_t is the intervention which is a function of a dummy Dis_t.

To find the optimal order of (seasonal or non-seasonal) Autoregressive (AR) and Moving Average (MA) component, I identify potential orders of p, q, P, and Q by observing the sample autocorrelation and partial autocorrelation plot. I run several variations of SARIMA and choose the model with the lowest value of estimated Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Lastly, the Ljung−Box Q test is applied to the residuals of the fitted model to check whether the model still suffers from autocorrelation. Only the models which the Q test cannot reject the null hypothesis of no autocorrelation are presented in the following section[20].

On the other hand, slightly different trend and seasonality modelling techniques are used with the QWI data. Since the QWI is estimated from the administrative records, I can employ county-level data without being concerned about a small sample bias[21]. First, the Box − Jenkins Methodology is applied to some series of county-level data to find optimal orders of AR and MA[22]. I then pool counties in each group of nationality together[23] and estimate unbalanced panel regression with autoregressive components (Baltagi and Wu, 1999) as follows:

$$y_{it} = \gamma_0 + \gamma_{1s} Season_t^s + \gamma_2 Dis_t + u_{it} \tag{4.7}$$

where y_{it} are dependent variables of county i at time t. $Season_t^s$ are quarterly dummies for quarter s (using 1^{st} quarter as a reference) and Dis_t is a disaster dummy which is equal to 1 if t are 2^{nd} and 3^{rd} quarter of 2011. I follow Baltagi and Wu (1999) and assume that the disturbances follow a one-way error

[20] This whole process is called Box Jenkins Methodology

[21] This contrasts to the CPS which aggregated data are used to increase the sample size in each group.

[22] I try to compare the ARMA model with other techniques, for example, deterministic trend with quarterly dummies (as in equation 4.3), or smoothing methods such as Holt-Winters exponential smoothing with both multiplicative and additive seasonal model. I found that the predicted series are not much different and ARMA model with seasonality seems to perform better in ex-post forecasting.

[23] Only counties which have at least 16 data points (4 years) are included.

component model i.e. $u_{it} = \mu_i + \eta_{it}$ with county effects $\mu_i \sim IID(0, \sigma^2_\mu)$ while the remainder disturbances η_{it} follows a stationary AR(1) process, i.e. $\eta_{it} = \rho\eta_{i,t-1} + \epsilon_{it}$ with $|\rho| < 1$ and ϵ_{it} is $IID(0, \sigma^2_\epsilon)$. Further, the $\mu_i's$ are independent of the $\eta'_{it}s$, and $\eta_{i0} \sim (0, \sigma^2_\epsilon/(1-\rho^2))$.

Using this specification with fixed effect, it is implicitly assumed that all counties in the same group share the same seasonal dummies and the coefficient of autoregressive component (ρ). If this method is approximately correct in modelling the underlying trend and seasonality, the coefficient of interest, γ_2, would illustrate the average adjustment effect of the shock on each dependent variable between the second and third quarter of 2011.

5 Results

This section illustrates the impact of Great Tohoku Earthquake and Tsunami 2011 on the labour market in the US auto industry through various empirical specifications discussed earlier. First, I verify the trivial impacts of the shock on labour inputs among Japanese auto makers[24] using $ShareJP$ in each state. Only 27 states with more than 400 direct employees are included in the sample. Table 3 presents estimates of changes in average weekly hours, overtime and employment from the CPS data. None of the regressions yields significant coefficients for share of Japanese employment. The relative intensity of Japanese auto makers in each state does not significantly affect any labour inputs in the motor vehicles manufacturing industry.

However, there are two concerns regarding this conclusion. First, owing to a small sample size in the CPS, these models involve an inclusion of more than 10 states with a very small sample size of auto workers in each month, that is, average sample sizes are fewer than five persons. This leads to an imprecise estimation of labour inputs at state level. Importantly, the CPS cannot be used to categorize workers into more detailed industries than a broad definition of auto mobile manufacturing (NAICS 3361-3363). Hence, these insignificant estimates might result from a cancellation of effects between sub-industries. For instance, a reduction in hours of work by OEM's assembly plants could be offset by a rise in working hours of local parts suppliers. Conversely, since the QWI provides 4-digit NAICS data, I can classify auto mobile manufacturing into three sub-industries[25], and identify any differential effects within the auto industry.

According to Table 4 and 5, none of the coefficients is significant at the 5% level. However, allowing for a significance level of 10%, the negative impacts of the shock, through relative employment of Japanese auto companies in each state, can be verified in two sub-industries. In auto assembling, workers in the

[24]Companies such as Toyota and Honda operated at adjusted levels of production or suspended their production on certain dates during April to July in their US plants due to parts and materials shortage (Toyota, 2011 and Honda, 2011)

[25]These sub-industries are motor vehicle manufacturing, that is, chassis and assembly plants (NAICS 3361), motor vehicle body and trailer manufacturing (NAICS 3362) and motor vehicle engines and parts manufacturing (NAICS 3363)

Table 3: Share of direct employment by Japanese auto makers and impacts on labour inputs (CPS data)

Dep. variables	(1)	(2)	(3)
HR_{it}[1]	-1.169	-1.243	-0.756
	(2.131)	(2.109)	(2.322)
OT_{it}	-1.301	-1.307	-1.221
	(1.029)	(1.020)	(1.190)
$LogEmp_{it}$	0.115	0.113	-0.0725
	(0.361)	(0.354)	(0.386)

Note: Standard errors are in parentheses.
All results are coefficients of $Dis_t * ShareJP_i$ from equation 4.2 - 4.4 corresponding to model (1) − (3) respectively.

