The Effect of Exchange Rate Movements on Heterogeneous Plants: A Quantile Regression Analysis

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Acknowledgements

Abstract

In this paper, we examine how the effect of movements in the real exchange rate on manufacturing plants depends on the plant's placement within the productivity distribution. Appreciations of the local currency expose domestic plants to more competition from abroad as export opportunities shrink and import competition intensifies. As a result, smaller less productive plants are forced from the market, which truncates the lower end of the productivity distribution. For surviving plants, appreciations can lead to a reduction in plant size, which, in the presence of scale economies, can lower productivity. We examine these mechanisms using quantile regression, which allows for the study of the conditional distribution of industry productivity. Using plant-level data that covers the entire Canadian manufacturing sector from 1984 to 1997, we find that many industries exhibit a downward sloping quantile regression curve, meaning that movements in the exchange rate do, indeed, have distributional effects on productivity.

JEL classification: D21, F1, L16, L60
Bank classification: Productivity; Exchange rates; Market structure and pricing

Résumé

Dans cette étude, nous examinons en quoi l'effet des variations du taux de change réel sur les usines manufacturières dépend de la position des usines à l'intérieur de la distribution de la productivité. Lorsque la monnaie nationale s'apprécie, les usines du pays se trouvent exposées à une concurrence accrue de l'étranger à mesure que les possibilités d'exportation diminuent et que la concurrence des importations s'intensifie. En conséquence, les petites usines peu productives sont chassées du marché, tronquant ainsi l'extrémité inférieure de la distribution de la productivité. Les mouvements d'appréciation de la monnaie peuvent amener les usines subsistantes à réduire leur taille, ce qui, en présence d'économies d'échelle, peut entraîner une baisse de la productivité. Nous examinons ces mécanismes en utilisant la régression quantile, qui permet d'étudier la distribution conditionnelle de la productivité des industries. En nous servant de données recueillies au niveau des usines dans la totalité du secteur manufacturier canadien de 1984 à 1997, nous constatons que de nombreuses industries présentent une courbe de régression quantile à pente descendante, ce qui signifie que les variations du taux de change ont bel et bien des effets distributifs sur la productivité.

Classification JEL : D21, F1, L16, L60
Classification de la Banque : Productivité; Taux de change; Structure de marché et fixation des prix

1 Introduction

In the last three decades, for many countries the most important determinants of international competition facing producers have been trade liberalization and large exchange rate fluctuations. Recent papers by Melitz (2003), Melitz and Ottaviano (2008) and Bernard, Eaton, Jensen and Kortum (2003) have proposed theoretical models in which trade liberalization affects the distribution of firms that populate the market, which, in turn, affects aggregate- and firm-level productivity. These models predict that trade liberalization will force less productive plants from the market, and shift market shares to more productive producers who take advantage of export market opportunities, resulting in an increase in aggregate productivity. These predictions have been confirmed by the empirical findings in Trefler (2004), Lileeva (2008), and Pavcnik (2002).

In contrast to the abundant theoretical and empirical work focusing on the impact of trade liberalization, the effects of exchange rate fluctuations have received little attention. Despite the frequent occurrence of large exchange rate movements, they are usually seen as transitory. However, if exchange rate movements are large and persistent, this can lead to persistent behaviour by plants (such as entry and exit), and the effects can be comparable to the effects of tariff changes. An appreciation of the home currency is equivalent to a reduction of import tariffs and an increase in the tariff in the export destination country and a depreciation is equivalent to the converse scenario. This equivalence has been noted by Feenstra (1989), who shows that the effects of exchange rate movements on domestic prices are comparable to the effects of tariff reductions.

Recent, emerging empirical evidence has confirmed that exchange rate movements can affect plant behaviour in ways comparable to changes in tariffs, and that these movements can have differing effects on plants within the same industry depending on their size, placement within the productivity distribution, and a number of other plant-specific factors. Real exchange rate appreciations give foreign producers a cost advantage in the domestic market, which raises the level of competition in the domestic market through increased import competition. This can force smaller, less productive plants from the market—truncating the lower end of the productivity distribution—which can lead to an increase in industry-level productivity. This is known as the selection effect. For surviving plants, the increased competition in the domestic market may lead to

a reduction in the scale of production, causing a reduction in plant productivity if the production technology exhibits increasing returns to scale. Moreover, appreciations make it more difficult for domestic plants to compete in export markets, which can reduce the scale of production for exporters, similarly affecting their level of productivity. Together, these last two effects are known as the scale effect. Empirical evidence of the selection effect of exchange rate movements has been identified by Baggs, Beaulieu and Fung (2009) and Tomlin (2010). Fung, Baggs and Beaulieu (2010) find evidence of the scale effect of exchange rate movements. These empirical findings suggest that appreciations of the exchange rate will lead to a squeezing of the productivity distribution, while depreciations will have the opposite effect. In support of this, below we present the stylized fact of a strong negative correlation between movements in the real exchange rate and the distribution of productivity within industries. The degree to which the exchange rate affects the distribution of productivity at the industry-level, the difference across industries, and the role of trade exposure are the unexplored empirical questions that we address in this paper.

More specifically, we consider the effect of movements in the real exchange rate on the conditional distribution of productivity within Canadian manufacturing industries. We make use of a unique plant-level data set covering the entire Canadian manufacturing sector from 1984 to 1997. During this period, the Canadian dollar fluctuated significantly against the currencies of its major trading partners, and in particular against the U.S. dollar, the currency of its most important trading partner. From 1984 to 1991, the Canadian dollar appreciated nearly 23 percent against the U.S. dollar, followed by a 19 percent depreciation from 1991 to 1997. As a small open economy where most of the industries are highly exposed to international trade, these large swings in the value of the Canadian dollar were associated with significant churning in the Canadian manufacturing sector in terms of plant turnover (entry and exit) and intra-industry resource reallocation, making a study of the effect of exchange rate movements on the distribution of productivity a relevant pursuit.[1] In addition, the advantage of focusing on the Canadian experience is that the Canadian economy is relatively stable as compared to developing countries—which are usually used to study the effects of large currency depreciations (devaluations)—making it possible to identify the effects

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[1] In the period we study, approximately 50 percent of manufacturing output in Canada is exported and 60 percent of the domestic market is attributable to imports.

of exchange rate movements.[2]

To provide a theoretical basis for the mechanisms we examine, we connect the models developed in Fung (2008) and Melitz and Ottaviano (2008) to establish a clear link between movements in the exchange rate and the decisions made by individual plants. The framework captures the effect of movements in the exchange rate on the market participation decisions of plants, as well as the effect on output, and thus labour productivity, of surviving plants.

