A Microeconomic Analysis of the Aggregate Disconnect between Exchange Rates and Exports*

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Abstract

We reconcile the conflicting evidence between the aggregate and the microeconomic data on the exchange rate elasticity of exports. The estimation of typical macroeconomic export equations provides us with insignificant estimates for this elasticity, while recent firm level evidence suggests significantly negative values. Using Japanese firm data, we estimate a monopolistic competition model of exporting firms, and show that the exchange rate elasticity of exports is significantly negative at both firm and aggregate levels, with consistent aggregation. We identify the preferences and technology parameters and find the importance of decreasing returns to scale and the high elasticity of substitution among consumption goods in determining the magnitude of this elasticity.

JEL Classification: F41, F12, C23, C43

Keywords: Exchange rate disconnect puzzle, Consistent aggregation, Firm level heterogeneity, Exchange rate elasticity of export

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I Introduction

Over the last three-decade experience of exchange rate floating among industrialized countries, there is yet to emerge a consensus regarding the impact of exchange rate fluctuations on real economic variables. The empirical literature that examined aggregate data has generally found small or insignificant effects of exchange rate fluctuations on the quantity of exports. For example, Baxter and Stockman (1989), and Flood and Rose (1995) show that the high volatility of exchange rates is not related to the high volatility of other macroeconomic variables, including exports. Similarly, Kenen and Rodrik (1986), and Hooper, Johnson and Marquez (1998) find that the relationship between the change in log real exports and the change in log exchange rates is small or statistically insignificant.

Table 1 reports these aggregate estimates of the elasticity of exports with respect to exchange rates for each of the seven industrialized (G-7) countries of Canada, France, Germany, Italy, Japan, U.K. and U.S., for the period of 1982-1997. The last column "pooled" in Table 1 reports the estimate of the pooled sample including all seven countries with country dummies. The exchange rate of each country is measured by the trade-weighted sum of the ratios of currencies of the trading partners to the domestic currency. That is, an increase in the exchange rate means an appreciation of the domestic currency, relative to the currencies of the trading partners. Thus, we may expect the coefficient on the log exchange rate to be significantly negative. However, estimates for this elasticity are not significantly different from zero for all the countries. For a sensitivity check, we run simple autoregressive distributed lag models of log exports on log exchange rates. In the levels specification, the coefficients on the exchange rate (the contemporaneous and lagged combined) are either insignificant or, if significant (e.g., the United States), even positive. In the first-differenced specification, the coefficients on the exchange rate are insignificant, except for Italy. This lack of association between exchange rates and exports at the aggregate level is the so-called "exchange rate disconnect puzzle."[1]

[1]Note that the "exchange rate disconnect puzzle" is different from the well-known "J-curve effect" in the international finance and trade literature. The exchange rate disconnect puzzle is about the lack of association between the movements of exchange rates and *gross export quantities*. The J-curve effect is about the sluggish

Recent work using firm level data suggests, however, that the relationship between exports and exchange rates is significantly negative. Goldberg and Tracy (1999) and Dekle and Ryoo (2007) find a large negative elasticity of exports with respect to exchange rates. Forbes (2002) studies the impact of a large devaluation on export sales of over 13,500 companies around the world, and finds that on average export sales improve by 4 percent a year after devaluation episodes.

This paper attempts to reconcile these apparently conflicting aggregate and firm level evidences. We build a simple model of monopolistic competition for exporting firms, and derive the relationship between exports and exchange rates as the exporting firm's supply function. Heterogeneity in these export functions arise, as productivity differs among firms. We then derive a macroeconomic relationship between exports and exchange rates by aggregating these firm level export functions. We show that the firm level productivity and its distribution need to be accounted for in this aggregation; otherwise the estimates for the exchange rate elasticity from the macroeconomic export function using aggregate data are inconsistent, because of omitted variable biases. In particular, we find that the joint distribution of firm-specific productivity and export shares should be taken into account in the aggregate export equations.

The bias from omitting these two variables in the aggregate export equation is large when estimating the exchange rate elasticity of exports. Including the averages of these two variables in the aggregate export equation helps to reduce this bias. We show, however, that without fully controlling for the movements in the joint distribution of firm productivity and export shares, the aggregate estimate of the exchange rate elasticity of exports is biased toward zero. We quantify this aggregation bias.

In this paper, we use panel data of exporting firms of Japan for the period 1982-1997, and estimate the exchange rate elasticity of exports at both the firm and aggregate levels. We find that the estimates of the exchange rate elasticity of exports is indeed negative at the firm level, as our model suggests. We then show that with consistent aggregation, the aggregate exchange

and J-shaped adjustment of trade balance (i.e., *net* export *sales*) to the improvement in terms of trade. See Backus, Kehoe and Kydland (1994) for a discussion of the J-curve effect.

rate elasticity of exports remains significantly negative, although the aggregate elasticity is still biased downwards, because the changes in the joint distribution of firm level heterogeneities cannot be fully controlled for.

The idea that price elasticities are biased downwards in the conventionally estimated aggregate trade equations, given the underlying aggregation problem, was postulated more than 50 years ago by Orcutt (1950). To the best of our knowledge, however, this is the first paper to estimate and explicitly compare the aggregate and firm level elasticities of exports with respect to exchange rates, where the macroeconomic export equation is obtained by consistently aggregating the firm level export equations. Blundell and Stoker (2005) carefully examine the general problems of aggregation over heterogeneous individuals. Our paper provides a specific example of seeking the sources of and explicitly quantifying the size of the aggregation bias in the export equations. Furthermore, we identify the preferences and technologies from these estimates of the export equations. We find the importance of decreasing returns to scale technology, and the high elasticity of substitution among the consumption goods in determining the magnitude of the exchange rate elasticity of exports. This identification of the deep parameters from the structural estimation of the export equation, again to the best of our knowledge, we do for the first time.

The paper is organized as follows. Section II introduces a standard monopolistic competition model of exporting firms. Section III discusses sources of bias in the aggregate export equations. Section IV estimates the model. The elasticity parameters (including the exchange rate elasticity) of the export equations are estimated at both the firm and aggregate levels. The preferences and technology parameters of the model are also identified from this estimation. Section V concludes.

[Table 1 here]

II Model

A Monopolistic competition

We consider a "New Open Economy" type of monopolistic competition model, pioneered by Obstfeld and Rogoff (1996), for exporting firms. There are firms indexed by $i \in [0, 1]$, each of which produces a single differentiated final good (indexed also by i) at each discrete date t. The firms are located either in a domestic country or in a foreign country. The final goods ranging from $[0, n]$ are produced by domestic firms and the rest are produced abroad.

A representative consumer gets utility from the following CES composite consumption Y_t such that

$$Y_t = \left(\int_0^1 y_{it}^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}},$$

where y_{it} denotes the consumption of good i at date t. The parameter θ governs the elasticity of substitution among the differentiated goods, which we assume

$$\theta > 1. \tag{1}$$

In this monopolistic competition framework, the domestic price level P_t is given by

$$P_t = \left[\int_0^n p_{it}^{1-\theta} di + \int_n^1 \left(\frac{p_{it}^f}{e_t} \right)^{1-\theta} di \right]^{\frac{1}{1-\theta}},$$

where p_{it} denotes the price of good i (ranging from 0 to n) in the domestic currency, p_{it}^f the price of good i (ranging from n to 1) in the foreign currency, and e_t the foreign currency price of the domestic currency. We assume the law of one price

$$p_{it}^f = e_t p_{it}.$$

This simplifies the domestic price level such that

$$P_t = \left[\int_0^1 p_{it}^{1-\theta} di \right]^{\frac{1}{1-\theta}}.$$

Similarly, the price level in the foreign country P_t^f is

$$P_t^f = \left[\int_0^1 \left(p_{it}^f \right)^{1-\theta} di \right]^{\frac{1}{1-\theta}}.$$

The domestic consumer chooses his final goods consumption bundle $(y_{it})_{i\in[0,1]}$ from utility maximization:

$$\max_{(y_{it})_{i\in[0,1]}} \left(\int_0^1 y_{it}^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}} \text{ subject to } \int_0^1 p_{it} y_{it} di \leq Z_t,$$

where Z_t denotes the nominal value of the total expenditures of the domestic consumer.[2] This gives the domestic demand for final good i as

$$y_{it} = \left(\frac{p_{it}}{P_t}\right)^{-\theta} \frac{Z_t}{P_t} = \left(\frac{p_{it}}{P_t}\right)^{-\theta} Y_t.$$

Similarly, foreign demand for good i is $y_{it}^f = \left(\frac{p_{it}^f}{P_t^f}\right)^{-\theta} Y_t^f$.