Table 4: Share of direct employment by Japanese auto makers and impacts on labour inputs based on QWI data

	Motor Vehicle Manufacturing[1]			Motor Vehicle Parts Manuf.[2]		
Dep. variables	(1)	(2)	(3)	(1)	(2)	(3)
$LogEmpEnd$	-0.032	-0.026	-0.344	0.165	0.166	0.212
	(0.302)	(0.300)	(0.485)	(0.133)	(0.131)	(0.292)
$LogEarnEnd$	-0.049	-0.049	-0.237*	-0.029	-0.028	0.012
	(0.074)	(0.073)	(0.131)	(0.050)	(0.049)	(0.063)
$LogPayroll$	-0.017	-0.015	0.002	0.140	0.140	0.108
	(0.457)	(0.449)	(0.288)	(0.123)	(0.121)	(0.183)

Note: Standard errors (clustered by states) are in parentheses while * indicate significant at 10% level.
All results are coefficients of $Dis_t * ShareJP_i$ from equation 4.2 - 4.4 corresponding to model (1) − (3) respectively.
[1] Numbers of observations are ranging from 918 to 999 state-quarter for LogEmpEnd and LogPayroll respectively.
[2] Numbers of observations are ranging from 1,003 to 1,027 state-quarter.

states where all OEMs' direct employment are belonged to Japanese firms experience a 0.237% reduction in average monthly earnings during 2011Q2 - Q3[26]. In other words, a worker in a state with $ShareJP = 1$ whose earnings is at the mean of Japanese counties receives \$7.68 less than his/her counterpart in a state with $ShareJP = 0$ per month. Also, a small negative employment effect can be observed in body and trailer manufacturing. In this sub-industry, employment in the states with $ShareJP = 1$ is reduced by 0.307% comparing to those states with $ShareJP = 0$[27].

Nevertheless, these negative impacts are not robust enough to withstand a variation in modelling of trend and seasonality. If the model which allows for different trend and seasonal effects among states (model (3)) is the correct one, only the trivial negative effect on Japanese assembly plants is supported by the data. Moreover, the coefficients of $ShareJP$ in Table 5 using all sub-industries confirm no significant effect on any labour inputs similar to those using the CPS data[28].

It seems that production adjustment of Japanese auto makers as a result of intermediate inputs shortage has small and negligible effects on labour inputs in the US auto industry. However, a constraint

[26]Since average earnings of workers in manufacturing sector depend on hourly wage and total number of hours worked, This surprisingly small effect could result from an adjustment in hours of work in the first few months after the shock.
[27]Because payroll is a multiplication of employment and average earnings, the similar size of negative and significant effect on payroll indicates that reduction in employment is a primary driving force of a change in payroll.
[28]The aggregation of these sub-industries is straightforward for numbers of employment and payroll. However, due to missing values in employment data, weighted average earnings data are computed by using a ratio of payroll to average earning per month as a proxy for employment.

Table 5: Share of direct employment by Japanese auto makers and impacts on labour inputs based on QWI data (cont.)

	Body and Trailer Manufacturing[1]			Motor Vehicle, Body and Parts Manuf.[2]		
Dep. variables	(1)	(2)	(3)	(1)	(2)	(3)
$LogEmpEnd$	-0.307*	-0.306*	0.496	0.085	0.086	0.238
	(0.165)	(0.161)	(0.345)	(0.147)	(0.145)	(0.298)
$LogEarnEnd$	-0.0333	-0.0323	0.00914	-0.046	-0.045	-0.018
	(0.0677)	(0.0666)	(0.156)	(0.0499)	(0.0493)	(0.0587)
$LogPayroll$	-0.309*	-0.310*	0.262	0.049	0.052	0.241
	(0.165)	(0.161)	(0.292)	(0.145)	(0.144)	(0.333)

Note: Standard errors (clustered by states) are in parentheses while * indicate significant at 10% level. All results are coefficients of $Dis_t * ShareJP_i$ from equation 4.2 - 4.4 corresponding to model (1) − (3) respectively.
[1] Numbers of observations are ranging from 1,003 to 1,027 state-quarter for LogEmpEnd and LogPayroll respectively.
[2] Numbers of observations are 1,003 state-quarter.

on the US operation among Japanese firms and a sharp drop in number of imported vehicles from Japan could benefit their competitors[29]. Using time series technique to model trend and seasonality, I estimate the adjustment in labour inputs (and implicitly production) by each group of OEMs and their local suppliers. Table 6 illustrates impacts of the disaster shock on different groups of auto companies as categorized earlier. None of the results is statistically different from zero at 10% significance level. With a significance level of 20%, overtime of workers in US intensive states is significantly increased by 0.55 hours per week on average during April to July 2011.

It is worth noting that all nine series have totally different optimal SARIMA specification. This striving for an optimal model in each series could cause common factors affecting any groups of auto companies equally (such as overall demand for motor vehicles or supply of labour in auto industry) to be overlooked. Yet, owing to aggregation process needed for mitigating a small sample bias in the CPS data, applying same specification to just three groups for each dependent variables in CPS data might not be appropriate. Therefore, I estimate unbalanced panel regression with autoregressive components of order 1 employing the county level QWI data as presented in Table 7.