In order to analyze empirically the distributional effects of exchange rate movements on productivity we use quantile regression. Whereas traditional least squares regression models examine the relationship between one or more covariates and the conditional mean of the dependent variable, quantile regression, as defined in Koenker and Bassett (1978), models the relationship between a set of independent variables and the conditional quantiles of the dependent variable. This approach enables the evaluation of the effect of movements in the real exchange rate at different points of the conditional productivity distribution, which gives insight into how heterogeneous plants react to large movements in the exchange rate.

In our empirical model, we specify and estimate the coefficients of a reduced-form model using quantile regression. The goal is to recover coefficient estimates for the effect of movements in the trade-weighted real exchange rate at different conditional quantiles of the productivity distribution, while controlling for a number of other industry- and plant-specific factors. We begin by estimating the model at the 10th, 25th, 50th, 75th and 90th conditional percentiles separately for 128 large manufacturing industries. We find that, on average, an appreciation of the real exchange rate has a positive effect on plant productivity at the lower end of the productivity distribution, reflecting the exit of smaller, less productive plants, and decreases productivity at the higher quantiles of the distribution, reflecting the scale effect on productivity. We explore this matter further by focusing our attention on individual industries.

The rest of the paper is organized as follows. In section 1.1, we review related literature. In section 2, we outline our theoretical motivation, which links the exchange rate to the decisions

[2]Forbes (2002) examines the effects of major devaluations on output and profit growth using data on commodity firms from 51 countries, nine of which experienced major currency devaluations (currency crises). However, the complexity of currency crises makes it difficult to disentangle the effects of exchange rate movements from the (much more complex) macro policy changes.

made by individual plants, and how this affects the distribution of industry productivity. Section 3 describes the data set we use, and in section 4, we briefly summarize the quantile regression framework, and then specify the empirical model used to analyze the relationship between the exchange rate and productivity. In section 5 we present our empirical findings. Finally, our conclusions are presented in section 6.

1.1 Related Literature

This paper builds on two groups of literature: (1) the impact of exchange rates on pricing (Campa and Goldberg, 2005), firm value (Dominguez and Tesar, 2006) and investment (Campa and Goldberg, 1999 and Harchaoui et al, 2005); and (2) the effect of trade liberalization on productivity. On the exchange rate side, Campbell and Lapham (2004) examine the adjustment of four retail trade industries to movements in the exchange rate and find that three of the four industries—gasoline service, food stores, and eating places—adjust mainly by changing the number of establishments. The remaining industry—drinking places—which has significant entry barriers, adjusts primarily through firm size (measured by average employment). As mentioned above, Baggs, Beaulieu and Fung (2009) examine the effects of real exchange rate movements on firm survival in the Canadian manufacturing sector. They find that a real appreciation of the Canadian currency reduces firms' probability of survival, but this effect is less pronounced for more productive firms. Tomlin (2010) confirms these results using a dynamic empirical structural model that captures the effect of movements in the exchange rate on manufacturing plant entry and exit decisions. Counterfactual analysis suggests that large currency depreciations can have a significant impact on industry productivity through entry and exit.

Fung, Baggs, and Beaulieu (2010) use plant-level data to analyze the impact of exchange rate movements on the scale of production and productivity of continuing Canadian manufacturing plants. Their findings suggest that, on average, a real appreciation (depreciation) of the Canadian currency reduces (increases) plant output, which in turn, leads to lower (higher) levels of labour productivity. The results indicate the existence of a scale effect, where exchange rate movements affect plant exploitation of economies of scale.[3] In addition, they find that the scale effect out-

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[3]The scale effect has been widely discussed in the context of trade liberalization. Before the implementation of

weighs any productivity effects that could result from exchange-rate-induced foreign input price changes. Ekholm, Moxnes and Ulltveit-Moe (2009) study the effect of real exchange rate shocks on productivity in the Norwegian manufacturing sector, and in the process, they control for firm-specific currency exposure. They find that exchange rate appreciations have a positive effect on the conditional mean of the total factor productivity distribution, reflecting firms' reaction to increased competition from foreign competitors.

On the trade liberalization side, Trefler (2004) examines the effect of the reduction of tariffs resulting from the 1989 Canada-U.S. Free Trade Agreement (FTA) on productivity levels in Canada. The study finds that trade liberalization had a positive effect on Canadian productivity in the long run. Lileeva (2008) explores how the FTA affected the exit probability of plants and the productivity distribution in Canadian manufacturing. Lileeva finds that mandated Canadian tariff cuts led to increases in industry-level productivity by eliminating smaller, less productive plants from the market, and to a shift of market shares to larger, more productive plants. Studies on trade liberalization and productivity have also been conducted for a number of other countries, including Chile (Pavcnik, 2002 and Tybout et al., 1991), Mexico (Tybout and Westbrook, 1995) and the U.S. (Bernard et al., 2003).

2   Theoretical Motivation

To motivate our empirical work below, we connect two theoretical models. The first is the model developed in Fung (2008), which is a modification of Krugman's (1979) model of international trade. Fung's model characterizes the decisions made by plants when facing a fluctuating exchange rate and labour is the only factor of production.[4] The partial equilibrium model—where wages and the exchange rate are assumed to be exogenous—predicts that an appreciation of the local currency increases the relative costs of domestic producers as compared to their foreign competitors, which intensifies competition and drives some plants out of the market. However, the model assumes that all plants are equally productive, so although it can predict entry and exit resulting from exchange

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the Canada-US Free Trade Agreement, Cox and Harris (1985) predicted a substantial scale efficiency gain from trade liberalization. However, Head and Ries (1999) and Trefler (2004) found little empirical evidence of a scale effect in the context of tariff concessions.

[4]The model assumes that each firm controls a single plant so that the firm and plant level decisions are the same.

rate movements, it does not address plant heterogeneity, and thus the selection effect of exchange rate fluctuations.

In order to incorporate plant heterogeneity, we turn to the model of international trade developed in Melitz and Ottaviano (2008). Here, trade liberalization increases the minimum cost (modeled as the inverse of productivity) needed to survive, which forces less productive (higher cost) firms from the market. This truncation of the productivity distribution results in higher average productivity. In contrast to the constant markup that results from the CES utility function that is commonly used in international trade models (see Krugman, 1980 and Melitz, 2003), Melitz and Ottaviano use a quasi-linear utility function, that allows for endogenously determined markups. As in Krugman (1979), trade liberalization causes a pro-competitive reduction in the markup of domestic firms.[5]

In Fung's model, a currency appreciation is comparable to a reduction in home tariffs and an increase in foreign trade barriers, and domestic producers either reduce their markup in order to survive or exit the market. In the Melitz and Ottaviano model with plant heterogeneity, less productive plants will not be able to lower their markup and remain profitable, and will therefore be driven out of the market. In the context of quantile analysis, as plants with lower productivity exit during appreciations, the productivity of plants in the lower quantiles of the productivity distribution should *increase*, as the plants making up these lower quantiles are now the plants with high enough productivity to survive.