Then, the world demand for good i, $y_{it}^w = y_{it} + y_{it}^f$, is given by

$$\begin{aligned} y_{it}^w &= \left(\frac{p_{it}}{P_t}\right)^{-\theta} Y_t + \left(\frac{p_{it}^f}{P_t^f}\right)^{-\theta} Y_t^f \\ &= \left(\frac{p_{it}}{P_t}\right)^{-\theta} Y_t^w \\ &= \left(\frac{p_{it}^f}{P_t^f}\right)^{-\theta} Y_t^w, \end{aligned}$$

where $Y_t^w = Y_t + Y_t^f$ denotes world aggregate consumption, and hence the world's real income. The inverse demand functions for the good i is:

$$p_{it} = P_t \left(\frac{y_{it}^w}{Y_t^w}\right)^{\frac{-1}{\theta}}, \tag{2}$$

$$p_{it}^f = P_t^f \left(\frac{y_{it}^w}{Y_t^w}\right)^{\frac{-1}{\theta}}. \tag{3}$$

B Supply function of exporting firms

The firm i at date t uses labor l_{it}, capital k_{it} and imported raw materials m_{it} to produce the differentiated good q_{it} according to the following generalized Cobb-Douglas form of technology

$$q_{it} = A_{it} \left(\frac{l_{it}}{\alpha}\right)^{\alpha} \left(\frac{k_{it}}{\beta}\right)^{\beta} \left(\frac{m_{it}}{\gamma}\right)^{\gamma},$$

[2]Note that the original budget constraint is $\int_0^n p_{it} y_{it} di + \int_n^1 \left(\frac{p_{it}^f}{e_t}\right) y_{it} di \leq Z_t$, which is simplified to $\int_0^1 p_{it} y_{it} di \leq Z_t$ due to the law of one price. Furthermore, the law of one price also implies that $P_t^f = e_t P_t$ equivalently $\frac{p_{it}}{P_t} = \frac{p_{it}^f}{P_t^f}$. This makes the demand function of domestic goods and that of foreign goods symmetric, given the prices of p_{it} and p_{it}^f.

where A_{it} denotes the firm level total factor productivity term. Define $\rho = 1 - (\alpha + \beta + \gamma)$. This parameter ρ measures the degree of returns to scale: $\rho > 0$ for decreasing returns to scale, $\rho = 0$ for constant returns to scale, and $\rho < 0$ for increasing returns to scale. Note that this returns to scale parameter relates to the firm level technology, not to the aggregate technology.

We assume that markets for these intermediate inputs are perfectly competitive. Let w_t, r_t and w_t^f denote the prices of labor l_{it}, capital k_{it} and imported raw materials m_{it}, respectively. Then, the cost function (the minimized cost for the given input prices w_t, r_t and w_t^f and output level q_{it}) dual to the production function above is

$$
\begin{aligned}
(4) \qquad C\left(w_t, r_t, \frac{w_t^f}{e_t}, q_{it}\right) &= w_t l_{it}^* \left(w_t, r_t, \frac{w_t^f}{e_t}, q_{it}\right) + r_t k_{it}^* \left(w_t, r_t, \frac{w_t^f}{e_t}, q_{it}\right) \\
&\quad + \frac{w_t^f}{e_t} m_{it}^* \left(w_t, r_t, \frac{w_t^f}{e_t}, q_{it}\right) \\
&= (\alpha + \beta + \gamma) \left(w_t\right)^{\frac{\alpha}{\alpha+\beta+\gamma}} \left(r_t\right)^{\frac{\beta}{\alpha+\beta+\gamma}} \left(\frac{w_t^f}{e_t}\right)^{\frac{\gamma}{\alpha+\beta+\gamma}} \left(\frac{q_{it}}{A_{it}}\right)^{\frac{1}{\alpha+\beta+\gamma}},
\end{aligned}
$$

where l_{it}^*, k_{it}^* and m_{it}^* denote the conditional factor demand functions. A well-defined cost function is required to be non-negative, homogeneous of degree one, monotone increasing, concave in input prices, and concave in output.[3] These properties of the cost function imply that the parameter space should satisfy

$$
(5) \qquad \alpha \geq 0, \ \beta \geq 0, \ \gamma \geq 0 \text{ and } \rho \geq 0.
$$

The total revenues of the monopolistic firm i facing the inverse demand functions in equations (2) and (3) is

$$
\begin{aligned}
(6) \qquad R\left(\frac{P_t^f}{e_t}, Y_t^w, y_{it}^w\right) &= p_{it} y_{it} + \frac{p_{it}^f}{e_t} y_{it}^f \\
&= \frac{P_t^f}{e_t} \left(Y_t^w\right)^{\frac{1}{\theta}} \left(y_{it}^w\right)^{1-\frac{1}{\theta}}.
\end{aligned}
$$

Given the cost function in (4), the revenue function in (6) and the market clearing condition

[3]See Blackorby, Primont, and Russell (1978) for a general discussion on the dual mapping between the cost function, and technology and the properties of the cost function.

$q_{it} = y_{it}^w$, the total supply of good i is determined to maximize profits:

$$\begin{aligned} y_{it}^w &= \arg\max_{y_{it}^w} R\left(\frac{P_t^f}{e_t}, Y_t^w, y_{it}^w\right) - C\left(w_t, r_t, \frac{w_t^f}{e_t}, y_{it}^w\right) \\ &= \left[\left(1-\frac{1}{\theta}\right)\frac{P_t^f}{e_t}\left(Y_t^w\right)^{\frac{1}{\theta}}\left(A_{it}\right)^{\frac{1}{\alpha+\beta+\gamma}}\left(w_t\right)^{-\frac{\alpha}{\alpha+\beta+\gamma}}\left(r_t\right)^{-\frac{\beta}{\alpha+\beta+\gamma}}\left(\frac{w_t^f}{e_t}\right)^{-\frac{\gamma}{\alpha+\beta+\gamma}}\right]^{\nu}, \end{aligned}$$

where

$$\nu = \left[\frac{\rho}{\alpha+\beta+\gamma} + \frac{1}{\theta}\right]^{-1}.$$

C Exchange rate elasticity of exports

Let s_{it} be the export share in the total supply of good i. Then, we have the following identity for exports

$$y_{it}^f = s_{it} y_{it}^w,$$

and hence the log export equation such that

$$\begin{aligned} \ln y_{it}^f &= \nu \ln\left(1-\frac{1}{\theta}\right) - \frac{\nu(\alpha+\beta)}{\alpha+\beta+\gamma}\ln e_t - \frac{\nu\alpha}{\alpha+\beta+\gamma}\ln w_t - \frac{\nu\beta}{\alpha+\beta+\gamma}\ln r_t \\ &\quad - \frac{\nu\gamma}{\alpha+\beta+\gamma}\ln w_t^f + \nu \ln P_t^f + \frac{\nu}{\theta}\ln Y_t^w + \frac{\nu}{\alpha+\beta+\gamma}\ln A_{it} + \ln s_{it}. \end{aligned} \tag{7}$$

Here, we assume that the export share s_{it} is exogenously determined. However, in general, the export share may depend on the exporting firm's productivity level. For example, firms with higher productivity may be able to overcome the fixed costs of exporting, and hence export a larger share of their output, as in Melitz (2003). Unfortunately, in the data, we do not directly observe the fixed costs as well as other potential factors that link export shares and productivity. In our empirical work, this may induce correlation between the idiosyncratic error term, and the export shares. Thus, in our empirical work, we instrument the export share, although we do not explicitly endogenize these shares.

From the log export equation (7) above, the elasticity of exports with respect to the exchange rate is given by:

$$\begin{aligned} \epsilon &= -\frac{\nu(\alpha+\beta)}{\alpha+\beta+\gamma} \\ &= -\frac{\theta(\alpha+\beta)}{1+\rho(\theta-1)}. \end{aligned} \tag{8}$$

First, the exchange rate elasticity of exports is *negative* for all parameter values satisfying the restrictions in equations (1) and (5). Thus, our model suggests that exports should decrease, as the exchange rate increases (i.e., as the domestic currency appreciates relative to the foreign currency). The magnitude of the elasticity, however, depends on the preferences (θ) and technology (α, β and ρ) parameters. The larger the share of non-imported inputs (the higher the $\alpha + \beta$), or the larger the elasticity of substitution among differentiated goods (the higher the θ), the larger the decrease in exports to the increase in exchange rates. However, the larger the degree of decreasing returns to scale (the higher the ρ), the smaller the decrease in exports to the appreciation. In the extreme case of constant returns to scale ($\rho = 0$) and no use of imported raw materials ($\gamma = 0$ and hence $\alpha + \beta = 1$), the elasticity is completely determined by the elasticity of substitution parameter θ, which has no upper bound, so that export quantities can be extremely sensitive to the movement of exchange rates. In the other extreme case, where the exporting firm relies entirely on imported inputs ($\alpha + \beta = 0$), export quantities would *not change at all* to the movement of exchange rates, *regardless* of the elasticity of substitution and returns to scale parameters. Therefore, identification of these preferences and technology parameters would allow us to have a deeper understanding on the exchange rate elasticity of exports.