On the one hand, Table 7 shows that there is no significant adjustment in labour inputs in the counties with the OEMs' assembly plants. On the other hand, workers employed in parts and engines manufacturing experience some adjustments. In the counties with German parts and engines plants, there are positive changes in all dimensions. Workers in this groups receive 0.182% higher average monthly earnings during the shock period. Meanwhile, rises in employment and payroll of these counties are only significant at the 20% significance level. Nonetheless, these results for German counties should be inferred with caution because they are based on just three counties. Further, after removing one outlier county in Indiana, all negative and significant effects among counties with the US parts and engines factories are deleted.

[29] 33% of Japanese auto makers' sales in the US are imported from outside North America with variations among companies, for instance, 28% for Toyota, 21% for Honda and 35% for Nissan (Edmunds.com, 2011).

Table 6: Optimal specification for each SARIMA(p,d,q)(P,D,Q)$_{12}$ with impacts of the shock intervention

	JP	US	DE
Series for HR			
$SARIMA$	$(2,1,0)(0,1,1)_{12}$	$(1,0,1)(1,1,0)_{12}$	$(1,0,0)(0,0,0)_{12}$
$\widehat{Dis}_t$ [1]	0.262	0.311	-0.353
	(1.370)	(0.814)	(2.752)
Series for OT			
$SARIMA$	$(3,1,0)(0,0,0)_{12}$	$([2,3],0,[2,3])(0,0,0)_{12}$ [2]	$(0,0,1)(1,0,0)_{12}$
$\widehat{Dis}_t$	-0.227	0.548†	0.451
	(1.301)	(0.396)	(0.457)
Series for LogEmp			
$SARIMA$	$(4,1,1)(1,0,0)_{12}$	$([1,4,5],1,0)(1,0,1)_{12}$	$(4,1,[3,4])(1,0,0)_{12}$
$\widehat{Dis}_t$	-0.185	0.010	0.009
	(0.248)	(0.077)	(0.294)
Obs.	88	88	88

Standard errors in parentheses; † denote significance at 20% level
[1] The exact specification of shock dummies is varied with the model
[2] This ([2,3],0,[2,3]) notation stands for AR2 and AR3 (not include AR1), d = 0 and MA2 and MA3

Table 7: Impacts on labour inputs by groups based on QWI data

	Assembly plants/data[1]			Parts & Engines plants/data[2]		
Dep. variables	JP	US	DE	JP	US	DE
$LogEmpEnd$	-0.083	0.053	NA	0.020	-0.238**[3]	0.136†
	(0.215)	(0.158)		(0.034)	(0.100)	(0.082)
	[33]	[335]	[21]	[318]	[1,032]	[42]
$LogEarnEnd$	0.028	0.064	0.105	0.079	0.008	0.182***
	(0.056)	(0.047)	(0.110)	(0.082)	(0.033)	(0.067)
	[362]	[584]	[259]	[407]	[1,050]	[126]
$LogPayroll$	0.011	-0.100	0.021	0.002	-0.186*[3]	0.134†
	(0.152)	(0.080)	(0.156)	(0.094)	(0.098)	(0.089)
	[374]	[600]	[269]	[418]	[1,075]	[129]

Note: All results are coefficients of Dis_t from Fixed Effect regression with AR(1) disturbances, that is, equation 4.7.
[1] These results estimate motor vehicles manufacturing data from counties with assembly plants.
[2] These results estimate motor vehicles parts and engines manufacturing data from counties with OEMs' parts and engines plants.
[3] After removing one outlier county, these negative and significant results disappear.
Standard errors are in parentheses while number of observations are in square blankets.
***, **, * and † indicate significant at 1% , 5% , 10% and 20% level respectively.

Table 8: Indirect Impacts on labour inputs by groups based on QWI data

	Assembly plants/Parts data[1]			Assembly w/o Parts plants/Parts data[2]		
Dep. variables	JP	US	DE	JP	US	DE
LogEmpEnd	0.065†	0.009	0.078	0.072	0.005	0.071
	(0.0469)	(0.046)	(0.087)	(0.056)	(0.056)	(0.099)
	[411]	[597]	[342]	[345]	[387]	[300]
LogEarnEnd	-0.041	0.029	0.062†	-0.018	0.037	0.047
	(0.060)	(0.037)	(0.041)	(0.064)	(0.049)	(0.045)
	[592]	[672]	[378]	[508]	[462]	[336]
LogPayroll	-0.044	-0.064	0.029	-0.026	-0.021	0.016
	(0.072)	(0.042)	(0.072)	(0.081)	(0.053)	(0.081)
	[609]	[688]	[387]	[523]	[473]	[344]

Note: All results are coefficients of Dis_t from Fixed Effect regression with AR(1) disturbances, that is, equation 4.7.
[1] These results estimate motor vehicles parts and engines manufacturing data from counties with assembly plants.
[2] These results estimate motor vehicles parts and engines manufacturing data from counties with assembly plants but none OEMs' parts and engines plants.
Standard errors are in parentheses while number of observations are in square blankets.
***, **, * and † indicate significant at 1% , 5% , 10% and 20% level respectively.