In addition to this, when production technology exhibits increasing returns to scale, an appreciation of the home currency can affect within-plant productivity by influencing the scale of production. Fung's model predicts two opposing effects of currency appreciations: the cost disadvantage facing domestic producers results in a sales reduction;[6] however, the exit of less productive plants opens opportunities for surviving plants to increase market share. If the exit rate is low, or if foreign producers absorb the domestic market share left by the exiting plants, surviving domestic

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[5]Feenstra (2003) discusses Krugman's (1979) use of an additively separable utility function that results in pro-competitive reduction of markups and notes that this function is not homothetic. Bergin and Feenstra (2000, 2001) and Feenstra (2003) propose the use of a symmetric translog expenditure function that is homothetic and leads to pro-competitive reduction of markups. This function is used in Fung (2008).

[6]Fung's model uses sales as a proxy for plant scale.

plants will sell less.[7] Under increasing returns to scale, a reduction in plant scale of production leads to a reduction in productivity. This is an instance of the scale effect. In the context of quantile analysis, we use the well documented fact that surviving plants are usually larger and more productive than exiting plants, and predict that an appreciation of the home currency *reduces* the productivity of surviving plants and that this effect will be more pronounced in larger plants that are at the upper end of the productivity distribution. Moreover, larger plants are more likely to be exporters that face a reduction in both domestic and export market sales during currency appreciations, further affecting productivity at higher quantiles of the productivity distribution.

Taken together, Fung (2008) and Melitz and Ottaviano (2008) predict that currency fluctuations will have distributional effects on industry productivity. As a further illustration, suppose β_a is a measure of the effect of a currency appreciation on the ath quantile of the productivity distribution of a given industry, and β_b of the bth quantile, where $a < b$. These models predict that $\beta_a > \beta_b$, and in our empirical model below, our aim is to test this prediction.

3   Data

3.1   Plant-Level Data

We are grateful to have had access to Statistics Canada's Annual Survey of Manufacturers (ASM) data base—a plant-level data set covering the entire Canadian manufacturing sector from 1984 to 1997. The data is organized at the 4-digit 1980 Standard Industry Code (SIC) level and has annual information on plants in 232 industries. The ASM involves questionnaires that collect detailed information on a plant's inputs and outputs, and the data set is confidential, meaning all results must be screened before release. Of the 232 4-digit industries in the data set, we select industries that average at least 50 plants throughout the sample period, and who never have fewer than 40 plants operating in a given year. This ensures that the exercise of studying industry productivity quantiles is meaningful. Using these selection criteria, we are left with 128 industries, 58,775 plants and 392,600 plant-year observations. Table 1 provides summary statistics on the mean sales and

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[7]Conversely, if the exit rate is high or if foreign competitors do not absorb the domestic market shares, Fung shows that it is possible that the effect of increase market share for surviving plants can dominate, leading to an increase in sales and productivity.

employment per plant, the mean number of plants per industry, and the mean industry import and export intensities at two points in time.[8] The Canada-U.S. FTA came into effect in 1989, therefore we present summary statistics for 1988 (pre-FTA tariff cuts) and 1997 (post-FTA tariff cuts).

Table 1: Summary Statistics

	Year	Mean	S.D.
Across all plants			
Sales per Plant (000s)	1988	5,828	24,100
	1997	8,506	46,700
Plant Employment	1988	40	121
	1997	46	127
Across industries			
Plants per Industry	1988	244	331
	1997	209	289
Import Intensity	1988	0.29	0.25
	1997	0.45	0.43
Export Intensity	1988	0.20	0.22
	1997	0.40	0.32

Note: All dollar amounts are reported in 1994 dollars.

In our empirical analysis, we aim to identify the effect of movements in the exchange rate on different conditional quantiles of the productivity distribution for each industry. We define labour productivity as total sales (in 1994 dollars) divided by total employment (measured as the total number of employees—production and non-production—working at a plant in a given year). We use this measure of productivity because total sales and total employment are the most complete, consistent and reliable measures of output and labour, respectively, provided in the ASM data set.[9] The data set lacks a measure of capital, precluding our ability to generate estimates of total factor productivity.[10]

As a first look at the relationship between the exchange rate and the distribution of productiv-

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[8]Import intensity is defined as (imports - re-exports) / (total shipments + imports - exports - re-exports). Export intensity is defined as exports / total shipments. All imports and exports are final goods. The import and export intensity variables are provided in the ASM data set.

[9]The ASM does report hours worked by employees, but the data is incomplete. In conducting the survey, smaller plants are asked to fill out shorter questionnaires, and in many cases these plants do not report hours worked. There are particular years where no smaller plants report hours worked.

[10]Using this data set, Tomlin (2010) generates estimates of plant-level total factor productivity for the agricultural implements industry using scaled energy inputs (scaled by the industry level energy-capital ratio) as a proxy for capital. This methodology is too computationally demanding to be used to generate productivity estimates for plants in 128 industries, and plants in several industry do not even report energy inputs.

ity, in Figure 1 we plot the nominal Canada-U.S. exchange rate (U.S. dollars per Canadian dollar) against a measure of productivity dispersion—the mean standard deviation across the 128 industries. In order to calculate this cross-industry measure of dispersion, we begin by normalizing plant productivity by the mean productivity level of each industry in each year (in doing so, we remove any trend growth in productivity). That is, normalized productivity is $pr_{ikt}^{norm} = pr_{ikt}/\bar{pr}_{it}$ x 100, where pr_{ikt} is the productivity of plant k in industry i at time t, and $\bar{pr}_{it}$ is the mean productivity in that industry and year. We then calculate the standard deviation of productivity for each industry and year giving us 1792 (128 industries x 14 years) measures of productivity dispersion. We then define productivity dispersion in year t as the average standard deviation over the 128 industries (centered around the common mean of 100). Finally, we set the value of both the exchange rate and dispersion measure to 100 in 1984. Given the relationship between the exchange rate and the distribution of productivity outlined above, we would expect an increase in the value of the Canadian dollar to be associated with a decrease in the dispersion of productivity, and the opposite for a decrease in the exchange rate. This relationship in is strikingly clear in Figure 1, where the correlation between the nominal Canada-U.S. exchange rate and our measure of productivity dispersion is -0.49. Of course, there may be many other factors affecting the distribution of productivity, and below we aim to disentangle these many factors and identify the effect of movements in the exchange rate on the conditional distribution of industry productivity.