In sum, our model of monopolistic competition implies: first, that the relationship between exports and exchange rates is log-linear, controlling for factor prices, the foreign price level, world real income, the firm level productivity and the export shares; and second, that the elasticity of exports with respect to the exchange rate is negative, the magnitude of which, depends on the preferences and technology parameters.

III Export equations

A The firm level export equation

The exchange rate elasticity of exports ϵ can be inferred by estimating the firm level log export equation (7). Note that the model imposes two restrictions on the coefficients in the log export function in (7). The sum of the coefficients of $\ln w_t$ and $\ln r_t$ is equal to the coefficient of $\ln e_t$, and the sum of the coefficients of $\ln w_t$, $\ln r_t$ and $\ln w_t^f$ is equal to the negative of the coefficient of $\ln P_t^f$. With these restrictions, the log export function can be re-written such that

$$\text{(9)} \qquad \ln y_{it}^f = \nu \ln\left(1 - \frac{1}{\theta}\right) - \frac{\nu(\alpha+\beta)}{\alpha+\beta+\gamma} \ln\left(e_t \frac{w_t}{w_t^f}\right) - \frac{\nu\beta}{\alpha+\beta+\gamma} \ln\left(\frac{r_t}{w_t}\right) + \nu \ln\left(\frac{P_t^f}{w_t^f}\right) + \frac{\nu}{\theta} \ln Y_t^w + \frac{\nu}{\alpha+\beta+\gamma} \ln A_{it} + \ln s_{it}.$$

To be specific, suppose that firm level total factor productivity A_{it} can be expressed as:

$$\text{(10)} \qquad \ln A_{it} = \widetilde{\kappa} + \widetilde{\tau} \ln \Phi_t + \widetilde{\delta} \ln z_{it} + \widetilde{u}_{it},$$

where Φ_t denotes aggregate total factor productivity (TFP), z_{it} the observable attributes of firm level productivity, and $\widetilde{u}_{it}$ the unobservable idiosyncratic productivity term.

We allow the firm's export share s_{it} to depend on the firm's unobserved idiosyncratic productivity term. Thus we instrument s_{it} by the average export share within the industry in which the firm belongs, *excluding* its own share (denoted by $\overline{s}_{it}$). That is, we use the following instrumental variables relationship:

$$\text{(11)} \qquad \ln s_{it} = a_0 + a_1 \ln \overline{s}_{it} + v_{it},$$

where $\ln \overline{s}_{it}$ is orthogonal to $\widetilde{u}_{it}$ as well as to v_{it}.

Substituting the productivity equation in (10) and the export share equation in (11) into the log export equation in (9), we get the following log-linear export equation:

$$\text{(12)} \quad \ln y_{it}^f = \varphi_0 + \varphi_1 \ln \widehat{e}_t + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t + \varphi_6 \ln z_{it} + \varphi_7 \ln \overline{s}_{it} + u_{it},$$

where the relationships between the coefficients in this export equation and the deep parameters are

$$\varphi_0 = \nu \ln\left(1 - \frac{1}{\theta}\right) + \frac{\nu\widetilde{\kappa}}{\alpha+\beta+\gamma} + a_0,$$

$$\text{(13)} \qquad \varphi_1 = -\frac{\nu(\alpha+\beta)}{\alpha+\beta+\gamma},$$

(14) $$\varphi_2 = -\frac{\nu\beta}{\alpha+\beta+\gamma},$$

(15) $$\varphi_3 = \nu,$$

(16) $$\varphi_4 = \frac{\nu}{\theta},$$
$$\varphi_5 = \frac{\nu\widetilde{\tau}}{\alpha+\beta+\gamma},$$
$$\varphi_6 = \frac{\nu\widetilde{\delta}}{\alpha+\beta+\gamma},$$
$$\varphi_7 = a_1,$$

and the normalized variables are defined such that

$$\widehat{e}_t = \frac{e_t w_t}{w_t^f},\ \widehat{r}_t = \frac{r_t}{w_t},\ \widehat{P}_t^f = \frac{P_t^f}{w_t^f},\ \text{and } u_{it} = \frac{\nu}{\alpha+\beta+\gamma}\widetilde{u}_{it} + v_{it}.$$

B The aggregate export equation

Consider a similar log-linear relation between exports and exchange rates defined on aggregate variables, such that

(17) $$\ln y_t^f = \phi_0 + \phi_1 \ln e_t + \boldsymbol{\phi}_2 \boldsymbol{\Psi}_t + \Omega_t,$$

where y_t^f is aggregate average exports, e_t the nominal exchange rate, $\boldsymbol{\Psi}_t$ the vector of control variables, and Ω_t the aggregate error term. Would the exchange rate elasticity of exports ϕ_1 estimated from this aggregate export equation (17) be consistent with the estimate for φ_1 in the firm level export equation (12)? Note that the level of exports is written as:

(18) $$y_{it}^f = \widehat{e}_t^{\varphi_1} \widehat{r}_t^{\varphi_2} \left(\widehat{P}_t^f\right)^{\varphi_3} \left(Y_t^w\right)^{\varphi_4} \Phi_t^{\varphi_5} z_{it}^{\varphi_6} \overline{s}_{it}^{\varphi_7} \exp\left(\varphi_0 + u_{it}\right).$$

Taking the cross-sectional average E_i on both sides of equation (18),

(19) $$\begin{aligned} y_t^f &\equiv E_i\left\{y_{it}^f\right\} \\ &= \exp\left(\varphi_0\right) \widehat{e}_t^{\varphi_1} \widehat{r}_t^{\varphi_2} \left(\widehat{P}_t^f\right)^{\varphi_3} \left(Y_t^w\right)^{\varphi_4} \Phi_t^{\varphi_5} E_i\left\{z_{it}^{\varphi_6} \overline{s}_{it}^{\varphi_7}\right\} E_i\left\{\exp\left(u_{it}\right)\right\}, \end{aligned}$$

because of the orthogonality of the error term u_{it} from z_{it} and $\overline{s}_{it}$. Taking the natural logarithms on both sides of equation (19),

$$
\begin{aligned}
(20)\quad \ln y_t^f &= \varphi_0 + \varphi_1 \ln \widehat{e}_t + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t \\
&\quad + \ln E_i \left\{ z_{it}^{\varphi_6} \overline{s}_{it}^{\varphi_7} \right\} + \ln E_i \left\{ \exp\left(u_{it}\right) \right\} \\
&= \varphi_0 + \varphi_1 \ln \widehat{e}_t + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t + \varphi_6 \ln z_t + \varphi_7 \ln s_t \\
&\quad + \ln E_i \left\{ \left(\frac{z_{it}}{z_t} \right)^{\varphi_6} \left(\frac{\overline{s}_{it}}{s_t} \right)^{\varphi_7} \right\} + \ln E_i \left\{ \exp\left(u_{it}\right) \right\} \\
&= \varphi_0 + \varphi_1 \ln \widehat{e}_t + \mathbf{\Theta \Lambda}_t + B_t + U_t,
\end{aligned}
$$

where

$$
\begin{aligned}
(21)\quad \mathbf{\Theta \Lambda}_t &= \varphi_1 \ln \left(\frac{w_t}{w_t^f} \right) + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t + \varphi_6 \ln z_t + \varphi_7 \ln s_t \\
(22)\quad B_t &= \ln E_i \left\{ \left(\frac{z_{it}}{z_t} \right)^{\varphi_6} \left(\frac{\overline{s}_{it}}{s_t} \right)^{\varphi_7} \right\} \\
(23)\quad U_t &= \ln E_i \left\{ \exp\left(u_{it}\right) \right\}.
\end{aligned}
$$

This gives us aggregated export$s$ consistent with firm level export$s$ in (12). The $\mathbf{\Theta \Lambda}_t$ term includes the variables that reflect the information set underlying the firm's decisions, such as relative factor prices, the general price level, real income of consumers, the firm's own productivity and the export share. The B_t term arises because of aggregation, which reflects the distribution of the heterogeneous characteristics of firms, e.g., firm level productivity and export shares. With only aggregated or macroeconomic data, we cannot control for $B_{t,}$ whose calculation requires firm level data. The U_t term is an aggregate time-series error term that is consistent with the firm level relation. Since the error term u_{it} is orthogonal to all the regressors in the firm level equation (12) over all i's and t's, U_t is orthogonal to the aggregate variables in the aggregate equation (20) over time t.