Moreover, the indirect effect of the OEMs' assembly plants on local parts and engines plants in the same county are estimated. Table 8 presents these results. Consistently, there is no significant change among the US counties. However, if allowing for a 20% significance level, there is a positive employment effect on parts and engines factories in the counties with Japanese assembly plants[30]. Also, in German counties, average monthly earnings of workers in parts and engines manufacturing is increased by 0.062%. Yet, interpretation of these indirect effects relies on the assumption that OEMs' assembly plants are the major purchasers of suppliers in their locality. This assumption might first sound at odds in a paper emphasizing a role of an international supply chain. But, many car producers such as Toyota do encourage suppliers to consider locating themselves near their assembly plants. Finally, according to the right column in Table 8, there is no significant effect in any groups after restricting the sample to counties with OEMs' assembly plants but not OEMs' parts and engines factories. It seems that the significant results on the left of Table 8 are driven by these excluded counties where assembly and parts plants owned by the same firm are located. Hence, the production interlink between assembly and parts plants in the same locality appears to be strong only if they are under the same auto company.

6 Other margins of adjustment

In this section, the focus is on other channels of adjustment briefly introduced earlier, namely substitution through import, hikes in price and changes in inventory. The analyses rely on descriptive trends and statistics rather any rigorous causal interferences. Regarding trade, Canada and Mexico are the major trade partners in motor vehicles and parts who gain reasonable trade surpluses from USA. In 2010, imports from Canada and Mexico accounted for 23% and 25.6% of total import value of US motor

[30]This could be a signal of substitution of intermediate inputs from Japan for local products.

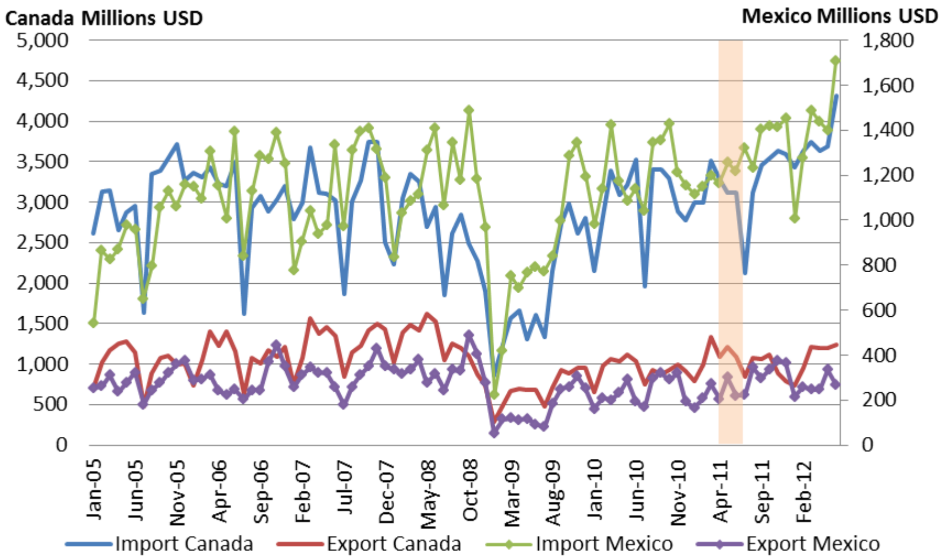

Figure 5: *US monthly trade in Automobiles and Light Duty Motor Vehicles, Including Chassis*

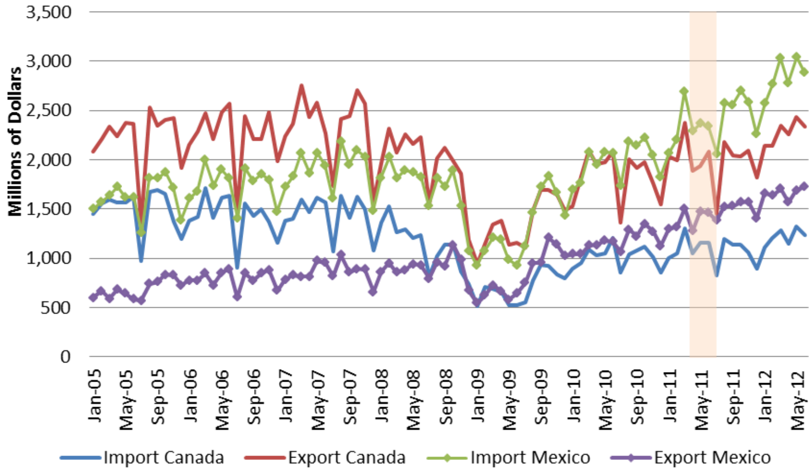

Figure 6: *US monthly trade in Motor Vehicle Engines and Parts*

vehicles and parts respectively[31].

Figure 5 and 6 display the import value of automobiles and parts. They move along normal trends and seasonality without any significant jumps during the shock (the shaded area). However, considering numbers of Detroit 3 and the Japan big 3 (Toyota, Honda and Nissan) assembly and parts manufacturing plants located along the US border, it is plausible not to detect any increases in the US import because the Japanese plants in Canada and Mexico could experience the same production set back as those in USA. Unless detailed data are available, the role of import substitution is inconclusive[32].

As for price, I explore a publicly available Consumer Price Index (CPI) from Bureau of Labor Statistics

[31] Passenger cars imported from Canada makes up almost a third of US import while trucks as well as engines and parts from Mexico constitutes of more than 84% and 31% respectively.

[32] The US Bureau of census has data on import for each product by trade partner and state. With geographical variation, it could shed some light on substitution of motor vehicle parts. However, these data are not free for public-use.