3.2   Industry-Specific Trade-Weighted Real Exchange Rate

The industries in our data set are heterogeneous in terms of the make up of their trading partners. In order to account for the importance of different trading partners, we use an industry-specific trade-weighted real exchange rate (hereafter *twrer*). The *twrer* is constructed using data from Canada's ten largest trading partners for each industry. The data on nominal exchange rates were collected from the IMF's International Financial Statistics, which are in the form of US dollars per national currency. The nominal exchange rates are then converted to units of currency of country j for one Canadian dollar: $E_{j/CAD} = E_{USD/CAD}/E_{USD/j}$. Each nominal exchange rate is then used to create a real exchange rate, which is defined as the nominal exchange rate multiplied by the ratio of the GDP deflator specific to that country (1995=100). Country-specific GDP deflators
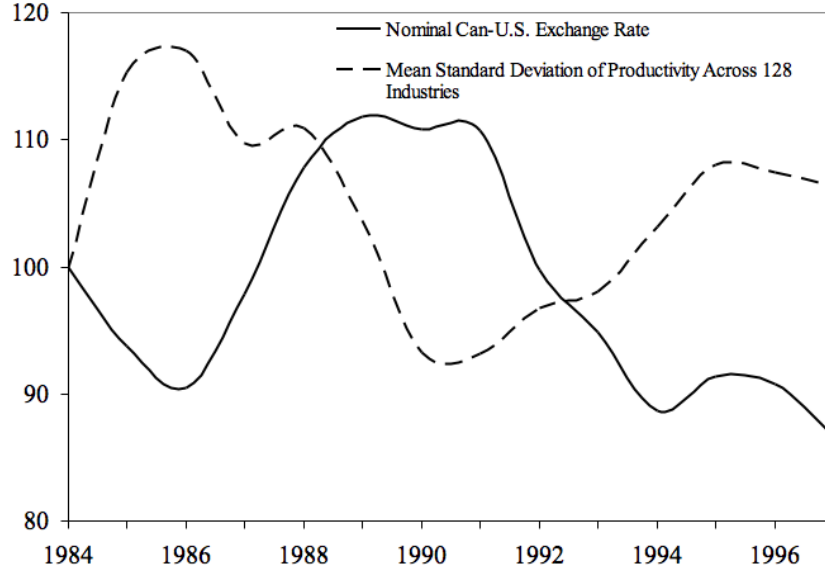
Figure 1: Productivity Dispersion and the Canada-U.S. Exchange Rate

were acquired from the World Development Indicators. Therefore we can define the real exchange rate for country j in year t as:

$$rer_{jt} = E_{j/CAD,t} \cdot \frac{P_{CA,t}}{P_{jt}}.$$

The real exchange rates are then normalized for each country using 1984 as the base year, giving us a relative real exchange rate:

$$rrer_{jt} = \frac{rer_{jt}}{rer_{j84}} \cdot 100. \tag{1}$$

Industry specific trade weights are constructed based on exports and imports from each 4-digit industry's ten largest trading partners. The weights are based on the sum of exports and imports from 1990 to 1994, with trade data collected from Industry Canada's Strategis data set. The trade weight for industry i, based on trade with its ten largest partners, can be expressed as:

$$TW_{ij} = \frac{(X + M)_{ij}}{\sum_{j \in top10_i}(X + M)_{ij}} \tag{2}$$

where $(X + M)$ is the sum of exports and imports from 1990 to 1994.[11] This allows for the shares and trade partners to vary by industry, but not by year. Weighting exchange rate fluctuations by

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[11]Overall, the top 10 trading partners make up 95 percent of the volume of trade.
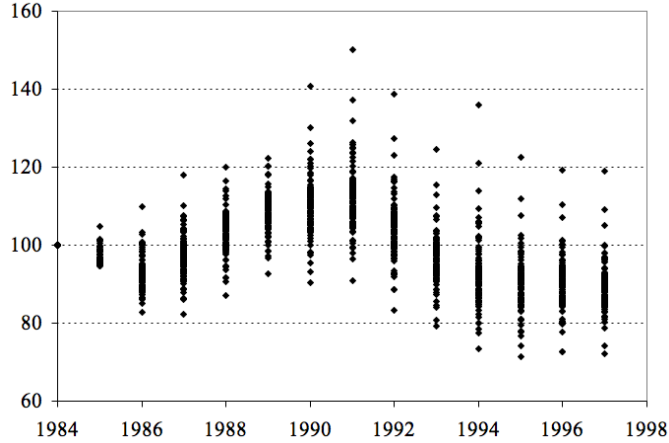
Figure 2: Trade Weighted Real Exchange Rate for 128 Industries

the industry's trade exposure allows for considerable heterogeneity in trade partners by industry. Combining the normalized real exchange rate from (1) with the trade weights produces the *twrer* used in our analysis below, which varies by industry and year:

$$twrer_{it} = \sum_{j \in top10_i} TW_{ij} rrer_{jt}. \tag{3}$$

The *twrer* are constructed for each of the 128 industries in the data set. Figure 2 presents the *twrer* for all of the 128 industries.[12]

4 Empirical Model

In this section, we begin by providing a brief introduction to the concept of quantile regression as outlined in Koenker and Bassett (1978), along with an explanation of how to interpret the results. Following this, we outline our empirical model and estimation strategy.

4.1 Quantile Regression

While classical linear regression methods based on minimizing the sum of squared residuals allows researchers to estimate models for conditional mean functions, quantile regression methods offer a

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[12]The *twrer* data used here is from Fung, Baggs and Beaulieu (2010). For a detailed description, see Fung, Baggs and Beaulieu (2010) and Baggs, Beaulieu and Fung (2009).

mechanism for estimating models for the full range of conditional quantile functions. As a result, quantile regression is capable of providing a more complete statistical analysis of the stochastic relationships among random variables.