C Sources of bias in typical aggregate export equations

C.1 Omitting variables in the firm's information set

A comparison of the typically estimated macroeconomic relation between exports and exchange rates in (17), with the consistently aggregated relation in equation (20) suggests that there are two categories of omitted variable bias in the aggregate export equation in (17).

First, if the set of control variables $\mathbf{\Psi}_t$ in the macroeconomic relation (17) omits one or more of the control variables in $\mathbf{\Lambda}_t$ (basically the variables in the exporting firms' information set) in the consistent aggregate relation in (20) and if there exists some degree of covariance over time between the omitted variables and the exchange rate, the aggregate exchange rate elasticity of exports ϕ_1 in (17) will be biased. For example, suppose the relative factor price $\widehat{r}_t = \frac{r_t}{w_t}$ (the ratio of the rental rates of capital to wage rates) is omitted, as in a typical macroeconomic export equation. Let $\widehat{\phi}_1$ be the OLS estimate for the exchange rate elasticity of exports from the typical macroeconomic export equation. Then, we have

$$\begin{aligned} E\left[\widehat{\phi}_1\right] &= \varphi_1 + \frac{Cov(\ln e_t, \ln \widehat{r}_t)}{Var\left(\ln e_t\right)}\varphi_2 \\ &= \varphi_1 + Corr(\ln e_t, \ln \widehat{r}_t)\frac{\sqrt{Var\left(\ln \widehat{r}_t\right)}}{\sqrt{Var\left(\ln e_t\right)}}\varphi_2. \end{aligned}$$

Thus, the larger the time-series correlation between the omitted variable and the exchange rate, the larger the omitted variable bias. The larger the variance of the omitted variable over time, the larger is the bias. However, the larger the variance of the exchange rate itself, the smaller is the omitted variable bias. That is, the omitted variable bias for the exchange rate elasticity of exports tends to be smaller for an economy where the exchange rate is *more volatile*. This may explain why we find strong correlations between exchange rate depreciations and export expansions in developing countries as documented by Tornell and Westermann (2002), where exchange rates are more volatile and factor prices are more regulated, and hence the smaller the*above* kind of omitted variable bias for the exchange rate elasticity of exports.

The direction as well as the size of the bias depend on the covariance as well as the coefficient on the omitted variable itself. In this example, according to our model ($\varphi_2 = -\frac{\nu\beta}{\alpha+\beta+\gamma} < 0$) and also according to our estimate, the coefficient φ_2 on the rental-to-wage ratio is negative. The data suggests $Cov(\ln e_t, \ln \widehat{r}_t)$ is also negative. Therefore, the bias from omitting the rental-to-wage ratio is positive. That is, omitting the rental-to-wage ratio will bias the aggregate elasticity of exports with respect to exchange rates, $\widehat{\phi}_1$, towards zero, and hence can be a source of the observed exchange rate disconnect.

C.2 Aggregation bias

The omission of the term $B_t = \ln E_i \left\{ \left(\frac{z_{it}}{z_t} \right)^{\varphi_6} \left(\frac{\bar{s}_{it}}{s_t} \right)^{\varphi_7} \right\}$ in the macroeconomic export equation creates a further source of omitted variable bias. This bias results from the aggregation of heterogeneous firms, which depends on the distribution of the relative productivity $\frac{z_{it}}{z_t}$, and the export shares $\frac{\bar{s}_{it}}{s_t}$ (normalized to the means).

Let ζ_t be the vector of parameters of the joint distribution of the productivity and export share terms at date t. If the movement of B_t is not independent from the movement of the mean values of z_t and s_t via some parameters in ζ_t, the coefficients on $\ln z_t$ and $\ln s_t$ in the typical macroeconomic export equations will be biased downwards. This is the usual "aggregation bias" in the aggregation literature as discussed in Blundell and Stoker (2005). Lewbel (1992) shows that the necessary and sufficient condition to avoid this aggregation bias in log-linear models is that the distribution is "mean-scaled," i.e., the distribution of those mean-scaled variables is independent from the mean values of z_t and s_t. When the mean-scaled property in Lewbel (1992) is satisfied for the joint distribution$s$ of productivity, and the export shares, the coefficients on labor productivity and the export shares themselves can be consistently estimated from the aggregate export equation (17).

However, even when the mean-scaled property is satisfied, omitting the distribution term B_t can generate another type of aggregation bias for the exchange rate elasticity of exports in (17), if B_t covaries with the exchange rate over time. Suppose, for example, that the joint distribution of $\frac{z_{it}}{z_t}$ and $\frac{\bar{s}_{it}}{s_t}$ is lognormal. Then, the ζ_t are time-varying variances of $\frac{z_{it}}{z_t}$ and $\frac{\bar{s}_{it}}{s_t}$ If the movements in any of these variances or covariance$s$ are correlated with exchange rates over time, the exchange rate elasticity of exports estimated from (17) will be biased. This type of aggregation bias cannot be avoided by typical aggregate export equations. By comparing the firm-level estimate of the exchange rate elasticity of exports (which is free from this aggregation bias) with the estimates from the aggregate export equation, which includes the same relevant prices and productivity variables but missing the B_t term, we can quantify the magnitude of this aggregation bias for the exchange rate elasticity of exports.

IV Estimation

A Data

We use annual firm level data from Japanese four-digit export industries during the years between 1982 and 1997, obtained from the Japan Development Bank Corporate database. Our sample firms are in the manufacturing sector. This is a database of large firms listed on the various stock exchanges of Japan. One important characteristic of Japan is that large exporters comprise the bulk of exports. Remarkably, the 10 largest Japanese firms comprise 40 percent of all exports (Canals, et. al. 2005). Another important characteristic is that there is virtually no exit or entry into our sample of exporters from 1982 to 1997. In our sample, there are 312 exporting firms in each year, covering over 90 percent of total Japanese manufacturing export sales value. These firms are categorized into 52 four-digit level industry groups, which we have aggregated into 6 broad categories of industries.

Exports and total sales are from the Japan Development Bank database. Export quantities are defined as export values divided by the industry specific Japanese export price indices (the base year of 1995, foreign currency bases) from the Bank of Japan Economic and Financial database. The aggregate Japanese export price index from the International Financial Statistics from the IMF is used as a proxy for the foreign price.

Firm level export shares are defined as exports divided by the sum of domestic sales and exports. Note that we use different price indices for domestic sales and export sales, to get real values, in order to calculate the "real quantity" share of exports. Aggregate export shares are defined as the average of the firm level export shares.

The exchange rate is measured by the reciprocal of the composite of the trade-weighted nominal rates of the Japanese Yen, to the foreign currencies of the top 15 trading partner countries of Japan. The annual nominal exchange rates are from the International Financial Statistics from IMF, and the trade weights are computed from the Japan Statistical Yearbook. For world real income, we take Japan's top 15 trading partners' real GDP's (obtained from the PWT version 6.1), and sum them, by weighting by the trade weights with Japan.

As a proxy for the prices of imported raw materials used by Japanese exporting firms, we take the average spot crude oil market price index from the International Financial Statistics. For industry specific domestic input prices, we take industry specific domestic wages from the Japan Statistical Yearbook. Industry specific labor productivity is defined industry output per worker at the four digit level. For the interest rate, we take the one year LIBOR (London Inter-Bank Offered Rate). For Japanese aggregate TFP, we take the TFP measure provided by Hayashi and Prescott (2002).

B Firm level estimation

Using the above exporting firm data as well as the aggregate data, we estimate the firm level export equation in (12)

$$\ln y_{it}^f = \varphi_0 + \varphi_1 \ln \widehat{e}_t + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t + \varphi_6 \ln z_{it} + \varphi_7 \ln \overline{s}_{it} + u_{it}.$$

Table 2 reports the estimates of the coefficients in this export equation. Depending on the assumptions regarding the unobserved heterogeneity in the error term u_{it}, we estimate the equation using ordinary least squares (OLS), fixed effect (FE), and random effect (RE) estimators. For all three cases, the signs of the estimated coefficients agree with the predictions of our model. That is, the coefficients on the exchange rate $\widehat{e}_t$, and the interest rate $\widehat{r}_t$ are negative, while the coefficients on the foreign price level $\widehat{P}_t^f$, world real income Y_t^w, aggregate TFP Φ_t, industry-specific labor productivity z_{it}, and the firm-specific (instrumented) export share $\overline{s}_{it}$ (all in log terms) are all positive. In particular, in contrast to the insignificant aggregate elasticities of exports with respect to exchange rates in Table 1, the firm level estimates for φ_1 (the exchange rate elasticity of exports) are *significantly negative* for all three cases: -0.41 for OLS, -0.77 for FE, and -0.75 for RE.