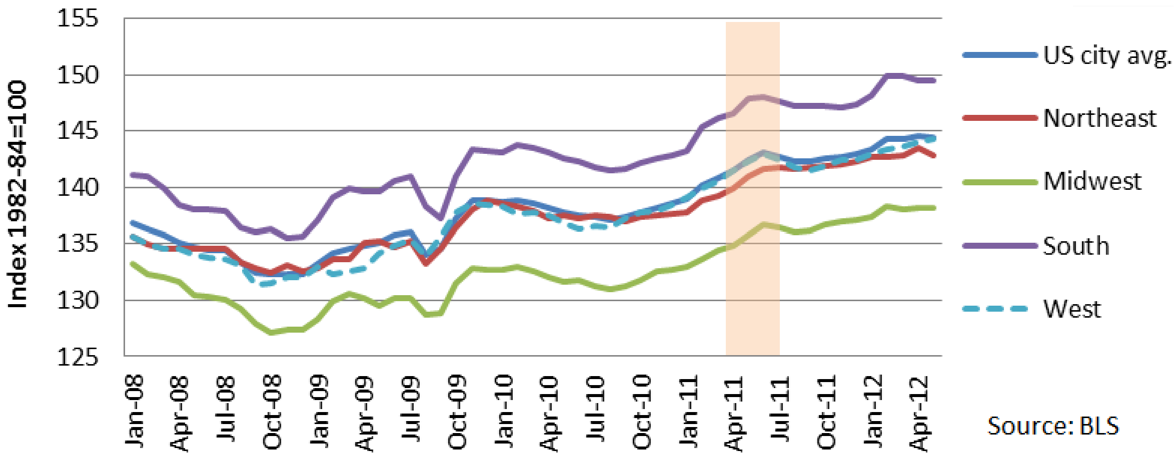

Figure 7: *CPI urban area for New Vehicles by region*

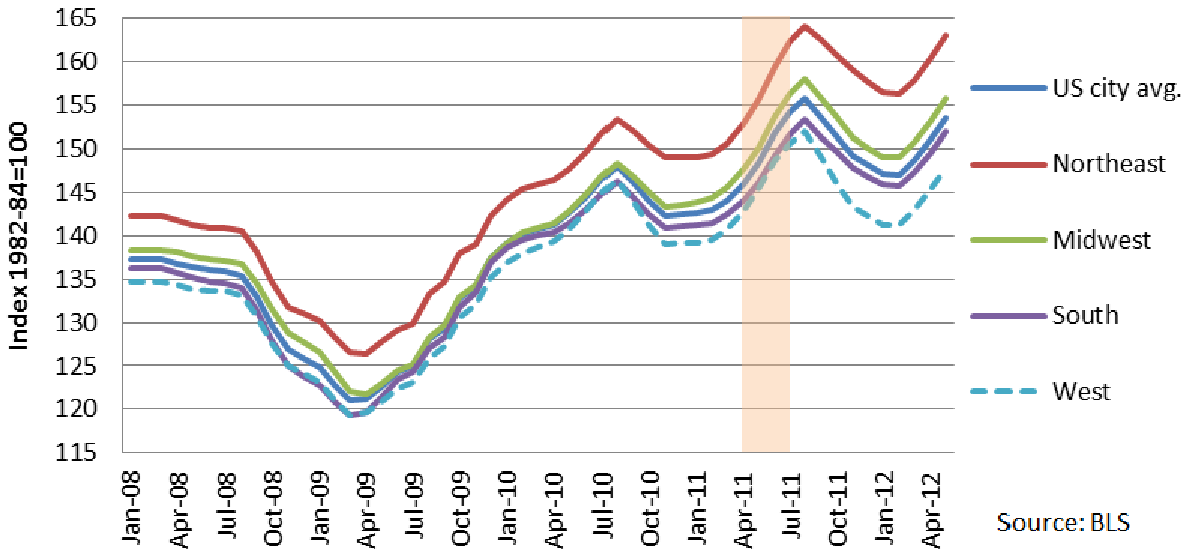

Figure 8: *CPI urban area for Used Cars and Trucks by region*

(BLS) to find any hikes in price as predicted by a simple Cournot competition model. Figure 7 and 8 show CPI for new and used vehicles respectively. Although CPI for used cars and trucks had a steeper rise in price during the shock period, both CPIs did not illustrate any noticeable hikes rather than upwards trend and seasonal effect due to higher demand for motor vehicles as a whole in 2011. Thus, any effects of the shock on overall prices were too small to be distinguishable.

However, in Figure 9, another measure computed by Edmunds.com called True Cost of Incentives^{SM} (TCI)[33] provides a supporting evidence for a spike in price. In May 2011, consumers (dealers) of those worst hit Japanese companies like Toyota and Honda did pay higher prices (receive less profit) implicitly by receiving less incentive from these companies while there was no significant reduction in TCI of other competitors. This contrasts to October 2011 when TCI dropped industry-wide because of an abrupt jump in demand for the newer model year '2012' vehicles[34] (Edmunds.com, 2011).

The final margin of adjustment is inventory. A measure called Day-To-Turn (DTT) from Edmunds.com is employed as a proxy for the level of each manufacturer's inventory. Days to Turn is the average number of days vehicles were in dealer inventory before being sold during the months indicated. The lower number of days the manufacturers get, the fewer inventories their dealers have on hand. Figure 12 displays significant drops in DTT for Hyundai, Kia and Volkswagen during the shock periods and thereafter which are corresponding to their gain in market share. Nevertheless, the South Korean auto makers could not fully benefit from the shock since they were constrained by their production capacity in US even before the disaster (AutoObserver.com, 2011). Meanwhile, the DTT of the US and Japanese Big 3 did not change much apart from a decrease between March and April 2011. US auto makers seemed to accumulate more inventory after the event; yet, as discussed earlier, it did not translate into a significant increase in labour inputs.