Quantile regression can be defined as:

$$y_{kt} = x'_{kt}\beta_\theta + \epsilon_{\theta kt} \quad \text{with} \quad \text{Quant}_\theta(y_{kt}|x_{kt}) = x'_{kt}\beta_\theta \tag{4}$$

where y_{kt} is the dependent variable for plant k at time t, x_{kt} is a vector of regressors, β_θ is the vector of parameters to be estimated, and $\epsilon_{\theta kt}$ are residuals. Let $Q_\theta(y_{kt}|x_{kt})$ denote the θth regression quantile that solves the following problem:

$$\min_\beta \frac{1}{n} \left\{ \sum_{k,t:y_{kt} \geq x'_{kt}\beta} \theta|y_{kt} - x'_{kt}\beta| + \sum_{k,t:y_{kt} < x'_{kt}\beta} (1-\theta)|y_{kt} - x'_{kt}\beta| \right\} = \min_\beta \frac{1}{n} \sum_{i=1}^{n} \rho_\theta \epsilon_{\theta kt} \tag{5}$$

where $\rho_\theta(\cdot)$ is defined as:

$$\rho_\theta(\epsilon_{\theta kt}) = \begin{cases} \theta \epsilon_{\theta kt} & \text{if } \epsilon_{\theta kt} \geq 0 \\ (\theta - 1)\epsilon_{\theta kt} & \text{if } \epsilon_{\theta kt} < 0 \end{cases} \tag{6}$$

Equation (5) is then solved by linear programming methods. As Buchinsky (1998) points out, as one increases θ continuously from 0 to 1, one traces the entire conditional distribution of y, conditional on x. The quantile regression coefficients can be interpreted as the partial derivative of the conditional quantile of the dependent variable y with respect to a particular regressor, i.e. $\partial Q_\theta(y|x)/\partial x$. In other words, the coefficients represent the marginal change in y at the θth conditional quantile due to a marginal change in the independent variable.

Quantile regression avoids the restrictive assumption that the error terms are identically distributed at all points of the conditional distribution of the dependent variable, implicitly acknowledging plant heterogeneity and the possibility that the estimated slope parameters vary at different quantiles of the response variable distribution. An alternative to quantile regression would be to divide the dependent variable into subsets based on its unconditional distribution and then do least squares fitting of each subset, but as pointed out in Koenker and Hallock (2001), such a strategy would be problematic for all the reasons pointed out in Heckman (1979). Therefore, quantile re-

gression is the best way to model the conditional distribution of productivity, conditional of the exchange rate.[13]

4.2 Econometric Framework and Estimation Strategy

The goal of this study is to recover coefficient estimates at various quantiles of the conditional distribution of productivity, conditional on the trade-weighted real exchange rate and other relevant variables. The basic regression model we look to estimate is:

$$pr_{ikt} = \beta_i \ln twrer_{it} + \theta_i^{CA} \tau_{it}^{CA} + \theta_i^{US} \tau_{it}^{US} + \epsilon_{ikt} \tag{7}$$

where pr_{ikt} is the logarithm of labour productivity for plant k, in industry i, at time t, $\ln twrer_{it}$ is the logarithm of the trade-weighted real exchange rate, and τ_{it}^{CA} and τ_{it}^{US} are the bilateral tariff rates on products brought into Canada and the U.S., respectively.[14] Because our data sample covers the period before and after the 1989 Canada-U.S. FTA, it is important that we control for possible correlation between movements in the *twrer* and the mandated tariff reductions in the post-1988 period.

In addition to controlling for mandated tariff reductions, it is important that we control for a number of other industry-specific factors that may bias our estimates of β_i. Industries may vary to the extent to which they are exposed to import and export competition, which can affect who—within an industry—is influenced most by movements in the exchange rate. We therefore use 4-digit industry-level import and export intensities to control for the disparate effects that movements in the exchange rate may have on different plants within an industry, depending on how exposed they are to trade. These import and export intensities are available in the ASM data set and are defined in Section 3.1.

In order to control for foreign business cycle fluctuations, we use a measure of U.S. shipments for the comparable industry at the 3-digit SIC level. For most industries, the U.S. is by far the most

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[13]Consider an industry with 100 plants in operation each period. If we were to separate the plants into deciles (ten plants in each group) and then run OLS for each group, the results would not only be sensitive to outliers at the tails of the overall distribution of plants, but outliers within each decile group. Therefore, the method used to separate plants into different groups can have an impact on the parameter estimates, which is undesirable.

[14]We are thankful to Alla Lileeva for providing us with the tariff data, which was used previously in Trefler (2004) and Lileeva (2008).

important trading partner, making U.S. industry-level shipments a reasonable approximation of foreign demand fluctuations. The data on U.S. shipments are from the NBER-CES Manufacturing Industry database by Bartelsman and Gray (1996). Moreover, the Canadian and U.S. business cycles are highly correlated, and so U.S. shipments are not only a good measure of foreign demand fluctuations, but overall business cycle fluctuations. However, to the extent that 4-digit industry-level demand deviates from the more aggregate demand fluctuations, we include Canadian 4-digit industry-level output (shipments) as a control variable to pick up information that is not captured in the 3-digit U.S. shipments.

For the final industry-level control, we use the Herfindahl-Hirschman Index (HHI) as a measure of domestic market concentration. The HHI measures the degree to which domestic industries are dominated by a small number of plants.[15] Industry concentration can change over time in reaction to currency fluctuations and the FTA mandated tariff cuts, which may affect plant decisions. Controlling for industry concentration addresses this possible correlation.

Note that all these control variables are at the industry level, which means they vary across time, but not individual plants. In order to control for plant-level heterogeneity, we construct two dummy variables that are relevant to our study. The first is a dummy for whether a plant is owned by a foreign firm or not. Plants that are foreign controlled may react differently to exchange rate fluctuations than plants that are owned by Canadian firms—particularly when it comes to decisions about entry and exit. That is, following an appreciation of the local currency, plants that are foreign owned may be more likely to shut down or voluntarily reduce the scale of production as they shift resources to plants in countries that have a cost advantage following the appreciation. The second plant-level control is a dummy for whether a plant is part of a multi-plant enterprise. Low productivity plants may be more likely to survive appreciations if they are part of a larger enterprise. Including a dummy for multi-plant enterprises controls for the effect this might have on plants' exit and production decisions.[16]

Finally, we also want to control for movements in aggregate productivity. Shocks to economy-

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[15]Note that we construct the HHI at the plant level, but do not account for multi-plant firms. The data are not available to calculate an industry concentration index at the firm level.

[16]Ideally we would like to include a dummy for whether a plant is exporting or not. Unfortunately, we only have complete export data for two years, which does not allow us to create a reliable measure of export status.

wide productivity are likely to affect plant- and industry-level productivity, and are also likely to be correlated with the exchange rate. If this is not controlled for, our estimates will suffer an omitted variable bias. Therefore, we include business sector total factor productivity (TFP) as a measure of aggregate productivity in our industry-level controls.