The estimates are very close between the fixed effect estimator and the random effect estimator, not only for the exchange rate elasticity, but also for all other coefficients. According to the Hausman specification test, the fixed effect model against the random effect model is not rejected.[4] Thus, we focus on the fixed effect estimates, and compare them with the OLS

[4] The Hausman test statistic is 6.27 and the p-value is 0.51.

estimates. The magnitude of the exchange rate elasticity is larger for the FE estimate than for the OLS estimate. The same is true for the interest rate elasticity, and the OLS estimate of the interest rate elasticity is insignificant, while its FE estimate is significant. The world income elasticity is small and insignificant for both the OLS and FE estimates. For the TFP elasticity, the OLS estimate is much larger than the FE estimate, but both are insignificant. The estimates of the industry productivity elasticity are significant both for the OLS and FE, but the OLS estimate is smaller than the FE estimate. The estimates of the firm export share elasticities are significant both for the OLS and FE, but the OLS estimate is larger than the FE estimate.

[Table 2 here]

We would like to know if there exists a subset of key variables, for which the bias for omitted variables can be particularly severe in estimating the exchange rate elasticity. To see this, Table 3 shows the OLS estimation results for various specifications, by omitting different subsets of variables in the model. The first column reports the result with all the variables in the model included; the exchange rate elasticity is significantly negative at -0.41. Omitting all variables other than the exchange rate (column 2), the exchange rate elasticity becomes significantly *positive* at 0.42, suggesting that even at the firm level, the omission of relevant control variables can result in the opposite sign, in the relationship between exchange rates and exports.

In column 3, the specification includes only four variables (i.e., interest rate, foreign price level, industry productivity and the firm export share, other than the exchange rate), which turn out to be significant for both the OLS and the FE estimates. We then omit world real income and domestic TFP. In this specification, we find that the exchange rate elasticity turns smaller and insignificant. Thus, omitting both world real income and domestic TFP seems to result in serious bias in estimating the exchange rate elasticity.

Columns 4 to 9 experiment, omitting a variable in the model one by one, from the interest rate to the firm export share. Here omitting any single variable in the model, except for omitting only world income, or only TFP biases the exchange rate elasticity towards zero and insignificant. Omitting only the domestic TFP raises the exchange rate elasticity. Omitting only the world income virtually has no effect.

The sensitivity analysis reported in columns 10 to 17 in Table 3 is done by omitting a group of related variables, rather than omitting each single variable. Column 10 includes only the quantity variables (Y_t^w, Φ_t, z_{it} and $\overline{s}_{it}$). Column 11 includes only the price variables ($\widehat{r}_t$ and $\widehat{P}_t^f$). Column 12 includes only the firm's supply-side variables ($\widehat{r}_t$, Φ_t, z_{it} and $\overline{s}_{it}$). Column 13 includes only the demand-side variables (Y_t^w and $\widehat{P}_t^f$). Column 14 drops only the productivity related variables, while column 15 includes only the productivity related variables (Φ_t, z_{it} and $\overline{s}_{it}$). Column 16 includes only the aggregate variables ($\widehat{r}_t$, $\widehat{P}_t^f$, Y_t^w and Φ_t). Column 17 includes only the industry or firm specific variables (z_{it} and $\overline{s}_{it}$). In none of the specifications is the exchange rate elasticity significantly negative.

[Table 3 here]

Table 4 repeats the same exercise for the fixed effect estimator. As a reminder, the FE estimate of the exchange rate elasticity was higher at -0.77, than the OLS estimate at -0.41. However, despite the differences in the magnitudes of the estimates and their significance levels, we get similar results for the FE as those for the OLS. Omitting any subgroups of the variables in our model involves sizeable biases. Only when either world income or TFP is omitted is the bias negligible. The only difference between the FE estimator and the OLS estimator is that the bias from omitting the two insignificant variables (world income and domestic TFP) in the full model is relatively small (with the estimate at -0.68) for the FE estimator, compared to the OLS estimator.

There are two other noticeable observations from the sensitivity analysis for the FE estimator. The bias in the exchange rate elasticity is the highest when industry level productivity (column 8) and the firm's export share variables are omitted (column 9). Thus, omitting the two firm level productivity variables seem to generate the most serious omitted variable biases. This, of course, does not mean that controlling for aggregate variables is unimportant. Column

17 confirms that excluding the aggregate variables also generates biases in our firm level regressions. However, even after correctly controlling for the aggregate variables, omitting either or both of the firm level productivity variables can generate substantial omitted variable biases, as shown in columns 8, 9 and 16.

[Table 4 here]

C Aggregate estimation

Suppose it is possible to estimate the consistently aggregated export equation (20)

$$\ln y_t^f = \varphi_0 + \varphi_1 \ln \widehat{e}_t + \varphi_2 \ln \widehat{r}_t + \varphi_3 \ln \widehat{P}_t^f + \varphi_4 \ln Y_t^w + \varphi_5 \ln \Phi_t + \varphi_6 \ln z_t + \varphi_7 \ln s_t + B_t + U_t.$$

Since it is consistently aggregated from the firm level equation (12), we should be able to obtain the same estimates for all the coefficients from φ_0 to φ_7, as we did from the firm level estimation of (12). However, the aggregation effect term $B_t = \ln E_i \left\{ \left(\frac{z_{it}}{z_t}\right)^{\varphi_6} \left(\frac{\overline{s}_{it}}{s_t}\right)^{\varphi_7} \right\}$ is not feasible to include in typical macroeconomic export equations for two reasons. First, we can hardly know the *time-varying* joint distributions of $\left(\frac{z_{it}}{z_t}, \frac{\overline{s}_{it}}{s_t}\right)$ *a priori*. Second and related, B_t itself involves the parameters φ_6 and φ_7 that need to be estimated. Thus, unless we are willing to assume parametric forms of the time-varying joint distributions of $\left(\frac{z_{it}}{z_t}, \frac{\overline{s}_{it}}{s_t}\right)$, we cannot even calculate B_t to correct for the aggregation bias. We can, however, quantify the size of this aggregation bias by comparing the estimates of the following aggregate export equation (which omits B_t)

$$(24) \quad \ln y_t^f = \psi_0 + \psi_1 \ln \widehat{e}_t + \psi_2 \ln \widehat{r}_t + \psi_3 \ln \widehat{P}_t^f + \psi_4 \ln Y_t^w + \psi_5 \ln \Phi_t + \psi_6 \ln z_t + \psi_7 \ln s_t + U_t$$

with the firm level estimates that are not subject to the aggregation bias. This is done in Table 5.

We construct the aggregate data from our firm level data so that they are consistently aggregated from the firm level data. We first estimate the aggregate export equation (24), and compare the estimates with the OLS firm level estimates. We also estimate it using differenced data, and compare with the fixed-effects estimator. The aggregate OLS estimates are more or less similar to the OLS firm level estimates for all the coefficients. That is, if the idiosyncratic error term u_{it} is indeed $i.i.d.$, the aggregation bias seems to be small for all coefficients, including the exchange rate elasticity.

However, if the u_{it} includes unobservable fixed effects, the aggregation bias seems to be substantial. First of all, omitting the term $B_t = \ln E_i \left\{ \left(\frac{z_{it}}{z_t}\right)^{\varphi_6} \left(\frac{\bar{s}_{it}}{s_t}\right)^{\varphi_7} \right\}$ underestimates the elasticity of the industry productivity z_t at 0.47, (compared to 0.68 in the firm level estimate); and overestimates the elasticity of the firm export share s_t at 0.93 (compared to 0.60 in the firm level estimate). It underestimates the interest rate elasticity at -0.17 (compared to -0.35 in the firm level estimate) while overestimates the TFP elasticity at 0.33 (compared to 0.19 in the firm level estimate). The foreign price elasticity remains virtually the same at 0.73 (compared to 0.74 in the firm level estimate). The world income elasticity (incorrectly) turns negative at -0.11, although it is insignificant. Finally, the aggregate estimation underestimates the exchange rate elasticity (our key parameter) at -0.65 (compared to -0.77 in the firm level estimate).