As for the Japanese firms, their DTT decreased markedly after the shock periods coinciding with a start to gain back their market share. It can be inferred that dealers of Japanese cars used their inventory as well as postpone transactions in order to cope with supply shortage. Soon after the shock had subsided, they completed any delayed deals before starting to gradually rebuild their inventory. This observation confirms the role of inventory on mitigating any adverse effects of supply shortage.

However, this temporary supply shock which caused a demand surge among Japanese's competitors does not seem to generate the 'Bullwhip' effect[35] as expected by some studies (Sucky, 2008). Partly, it

[33] According to Edmunds.com, this measure is average incentive cost per retail vehicle sold in the U.S. for the months indicated. It takes into account subvented interest rates and lease programs, as well as cash rebates to consumers and dealers based on sales volume, including the mix of vehicle makes and models for each month, as well as on the proportion of vehicles for which each type of incentive was used.

[34] Normally, the newer models are barely discounted compared to the older, 2011, models.

[35] It is an effect of wrong expectation on demand variation which leads to excessive hoarding of inventory among downstream supplier. Then, this accumulated effect forces manufacturer to produce too many goods with all its available capacity.

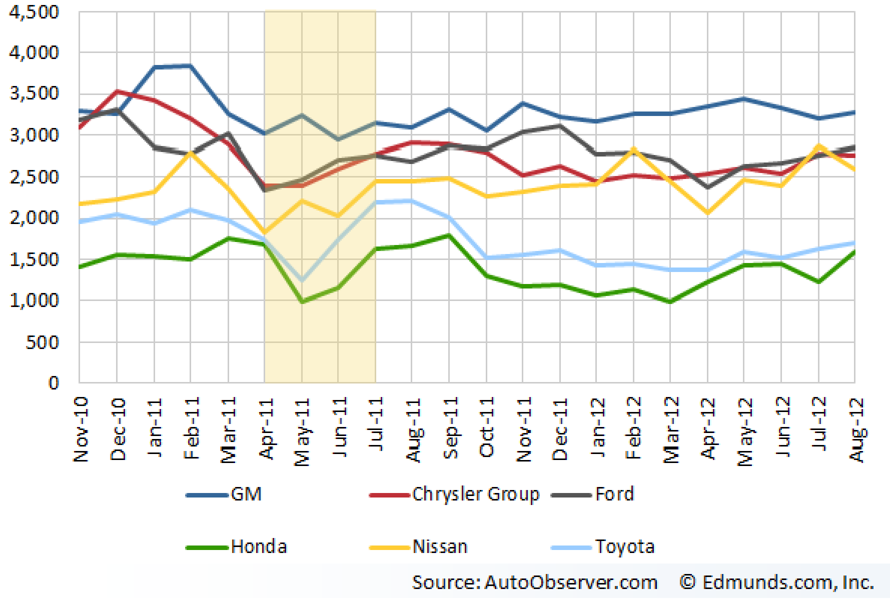

Figure 9: *Manufacturer True Cost of Incentives (USD)*
Detroit 3 and Japan big 3

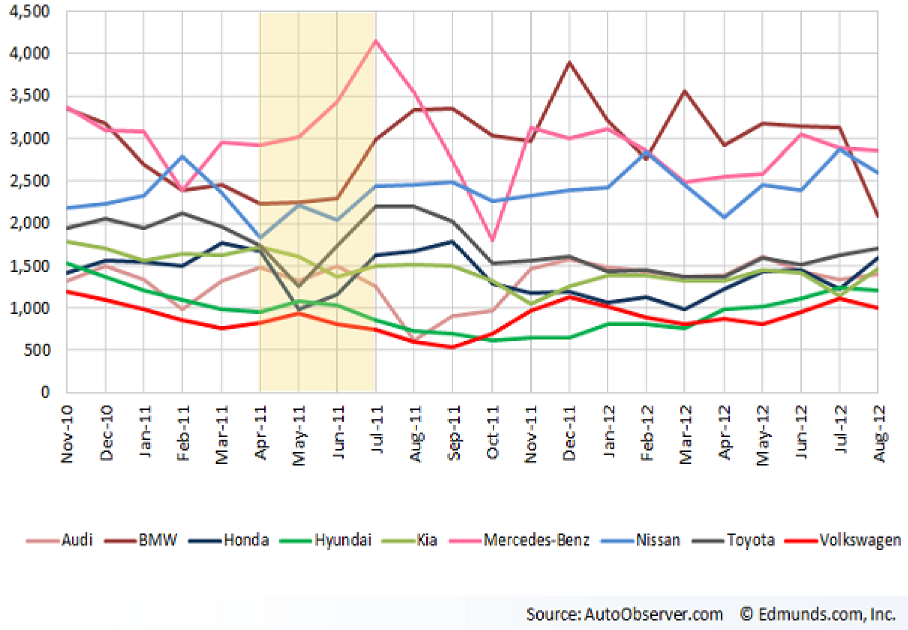

Figure 10: *Manufacturer True Cost of Incentives (USD)*
Germany, South Korea and Japan