Including all of these control variables in (7) gives us the following regression model:

$$pr_{ikt} = \beta_i \text{ln} twrer_{it} + \alpha_i^{CA} \tau_{it}^{CA} + \alpha_i^{US} \tau_{it}^{US} + \gamma_i \text{ln} TFP_t + \lambda_i x_{it} + \eta_i y_{ikt} + \delta_t + \epsilon_{ikt} \tag{8}$$

where x_{it} is the vector of industry-level controls (including import and export intensities, as well as the logarithm of U.S. shipments, domestic industry shipments and the HHI), y_{ikt} is the vector of plant-level dummies, and $\text{ln} TFP_t$ is the logarithm of business sector total factor productivity. We also control for other common macroeconomic shocks by including a time trend δ_t. Equation (8) is our final estimation equation and our aim is to recover estimates of the parameter vector $\{\beta_i, \alpha_i^{CA}, \alpha_i^{US}, \gamma_i, \lambda_i, \eta_i\}$ for each industry. More specifically, our interest is the coefficient estimates of β_i at different conditional quantiles of the productivity distribution.

5 Results

5.1 Quantile Regression Results

We begin by using quantile regression to estimate the coefficients in (8) separately for each of the 128 industries in the data set. We estimate the model at each decile of the conditional productivity distribution (i.e. the 10th, 20th,..., 90th percentiles) and present the average estimates of β across all industries graphically in Figure 3. That is, the values of β reported on the y-axis are calculated as $\hat{\beta} = \sum_i \hat{\beta}_i$.[17] The x-axis reports the quantile at which regression the model was estimated. It is clear that the average OLS estimate of β (the horizontal dash and dot line) does not tell the whole story. The downward sloping quantile regression curve shows that the value of the estimated coefficient on the *twrer* varies over the conditional productivity distribution. When the quantile regression

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[17]Because we are looking at the conditional distribution of within-industry productivity, conditional on the real exchange rate, we must retrieve estimates of β for each industry and then average over all industries. Standard errors could be retrieved using the bootstrap method, but this process would be computationally burdensome. Therefore, we do not report standard errors.

Table 2: Exchange Rate Coefficient Estimates for 128 Industries

1980 SIC	Regression Quantile					1980 SIC	Regression Quantile					1980 SIC	Regression Quantile				
	0.1	0.25	0.5	0.75	0.9		0.1	0.25	0.5	0.75	0.9		0.1	0.25	0.5	0.75	0.9
1011	1.01	0.19	-0.38	0.08	0.20	2561	0.34	**1.43**	0.79	0.66	-0.40	3241	14.41	**10.50**	**15.09**	-9.44	-10.81
1012	0.67	0.42	-0.07	0.38	0.27	2599	1.06	0.57	0.60	1.04	-0.97	3242	1.19	**5.25**	**3.57**	-0.23	1.77
1021	-0.48	-0.09	0.39	-0.03	**1.12**	2611	0.35	**0.52**	**0.56**	**-1.18**	**-1.72**	3243	-5.57	-3.02	-2.68	-2.33	0.74
1031	0.54	0.39	0.59	0.49	0.19	2612	0.95	0.05	0.02	-0.23	-1.22	3253	0.12	-0.68	0.27	-0.16	1.01
1041	0.02	-0.02	0.86	1.28	0.60	2619	-2.58	-1.30	**-2.92**	**-5.28**	-2.18	3256	1.68	0.68	0.51	0.09	0.61
1049	**2.28**	0.52	0.25	1.30	0.36	2641	-1.94	-1.42	3.69	0.55	6.67	3259	**-6.52**	**-4.62**	**-4.71**	-4.14	-1.94
1053	1.80	**0.75**	**-1.02**	**-1.39**	**-1.60**	2649	-0.43	-1.18	-0.59	-3.04	-3.10	3271	2.24	-0.14	-0.40	0.18	-0.42
1072	-0.43	-0.61	-0.49	-0.90	-1.42	2691	1.09	0.37	-0.16	0.98	-0.55	3281	-2.69	-0.88	**-2.11**	**-1.82**	-2.20
1083	-1.07	-0.07	0.55	0.42	-1.41	2692	**-2.66**	**-3.70**	**-4.19**	-1.78	-2.01	3311	0.83	0.59	-0.86	0.07	1.12
1111	0.02	0.67	0.95	1.15	1.52	2699	0.35	0.09	**-0.52**	**-1.82**	**-2.18**	3331	-1.07	-0.62	**-1.57**	**-2.57**	-1.97
1599	0.33	0.21	0.52	0.13	-1.55	2731	0.52	2.16	0.04	-1.41	-1.37	3332	2.34	1.76	-0.09	0.01	0.02
1611	-2.11	-0.71	-0.81	**-1.68**	-0.74	2732	0.63	**-1.29**	-1.36	-0.67	-1.20	3351	-5.65	-3.09	-2.96	-1.15	-7.47
1621	0.72	0.41	0.70	0.36	2.88	2791	2.23	1.21	-0.13	-0.37	0.03	3352	0.97	-0.12	-0.21	-0.70	-1.79
1631	2.51	-0.72	0.27	0.93	0.53	2792	-0.71	0.23	0.89	-0.20	**2.56**	3359	0.96	0.09	-0.31	-0.39	-0.13
1691	**1.58**	-0.52	-0.57	**-1.46**	**-2.46**	2799	1.36	-0.53	-0.12	-1.40	0.01	3361	**1.09**	-0.08	**-0.63**	**-1.56**	-1.08
1699	-0.26	0.19	**1.26**	0.89	**-1.68**	2811	1.21	-1.16	-0.78	-0.82	-0.47	3371	0.86	0.06	-1.23	-1.45	-2.39
1712	**1.67**	**1.33**	1.19	0.08	0.77	2819	**0.72**	-0.19	**-0.87**	**-0.98**	**-1.00**	3372	**-3.65**	-1.95	**-1.20**	0.17	0.88
1713	-0.39	-0.24	-0.48	-0.74	1.77	2821	1.04	0.09	-0.18	-0.66	-0.05	3379	-0.72	-1.01	**-1.57**	-1.88	**-2.35**
1719	-1.73	-0.79	0.00	0.67	0.17	2921	-0.64	-0.13	0.41	0.24	0.01	3399	0.14	0.28	0.22	-0.48	-1.51
1829	-1.87	-0.66	-1.23	2.44	-3.96	2941	0.32	**1.39**	**1.21**	0.61	0.38	3542	**2.03**	0.16	**-1.56**	-0.75	-0.56
1831	0.64	-1.09	-2.58	-0.77	-0.19	2961	2.07	**2.94**	1.04	0.71	-1.28	3549	**1.82**	0.40	1.11	0.59	-0.27
1931	**1.29**	**1.20**	0.68	0.42	-0.04	2999	-2.67	0.32	0.21	-0.94	-0.08	3562	0.94	**1.22**	0.27	-0.73	-0.97
1993	0.27	-0.48	-0.41	-0.43	-0.74	3021	0.84	0.60	0.66	-0.01	-0.88	3599	-2.10	-1.44	**-2.56**	0.13	-1.16
2431	1.72	1.44	1.60	0.01	-1.59	3029	0.53	0.05	-0.35	0.65	-0.02	3699	**11.23**	3.35	**-6.05**	-3.55	-8.90
2432	**2.31**	0.27	0.49	1.93	-3.54	3031	**1.70**	0.64	0.13	-0.55	-0.20	3711	-0.91	0.79	0.12	-1.90	-0.62
2433	0.16	0.65	1.14	-0.38	-2.89	3039	1.33	0.34	**-1.29**	**-4.42**	**-5.69**	3712	-1.79	-2.07	-0.04	0.12	-3.80
2434	0.72	0.11	0.27	0.44	1.61	3042	0.31	1.59	1.02	0.75	1.02	3722	-0.25	-0.61	-0.65	-0.37	0.98
2441	-0.85	-0.09	1.16	0.52	1.41	3049	0.07	0.05	**-0.42**	-0.19	-0.80	3731	-0.35	-1.04	-1.18	-0.41	0.08
2442	-1.30	-1.07	1.48	-0.35	-2.08	3053	-0.07	**-1.21**	**-1.46**	-1.68	**-2.45**	3741	0.92	0.75	-0.32	-0.36	-1.17
2443	0.67	1.28	-0.47	2.08	0.99	3061	-0.96	-0.87	**-1.46**	**-2.49**	**-3.88**	3751	0.44	-0.72	-0.86	0.26	-1.04
2451	1.43	-0.08	-0.68	0.31	-0.78	3062	-0.07	**-0.62**	**-0.46**	-0.61	-0.54	3761	1.77	0.84	-0.77	-1.12	-0.92
2491	-0.08	0.40	0.21	1.02	-1.10	3063	-0.27	**-1.80**	**-2.34**	**-2.83**	-4.50	3771	0.45	0.50	-1.63	-1.96	-1.47
2492	-0.44	-0.28	0.67	-0.46	1.38	3069	-0.02	-0.28	-0.45	**-1.67**	**-3.38**	3791	4.22	2.43	-3.89	-1.53	-6.54
2494	0.65	**1.40**	-0.29	0.19	-0.66	3071	1.47	-0.11	-0.48	-0.42	0.11	3799	1.33	**1.20**	0.60	-0.86	-0.71
2495	2.17	-0.09	-0.56	-0.13	1.19	3099	-1.99	-0.36	**0.92**	-0.27	-0.95	3911	0.67	0.68	0.32	-0.82	-1.78
2499	0.71	0.80	0.30	-0.01	0.00	3111	-0.15	-0.32	-0.46	**-1.05**	**-2.34**	3912	1.30	0.66	0.70	-1.56	0.67
2511	-0.27	-0.73	0.93	1.16	3.97	3121	-1.11	-0.17	0.01	0.80	0.62	3914	**-1.03**	**-0.88**	-0.03	0.46	-0.56
2512	-0.01	0.22	-0.43	-0.05	0.31	3191	1.57	**-1.71**	-1.19	-1.07	0.27	3931	2.53	1.49	0.79	-2.34	-3.45
2521	-2.53	-1.14	-1.06	-2.50	-3.57	3192	**2.17**	**1.10**	0.37	-0.24	0.50	3932	-3.30	-0.38	1.49	0.79	0.23
2541	0.51	0.35	0.13	-0.49	-0.53	3193	-0.35	-1.40	-0.76	-0.52	1.65	3971	2.23	**0.81**	-0.66	**-2.25**	**-4.63**
2542	0.24	0.00	-0.06	-0.04	0.07	3194	0.29	**-1.30**	**-1.65**	-1.47	-2.25	3994	-3.96	**-4.68**	**-3.39**	-1.97	-0.51
2543	**3.18**	**0.92**	-1.00	-0.61	0.09	3199	**2.48**	**1.58**	**1.61**	**1.47**	0.30	3999	-0.03	**0.57**	**0.52**	-0.34	**-1.02**
2549	**2.15**	**-1.04**	-0.83	-1.24	-0.53	3211	0.86	-0.23	**-1.05**	-1.07	**-2.85**	Mean	0.38	0.05	-0.21	-0.60	-0.89