[Table 5 here]

D Identification of the deep parameters

Recall that the exchange rate elasticity in equation (8) is:

$$\epsilon = -\frac{\theta\left(\alpha+\beta\right)}{1+\rho(\theta-1)},$$

which shows that the responsiveness of exports to exchange rates depends on the deep parameters of preferences and technology. We can uncover the deep parameters $(\theta, \alpha, \beta, \gamma, \rho)$ from the elasticity parameters φ_1 to φ_4 in the export equation, using the parameter mappings in equations (13) to (16). From the deep parameters, we can uncover the preferences and the technology of Japanese exporting firms and determine the effects of the preference and technological parameters on the exchange rate elasticity of exports.

The elasticity of substitution parameter θ of the utility function is identified by $\theta = \frac{\varphi_3}{\varphi_4}$.

Given this θ, $\alpha+\beta+\gamma$ is identified from equation (15) such that:

$$\begin{aligned} \varphi_3 &= \nu \\ &= \left[\frac{\rho}{\alpha+\beta+\gamma}+\frac{1}{\theta}\right]^{-1} \\ &= \left[\frac{1-(\alpha+\beta+\gamma)}{\alpha+\beta+\gamma}+\frac{1}{\theta}\right]^{-1}. \end{aligned} \tag{25}$$

Then, from equation (13), we identify $\alpha+\beta$ such that

$$\begin{aligned} \varphi_1 &= -\frac{\nu(\alpha+\beta)}{\alpha+\beta+\gamma} \\ &= -\frac{\varphi_3(\alpha+\beta)}{\alpha+\beta+\gamma}, \end{aligned} \tag{26}$$

given the $\alpha+\beta+\gamma$ from equation (25). γ is identified from the difference between the $\alpha+\beta+\gamma$ from equation (25), and the $\alpha+\beta$ from equation (26). Then, using the equations (13) and (14), β is identified by

$$\beta = \frac{\varphi_2}{\varphi_1}(\alpha+\beta), \tag{27}$$

given the $\alpha+\beta$ from equation (26). Finally, α is identified from the difference between the $\alpha+\beta$ in equation (26), and the β in equation (27).

In sum, the preferences and technology parameters are identified such that

$$\theta = h_\theta(\boldsymbol{\varphi}_{\mathbf{s}}) = \frac{\varphi_3}{\varphi_4}, \tag{28}$$

$$\alpha = h_\alpha(\boldsymbol{\varphi}_{\mathbf{s}}) = \frac{\varphi_2-\varphi_1}{1+\varphi_3-\varphi_4}, \tag{29}$$

$$\beta = h_\beta(\boldsymbol{\varphi}_{\mathbf{s}}) = \frac{-\varphi_2}{1+\varphi_3-\varphi_4}, \tag{30}$$

$$\gamma = h_\gamma(\boldsymbol{\varphi}_{\mathbf{s}}) = \frac{\varphi_1+\varphi_3}{1+\varphi_3-\varphi_4}, \tag{31}$$

where $\boldsymbol{\varphi}_{\mathbf{s}} \equiv (\varphi_1, \varphi_2, \varphi_3, \varphi_4)$. The implied returns to scale parameter ρ is

$$\rho = h_\rho(\boldsymbol{\varphi}_{\mathbf{s}}) = \frac{1-\varphi_4}{1+\varphi_3-\varphi_4}. \tag{32}$$

Table 6 reports the uncovered preferences and technology parameters for each set of estimates from the firm level OLS estimation, the firm level fixed effect estimation, the aggregate level$s$ estimation, and the aggregate first-differenced estimation. Standard errors of these deep parameters are computed using delta methods. (See Appendix for details.)

There are some noticeable features of the deep parameters that are robust to the specifications of the error terms. First, Japanese exporting firms are facing strong *decreasing* returns to scale. The estimated ρ varies between 0.52 and 0.65, which are significantly different from zero (i.e., constant returns to scale technology). Furthermore, the standard errors of the ρ parameter are small for all specifications, and hence ρ seems to be fairly precisely estimated. Note that the higher the ρ, the smaller the exchange rate elasticity. That is, the exchange rate elasticity is likely to be overestimated when the typical constant returns to scale Cobb-Douglas production function for firm level technology is used in deriving the export equation.

Second, the elasticity of substitution parameter in demand θ is much larger than unity, varying from 4 to 10, except for the case of first-differenced aggregate estimation.[5] When $\rho < 1$, as the elasticity of substitution parameter θ becomes larger, the larger the decrease in exports to the appreciation of exchange rate. Obviously, in the extreme case of Leontief preferences of $\theta = 0$, exports do not respond at all to the movement of exchange rate. Our large estimates for θ implies that the observed significant elasticity of exports with respect to exchange rate is indeed related to the high substitutability among the differentiated consumption goods.[6]

Third, the relative size of the labor share α and the capital share β varies depending on the specifications. Note, however, that the relative share between domestic labor and capital does not affect the exchange rate elasticity. Only the sum $\alpha + \beta$ matters relative to the imported input share γ. Here in our estimates, not only the sum, but also each of the domestic input share parameters α and β, are larger than the imported raw material share parameter γ. In fact, the estimates for γ itself are very small.[7] Thus, the observed magnitude of the exchange

[5] This is because the elasticity of the world income is estimated (incorrectly) to be negative although insignificant.

[6] However, this parameter seems to be less precisely estimated compared with the returns to scale parameter, particularly for the high OLS estimate at 10.4. The lower FE estimate for θ at 3.89 seems to be relatively precise. In fact, the FE estimates are more precise than those of other specifications for all deep parameters except for γ.

[7] The FE estimate for γ is slightly negative but with a high standard error.

rate elasticity does not seem to be related to the share of imported inputs.

[Table 6 here]

V Conclusion

We build a monopolistic competition model of exporting firms, to derive an export equation at the firm level, which can be consistently aggregated up to the macroeconomic level. We use our framework to reconcile the conflicting evidence in the existing literature regarding the exchange rate elasticities at the firm and macroeconomic levels. We show that the estimates for all elasticity parameters are similar between the firm and (consistently) aggregated levels once all the variables relevant to the firm's export supply decision are taken into account. In particular, we found a significantly negative elasticity of exports with respect to exchange rates in both the firm and aggregated level export equations.

We show that the omission of only some part of the key variables in the information set of exporting firms can lead to the puzzling observation of the lack of association between the movements in export quantities and exchange rates, i.e., the "exchange rate disconnect puzzle." Specifically, we found that omitting firm level productivity and export share variables may yield a substantial bias for the estimates of the elasticity of exports. Furthermore, missing some distributional characteristics of firm level heterogeneities such as the correlation between the productivity and export share variables (which is inevitable in the macroeconomic export equations without using firm level data) turns out to yield a sizeable aggregation bias.

We also identified the deep parameters of preferences and technology, and found substantial decreasing returns to scale in the Japanese exporting firms' technology and a fairly high elasticity of substitution among the differentiated goods in consumer preferences. Both parameters turn out to be important factors in determining the magnitude of the exchange rate elasticity of exports.

Our paper provides an example of how theory combined with an appropriate use of microeconomic data can be helpful in solving macroeconomic empirical puzzles. In this paper, we have resolved the conflicting existing evidence between the firm and aggregate level data, regarding the so-called exchange rate disconnect puzzle from this perspective of empirical analysis.

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A Appendix

A Standard errors for the deep parameters

Let's denote the variance-covariance matrix $V(\boldsymbol{\varphi}_{\mathbf{s}})$ for the estimator $\boldsymbol{\varphi}_{\mathbf{s}} = (\varphi_1, \varphi_2, \varphi_3, \varphi_4)$ such that[8]

$$V(\boldsymbol{\varphi}_{\mathbf{s}}) = \begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{13} & \sigma_{14} \\ \sigma_{12} & \sigma_2^2 & \sigma_{23} & \sigma_{24} \\ \sigma_{13} & \sigma_{23} & \sigma_3^2 & \sigma_{34} \\ \sigma_{14} & \sigma_{24} & \sigma_{34} & \sigma_4^2 \end{bmatrix}.$$

[8] The variance and covariance matrix for each of the four estimators of firm level OLS estimation, firm level FE estimation, aggregate level estimation, and aggregate differenced estimation is available upon request.