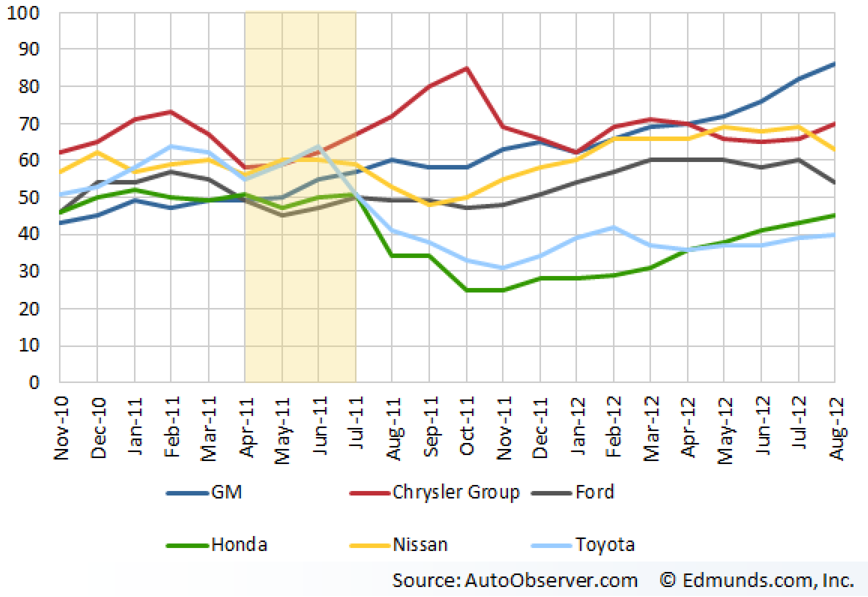

Figure 11: *Manufacturer Days To Turn (days)*
Detroit 3 and Japan big 3

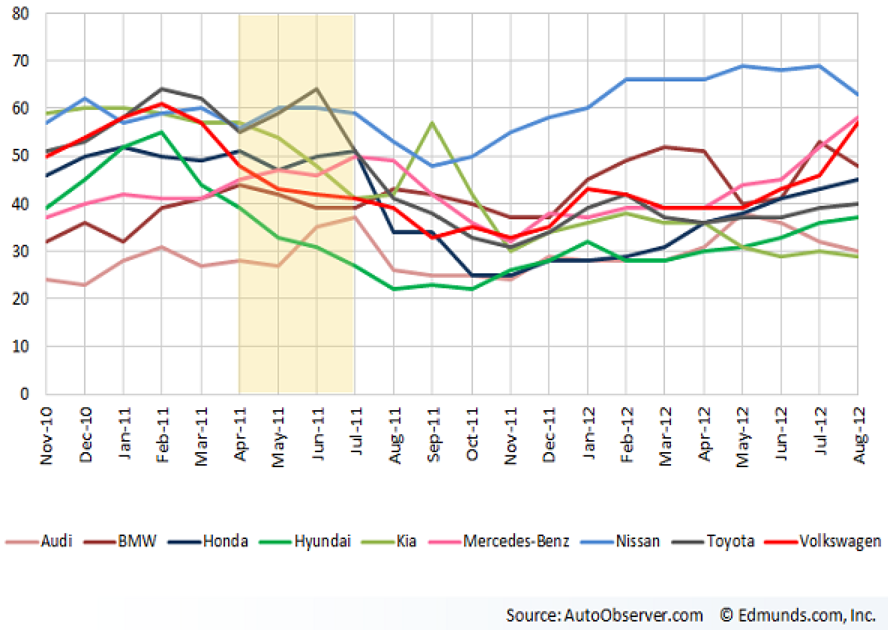

Figure 12: *Manufacturer Days To Turn (days)*
Germany, South Korea and Japan

could result from the temporary nature of the shock. Hence, competitors and their dealers would expect only a transitory rise in demand. Any reaction might be constrained by nature of car production which requires advanced planning such as intermediate inputs management and capacity enhancement. Yet, some companies who gained from the Japanese market share like Chrysler and Kia did accumulate their inventory markedly after the shock. Then, they seemed to reach their new stable DTT after Oct 2011.

7 Conclusion

In examining the Great Tohoku Earthquake and Tsunami as an external shock to Japanese auto makers in the US, this paper has found relatively small changes in response to such an abrupt yet transitory international supply shock. Although the disaster caused a major disruption on Japanese motor vehicles and motor parts export and lead to a significant drop of Japanese auto makers market share in the US, Japanese companies regained their position less than a year after the event. The level of labour inputs (used as a proxy for changes in production) was not significantly reduced among Japanese companies and their local suppliers, whereas their competitors (particularly, plants in the US intensive states and German parts and engines plants) seemed to adjust their labour inputs slightly to capitalize on Japanese losses.

In terms of other margins of adjustment, inventories and sales incentive appear to be major tools employed to mitigate either positive demand or negative supply shocks on both groups of companies. Meanwhile, there is no clear evidence in support of import substitution or spikes in price. Yet, movement in production and sales incentive are consistent with a prediction from a simple Cournot model. That is an overall price should rise as a result of a supply shock on one producer because it is not optimal for its competitors to increase their output enough to fully offset the shortfall.

However, a major challenge in any extension on this topic is data availability. With more data, several potential research questions can be answered using this disaster and the auto industry as a case study. For example, detailed import data by state and product could shed some light on the role of import substitutability in the event of a shock along the global production chain. Regarding supply shock and oligopoly market, better data on production and price by manufacturer and model would enable empirical testing of the prediction of the theory on movement of output and price after a temporary supply shock. Finally, detailed inventory data could illustrate a role for inventory management as a buffer to the supply shock in contrast to the so-called Bullwhip effect, where poor inventory management amplifies adverse effects of demand variability.