Note: Emboldened coefficient estimate indicates significance at the 10% level. Standard errors are calculated using the bootstrap method with between-quantiles blocks.

solution is evaluated at the median, there is little difference from the conditional mean (least squares) estimate—a one percent appreciation of the *twrer* is associated with a reduction of roughly 0.25 percent in mean and median plant productivity. However, at the lower end of the conditional productivity distribution, we see that a one percent increase in the *twrer* is associated with a 0.4 percent increase in productivity at the 10th percentile, while at the upper end of the conditional distribution, it leads to a nearly 0.9 percent decrease in productivity at the 90th percentile. These results are in line with the predictions of the theoretical model outlined in Section 2.
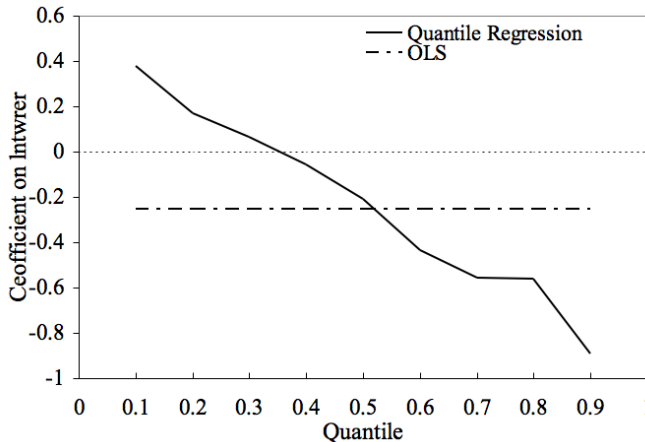

Figure 3: Average (Across Industries) Parameter Estimates on the Exchange Rate

This cursory analysis of cross-industry parameter estimates provides some evidence that movements in the exchange rate affect plants differently depending on where they fall in the industry productivity distribution. In Table 2, we present the coefficient estimates on the *twrer* for each of the 128 industries at the 10th, 25th, 50th, 75th and 90th conditional percentiles.[18] To give an idea of the number of industries exhibiting a downward sloping quantile regression curve, we count the number of industries where $\hat{\beta}_{10} > \hat{\beta}_{90}$ and either $\hat{\beta}_{10}$ or $\hat{\beta}_{90}$ are significant at the 10% level (where $\hat{\beta}_{10}$ is the estimate on the *twrer* at the 10th conditional percentile of the productivity distribution). We find that 29 industries meet this condition, while for comparison purposes, six industries exhibit upward sloping quantile regression curves based on the converse definition (i.e. $\hat{\beta}_{10} < \hat{\beta}_{90}$). Table

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[18]We have tested the robustness of our coefficient estimates on the *twrer* by estimating different specifications of (8) and find little difference in the coefficient estimates. More importantly, we find that the downward sloping quantile regression curves exist across the different specifications. Coefficient estimates under these different specifications are available upon request.