The gradients of the parameter mappings h_θ to h_ρ in equations (28) to (32) are given by

$$\begin{aligned}
\nabla h_\theta(\boldsymbol{\varphi}_\mathbf{s})' &= \left[0, 0, \frac{1}{\varphi_4}, -\frac{\varphi_3}{\varphi_4^2}\right], \\
\nabla h_\alpha(\boldsymbol{\varphi}_\mathbf{s})' &= \left[\frac{-1}{1+\varphi_3-\varphi_4}, \frac{1}{1+\varphi_3-\varphi_4}, \frac{\varphi_1-\varphi_2}{(1+\varphi_3-\varphi_4)^2}, \frac{\varphi_2-\varphi_1}{(1+\varphi_3-\varphi_4)^2}\right], \\
\nabla h_\beta(\boldsymbol{\varphi}_\mathbf{s})' &= \left[0, \frac{-1}{1+\varphi_3-\varphi_4}, \frac{\varphi_2}{(1+\varphi_3-\varphi_4)^2}, \frac{-\varphi_2}{(1+\varphi_3-\varphi_4)^2}\right], \\
\nabla h_\gamma(\boldsymbol{\varphi}_\mathbf{s})' &= \left[\frac{1}{1+\varphi_3-\varphi_4}, 0, \frac{1-\varphi_1-\varphi_4}{(1+\varphi_3-\varphi_4)^2}, \frac{\varphi_1+\varphi_3}{(1+\varphi_3-\varphi_4)^2}\right], \\
\nabla h_\rho(\boldsymbol{\varphi}_\mathbf{s})' &= \left[0, 0, \frac{\varphi_4-1}{(1+\varphi_3-\varphi_4)^2}, \frac{\varphi_3}{(1+\varphi_3-\varphi_4)^2}\right].
\end{aligned}$$

Then, the standard error for each deep parameter x (for $x = \theta, \alpha, \beta, \gamma$ and ρ) is computed such that

$$\sigma_x = \left[\nabla h_x(\boldsymbol{\varphi}_\mathbf{s})' V(\boldsymbol{\varphi}_\mathbf{s}) \nabla h_x(\boldsymbol{\varphi}_\mathbf{s})\right]^{\frac{1}{2}},$$

where $\nabla h_x(\boldsymbol{\varphi}_\mathbf{s})$ is the gradient of the function h_x evaluated at the estimate of $\boldsymbol{\varphi}_\mathbf{s}$.

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Table 1 Disconnect puzzle with Macroeconomic Data

Using log level data[1]	Canada	France	Germany	Italy	UK	US	Japan	Pooled[3]
Exchange Rate[2]	-0.11 (0.23)	0.87 (1.01)	0.21 (0.77)	-1.72 (0.90)*	-0.12 (0.13)	0.12 (0.29)	0.08 (0.38)	-0.12 (0.20)
Constant	0.01 (0.002)**	0.00 (0.01)	0.00 (0.01)	0.00 (0.02)	0.01 (0.002)*	0.01 (0.01)	0.00 (0.01)	0.01 (0.00)**
R-squared	0.0013	0.0031	0.0004	0.0121	0.0043	0.0011	0.0002	0.0003

Using log level data[1]	Canada	France	Germany	Italy	UK	US	Japan	Pooled[3]
Exchange Rate[2]	-0.13 (0.22)	1.09 (0.86)	0.30 (0.61)	-0.56 (0.68)	0.02 (0.12)	0.51 (0.26)*	0.34 (0.29)	0.17 (0.16)
Lagged Exchange Rate	-0.04 (0.22)	-0.47 (0.86)	-0.75 (0.64)	-0.01 (0.68)	0.01 (0.13)	-0.63 (0.26)**	-0.35 (0.29)	-0.37 (0.16)**
Lagged Export	0.75 (0.04)***	0.37 (0.06)***	0.19 (0.07)***	-0.16 (0.08)**	0.68 (0.05)***	0.55 (0.05)***	0.08 (0.07)	0.34 (0.03)***
Constant	1.54 (0.32)***	-0.95 (-0.94)	4.93 (0.71)***	6.87 (0.98)***	0.88 (0.27)***	1.83 (0.31)***	3.46 (0.32)***	2.91 (0.18)***
R-squared	0.99	0.85	0.85	0.74	0.98	0.97	0.70	0.92

Using log differenced data	Canada	France	Germany	Italy	UK	US	Japan	Pooled[3]
Exchange Rate[2]	0.04 (0.20)	1.67 (1.04)	1.09 (0.75)	-2.30 (0.79)***	-0.09 (0.12)	0.07 (0.29)	0.21 (0.37)	-0.04 (0.19)
Lagged Exchange Rate	-0.50 (0.21)**	-0.97 (1.18)	-1.19 (0.68)*	0.72 (0.75)	-0.05 (0.12)	-0.14 (0.25)	-0.12 (0.39)	-0.13 (0.18)
Lagged Export	-0.32 (0.08)***	-0.31 (0.08)***	-0.41 (0.06)***	-0.47 (0.06)***	-0.55 (0.06)***	-0.32 (0.05)***	-0.49 (0.07)***	-0.42 (0.04)***
Constant	0.01 (0.002)***	0.00 (0.01)	0.01 (0.01)	0.00 (0.01)	0.01 (0.002)***	0.01 (0.00)	0.00 (0.01)	0.01 (0.002)***
R-squared	0.12	0.10	0.18	0.24	0.29	0.10	0.24	0.18

Note: Monthly IFS data for the period from 1982 to 1997 are used.
Heteroskedasticity robust standard errors are in parenthesis. * significant at 10%; ** at 5%; *** at 1%.
1. Linear trends are included.
2. Nominal effective exchange rates.
3. Using G-7 countries with the country dummy.

Table 2 Firm Level Estimation Results

	OLS	FE	RE
Exchange rate[1]	-0.41 (0.19)**	-0.77 (0.06)***	-0.75 (0.06)***
Interest rate[2]	-0.23 (0.14)	-0.35 (0.04)***	-0.34 (0.04)***
Foreign price[3]	0.52 (0.25)**	0.74 (0.07)***	0.73 (0.08)***
World real income	0.05 (0.55)	0.19 (0.16)	0.18 (0.16)
TFP	2.16 (2.17)	0.19 (0.65)	0.30 (0.64)
Industry productivity	0.21 (0.06)***	0.68 (0.04)***	0.66 (0.04)***
Firm export share[4]	1.07 (0.03)***	0.60 (0.03)***	0.63 (0.03)***
Constant	2.31 (7.95)	-1.77 (2.39)	-1.53 (2.40)
F-statistics[5]	175.68	373.76	2895.14
R^2: within between overall	0.17	0.45 0.11 0.13	0.45 0.12 0.15
Number of observation	5445	5445	5445

Note: All variables are in log terms.

Heteroskedasticity robust standard errors are in parenthesis. * significant at 10%; ** at 5%; *** at 1%.

1. Exchange rate is multiplied by the relative price of domestic and imported inputs.
2. The interest rate is divided by the wage index.
3. Export price is divided the imported input price.
4. The firm's export share is instrumented by the average export share within an industry excluding its own export share.
5. Wald chi square static is reported for the random effect model.