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Appendices

A) Japanese Export in Motor vehicle and Motor parts & accessories

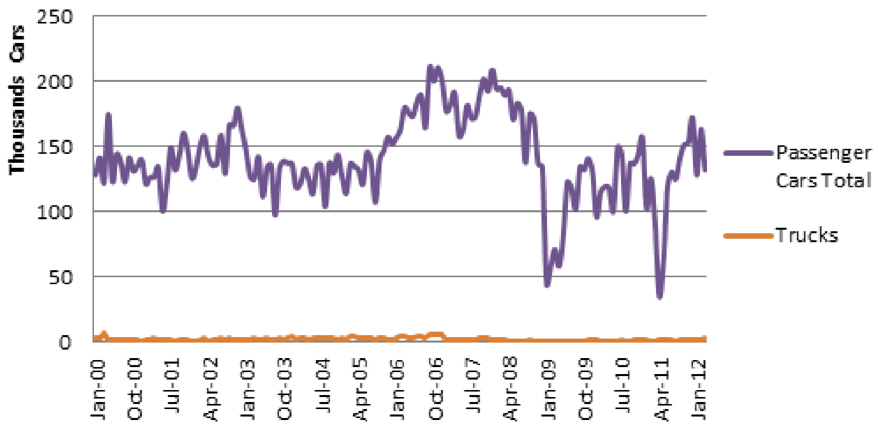

Figure 13: *Japan's Export in Motor Vehicles (units) to USA Jan 2000 - Mar 2012*

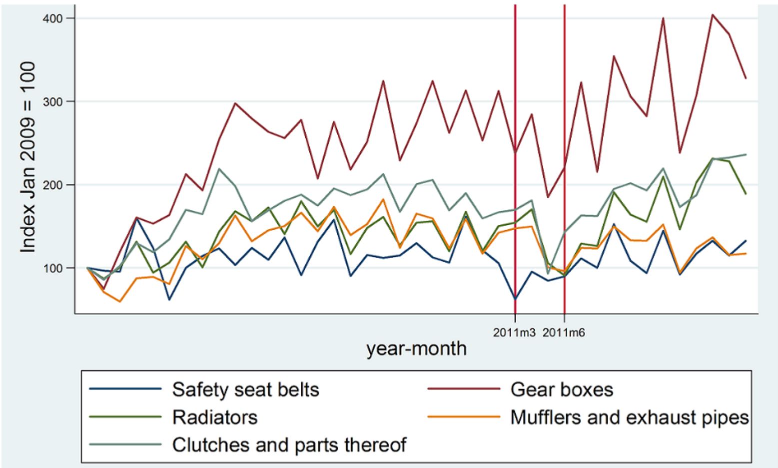

Figure 14: *Japan's Export Value to USA (Monthly indices) for Selected Motor Vehicles Parts & Accessories*

B) Car sales in the US market by manufacturers (units)

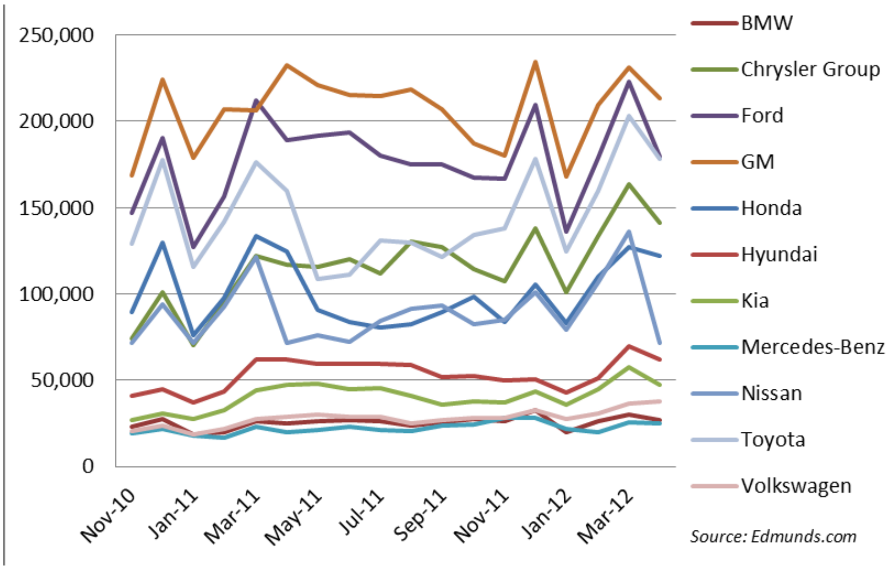

Figure 15: *Car sales in the US market by manufacturers (units) Nov 2010 - Apr 2012*

C) Japanese auto makers direct employment

Using Auto Alliance's data, I calculate share of direct employment by Japanese auto makers in each states. The following table includes states with more than 400 direct employees of any auto companies.

Table 9: Share of Japanese auto makers direct employment in each state

State	Share	State	Share
Alabama	48.96%	Michigan	1.33%
Arizona	49.37%	Mississippi	97.68%
Arkansas	100%	Missouri	11.34%
California	80.91%	New Jersey	12.78%
Colorado	8.64%	New York	1.08%
Florida	1.76%	North Carolina	0.58%
Georgia	45.07%	Ohio	35.26%
Illinois	16.54%	Oregon	9.41%
Indiana	41.32%	South Carolina	0%
Iowa	100%	Tennessee	56.04%
Kansas	0%	Texas	26.96%
Kentucky	57.96%	Virginia	9.29%
Maryland	62.00%	West Virginia	90.42%
Massachusetts	64.96%		