Table 3 Firm Level Estimation Results (OLS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Exchange rate[1]	-0.41 (0.19)**	0.42 (0.04)***	-0.16 (0.12)	-0.21 (0.14)	-0.14 (0.13)	-0.40 (0.16)**	-0.45 (0.18)**	-0.24 (0.18)	-0.33 (0.20)*	-0.05 (0.10)	0.20 (0.11)*	-0.15 (0.10)	0.09 (0.14)	-0.27 (0.19)	-0.09 (0.09)	-0.24 (0.20)	0.02 (0.07)
Interest rate[2]	-0.23 (0.14)		-0.25 (0.12)**		-0.14 (0.13)	-0.23 (0.12)*	-0.30 (0.12)**	-0.21 (0.14)	-0.34 (0.15)**		-0.29 (0.13)**	-0.15 (0.11)		-0.38 (0.13)***		-0.33 (0.15)**	
Foreign price[3]	0.52 (0.25)**		0.16 (0.20)	0.39 (0.24)*		0.52 (0.25)**	0.47 (0.25)*	0.48 (0.25)*	0.83 (0.27)***		0.30 (0.21)		0.40 (0.23)*	0.77 (0.27)***		0.81 (0.27)***	
World real income	0.05 (0.55)			-0.43 (0.45)	-0.03 (0.54)		0.53 (0.25)**	0.04 (0.55)	0.43 (0.58)	-0.34 (0.45)			0.62 (0.25)**	0.78 (0.26)***		0.42 (0.58)	
TFP	2.16 (2.17)			3.99 (1.86)**	1.20 (2.15)	2.33 (0.99)**		2.85 (2.16)	1.20 (2.31)	2.59 (1.69)		1.09 (0.78)			1.45 (0.72)**	1.59 (2.30)	
Industry productivity	0.21 (0.06)***		0.23 (0.06)***	0.20 (0.06)***	0.20 (0.06)***	0.21 (0.06)***	0.21 (0.06)***		0.11 (0.06)**	0.20 (0.06)***		0.20 (0.06)***			0.20 (0.06)***		0.23 (0.05)***
Firm export share[4]	1.07 (0.03)***		1.07 (0.03)***	1.07 (0.03)***	1.08 (0.03)***	1.07 (0.03)***	1.07 (0.03)***	1.07 (0.03)***		1.08 (0.03)***		1.08 (0.03)***			1.08 (0.03)***		1.08 (0.03)***
Constant	2.31 (7.95)	13.54 (0.21)***	10.19 (1.06)***	9.32 (6.55)	8.16 (7.22)	2.92 (3.29)	-2.62 (6.17)	3.09 (7.96)	-4.51 (8.44)	11.92 (6.28)*	11.68 (0.81)***	7.76 (2.24)***	-1.38 (6.07)	-7.68 (6.52)	7.46 (2.23)***	-4.04 (8.44)	11.74 (0.69)***
F-statistics	175.68	99.85	244.12	204.69	204.20	204.99	204.58	204.38	20.07	244.96	35.29	245.07	35.21	28.50	306.13	22.98	405.62
R^2	0.17	0.02	0.17	0.17	0.17	0.17	0.17	0.17	0.02	0.17	0.02	0.17	0.02	0.02	0.17	0.02	0.17
Number of observation	5445	5613	5445	5445	5445	5445	5445	5445	5613	5445	5613	5445	5613	5613	5445	5613	5445

Note: All variables are in log terms.

Heteroskedasticity robust standard errors are in parenthesis. * significant at 10%; ** at 5%; *** at 1%.

1. Exchange rate is multiplied by the relative price of domestic and imported inputs.
2. The interest rate is divided by the wage index.
3. Export price is divided the imported input price.
4. The firm's export share is instrumented by the average export share within an industry excluding its own export share.

Table 4 Firm Level Estimation Results (Fixed Effect Model)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Exchange rate[1]	-0.77	0.42	-0.68	-0.45	-0.36	-0.74	-0.78	-0.23	-1.10	-0.22	0.20	-0.35	0.10	-0.26	-0.26	-0.23	-0.26
	(0.06)***	(0.02)***	(0.05)***	(0.04)***	(0.04)***	(0.05)***	(0.06)***	(0.05)***	(0.06)***	(0.03)***	(0.03)***	(0.03)***	(0.04)***	(0.05)***	(0.03)***	(0.06)***	(0.03)***
Interest rate[2]	-0.35		-0.33		-0.21	-0.32	-0.35	-0.22	-0.46		-0.29	-0.20		-0.38		-0.32	
	(0.04)***		(0.03)***		(0.03)***	(0.03)***	(0.03)***	(0.04)***	(0.04)***		(0.03)***	(0.02)***		(0.03)***		(0.05)***	
Foreign price[3]	0.74		0.63	0.54		0.74	0.74	0.50	1.00		0.29		0.38	0.75		0.79	
	(0.07)***		(0.06)***	(0.07)***		(0.07)***	(0.08)***	(0.07)***	(0.08)***		(0.06)***		(0.07)***	(0.08)***		(0.08)***	
World real income	0.19			-0.53	0.06		0.23	0.04	0.41	-0.39			0.60	0.76		0.37	
	(0.16)			(0.12)***	(0.17)		(0.07)***	(0.17)	(0.17)**	(0.12)***			(0.07)***	(0.08)***		(0.20)*	
TFP	0.19			3.03	-0.87	0.87		2.80	-1.92	1.21		-0.66			-0.09	1.73	
	(0.65)			(0.49)***	(0.68)	(0.28)***		(0.66)***	(0.66)***	(0.48)**		(0.25)***			(0.24)	(0.78)**	
Industry productivity	0.68		0.72	0.63	0.62	0.68	0.68		1.12	0.60		0.62			0.59		0.58
	(0.04)***		(0.04)***	(0.04)***	(0.04)***	(0.04)***	(0.04)***		(0.04)***	(0.04)***		(0.04)***			(0.04)***		(0.04)***
Firm export share[4]	0.60		0.59	0.64	0.66	0.61	0.60	0.96		0.68		0.66			0.68		0.68
	(0.03)***		(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***		(0.04)***		(0.03)***			(0.03)***		(0.03)***
Constant	-1.77	13.54	2.98	8.79	6.88	0.68	-2.21	2.93	-7.07	12.37	11.70	7.61	-0.92	-7.14	7.21	-3.17	7.01
	(2.39)	(0.08)***	(0.59)***	(1.73)***	(2.12)***	(0.90)	(1.70)	(2.44)	(2.48)***	(1.65)***	(0.21)***	(0.57)***	(1.68)	(1.89)***	(0.57)***	(2.74)	(0.44)***
F-statistics	373.76	602.77	519.45	416.12	423.08	434.81	434.41	341.84	342.80	490.00	239.08	506.48	206.69	182.99	606.92	147.06	794.31
R^2: within	0.45	0.17	0.45	0.44	0.44	0.45	0.45	0.40	0.39	0.43	0.18	0.44	0.18	0.20	0.43	0.20	0.43
between	0.11	0.00	0.10	0.12	0.12	0.11	0.11	0.15	0.01	0.13	0.00	0.12	0.00	0.00	0.13	0.00	0.13
overall	0.14	0.02	0.13	0.15	0.15	0.14	0.14	0.17	0.01	0.15	0.02	0.15	0.02	0.02	0.15	0.02	0.15
Number of observation	5445	5613	5445	5445	5445	5445	5445	5445	5613	5445	5613	5445	5613	5613	5445	5613	5445

Note: All variables are in log terms.

Heteroskedasticity robust standard errors are in parenthesis. * significant at 10%; ** at 5%; *** at 1%.

1. Exchange rate is multiplied by the relative price of domestic and imported inputs.
2. The interest rate is divided by the wage index.
3. Export price is divided the imported input price.
4. The firm's export share is instrumented by the average export share within an industry excluding its own export share.

Table 5 Magnitudes of Estimation Bias

	Firm level Estimation (OLS)	Aggregate Estimation (using level data)	Firm level Estimation (FE)	Aggregate Estimation (using differenced data)
Exchange rate[1]	-0.41 (0.19)**	-0.45 (0.13)***	-0.77 (0.06)***	-0.65 (0.17)***
Interest rate[2]	-0.23 (0.14)	-0.23 (0.06)***	-0.35 (0.04)***	-0.17 (0.05)**
Foreign price[3]	0.52 (0.25)**	0.53 (0.15)***	0.74 (0.07)***	0.73 (0.14)***
World real income	0.05 (0.55)	0.08 (0.21)	0.19 (0.16)	-0.11 (0.17)
TFP	2.16 (2.17)	1.79 (1.17)	0.19 (0.65)	0.33 (1.17)
Industry productivity	0.21 (0.06)***	0.28 (0.15)*	0.68 (0.04)***	0.47 (0.25)*
Firm export share[4]	1.07 (0.03)***	1.09 (0.15)***	0.60 (0.03)***	0.93 (0.26)***
Constant	2.31 (7.95)	1.89 (3.11)	-1.77 (2.39)	0.04 (0.02)
F-statistics	175.68	405.85	373.76	76.06

Note: All variables are in log terms.

Heteroskedasticity robust standard errors are in parenthesis. * significant at 10%; ** at 5%; *** at 1%.

1. Exchange rate is multiplied by the relative price of domestic and imported inputs.
2. The interest rate is divided by the wage index.
3. Export price is divided the imported input price.
4. The firm's export share is instrumented by the average export share within an industry excluding its own export share.

Table 6 Preferences and Technology Parameters

Parameters	Firm level Estimation		Aggregate Estimation	
	OLS	FE	Level data	Differenced data
θ	10.40 (113.20)	3.89 (3.30)	6.63 (17.34)	-6.64 (10.07)
α	0.12 (0.11)	0.27 (0.04)	0.15 (0.06)	0.26 (0.06)
β	0.16 (0.12)	0.23 (0.04)	0.16 (0.05)	0.09 (0.03)
γ	0.07 (0.10)	-0.02 (0.03)	0.06 (0.06)	0.04 (0.04)
ρ	0.65 (0.17)	0.52 (0.05)	0.63 (0.08)	0.60 (0.06)

Note: Standard errors in parentheses are calculated by delta methods.