3 presents further counts at different quantiles of the conditional productivity distribution. We see that 20 to 25 percent of industries exhibit clear, downward sloping quantile regression curves based on the slope definitions provided herein (again, we provide counts for the number of industries exhibiting upward sloping quantile regression curves for comparison purposes only).

Table 3: A Comparison of Coefficient Estimates

Slope<0	Count	Slope>0	Count
$\hat{\beta}_{10} > \hat{\beta}_{75}$	26	$\hat{\beta}_{10} < \hat{\beta}_{75}$	6
$\hat{\beta}_{10} > \hat{\beta}_{90}$	29	$\hat{\beta}_{10} < \hat{\beta}_{90}$	6
$\hat{\beta}_{25} > \hat{\beta}_{90}$	30	$\hat{\beta}_{25} < \hat{\beta}_{90}$	10
$\hat{\beta}_{25} > \hat{\beta}_{75}$	33	$\hat{\beta}_{25} < \hat{\beta}_{75}$	7

Note: A count indicates that $\hat{\beta}_a > \hat{\beta}_b$ and either $\hat{\beta}_a$ or $\hat{\beta}_b$ is significant at the 10% pevel, or both.

5.2 Selected Industry Results

With this, we now turn our attention to eight industries that exhibit downward sloping quantile regression curves. The names of the eight industries and some summary statistics are presented in Table 4. These industries are not intended to be representative of all industries—rather, they were selected for illustrative purposes, to examine, in detail, how movements in the exchange rate can affect the distribution of within-industry productivity.

The trade-weighted real exchange rate for these industries is presented in Figure 4. In general, these eight industries experienced similar movements in the trade-weighted real exchange rate. For each industry, we estimate (8) at each decile of the conditional productivity distribution, and present the coefficient estimates on the *twrer* graphically in Figure 5. In this figure, where again the y-axis reports the coefficient estimate and the x-axis the quantile of the productivity distribution at which the model was estimated, we contrast the quantile regression results against OLS estimates (the horizontal dash and dot line). It is clear that for these industries, the OLS estimates do not capture the distributional effects of exchange rate movements on productivity. The quantile regression curves show that the value of the estimated coefficient on the *twrer* varies over the conditional productivity distribution, and more specifically, it varies in a way that is consistent

Table 4: Summary Statistics for Eight Industries

| SIC		Mean	S.D.	SIC		Mean	S.D.
1053	*Feed Industry*			1691	*Plastic Bag Industry*		
	Plants per Year	504	31.8		Plants per Year	82	17.5
	Import Intensity	0.07	0.03		Import Intensity	0.40	0.24
	Export Intensity	0.08	0.02		Export Intensity	0.29	0.15
	Plant Employment	18	25.2		Plant Employment	50	54.8
	Plants Sales (000s)	6,689	10,100		Plants Sales (000s)	7,326	10,100
1931	*Canvas Products Industry*			2611	*Wooden Household Furniture*		
	Plants per Year	162	12.7		Plants per Year	617	161.7
	Import Intensity	0.16	0.03		Import Intensity	0.24	0.06
	Export Intensity	0.07	0.04		Export Intensity	0.27	0.18
	Plant Employment	14	20.4		Plant Employment	23	51.0
	Plants Sales (000s)	1,008	1,901		Plants Sales (000s)	1,702	4,444
3053	*Industrial Fasteners*			3061	*Basic Hardware*		
	Plants per Year	92	14.2		Plants per Year	69	7.4
	Import Intensity	0.61	0.10		Import Intensity	0.55	0.10
	Export Intensity	0.42	0.10		Export Intensity	0.36	0.15
	Plant Employment	49	78.3		Plant Employment	60	91.2
	Plants Sales (000s)	6,427	18,100		Plants Sales (000s)	7,224	11,900
3111	*Agricultural Implements*			3971	*Sign and Sign Display*		
	Plants per Year	228	20.8		Plants per Year	585	47.7
	Import Intensity	0.70	0.05		Import Intensity	0.05	0.01
	Export Intensity	0.51	0.06		Export Intensity	0.12	0.06
	Plant Employment	42	118.3		Plant Employment	15	25.1
	Plants Sales (000s)	5,626	28,400		Plants Sales (000s)	1,124	2,355
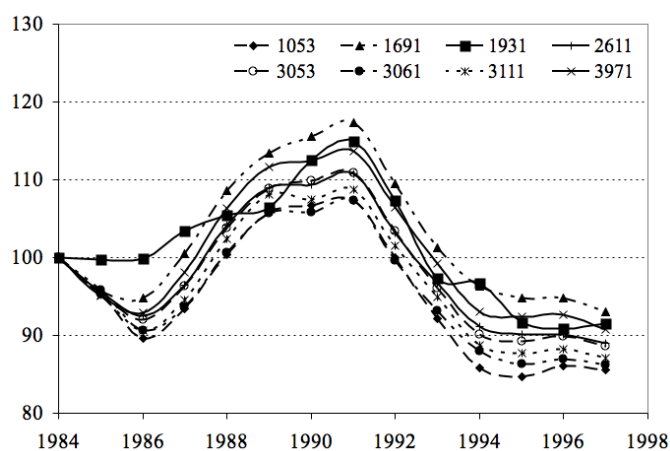
Figure 4: Trade-Weighted Real Exchange Rate for Eight Industries

Note: The eight industries are: the feed industry (SIC 1053); the plastic bag industry (SIC 1691); the canvas products industry (SIC 1931); the wooden household furniture industry (SIC 2611); the industrial fastener industry (SIC 3053); the basic hardware industry (SIC 3061); the agricultural implements industry (SIC 3111); and, the sign and sign display industry (SIC 3971).

(a) Feed Industry (1053)

(b) Plastic Bag Industry (1691)

(c) Canvas Products Industry (1931)

(d) Wooden Household Furniture (2611)

(e) Industrial Fastener Industry (3053)

(f) Basic Hardware Industry (3061)

(g) Agricultural Implements (3111)
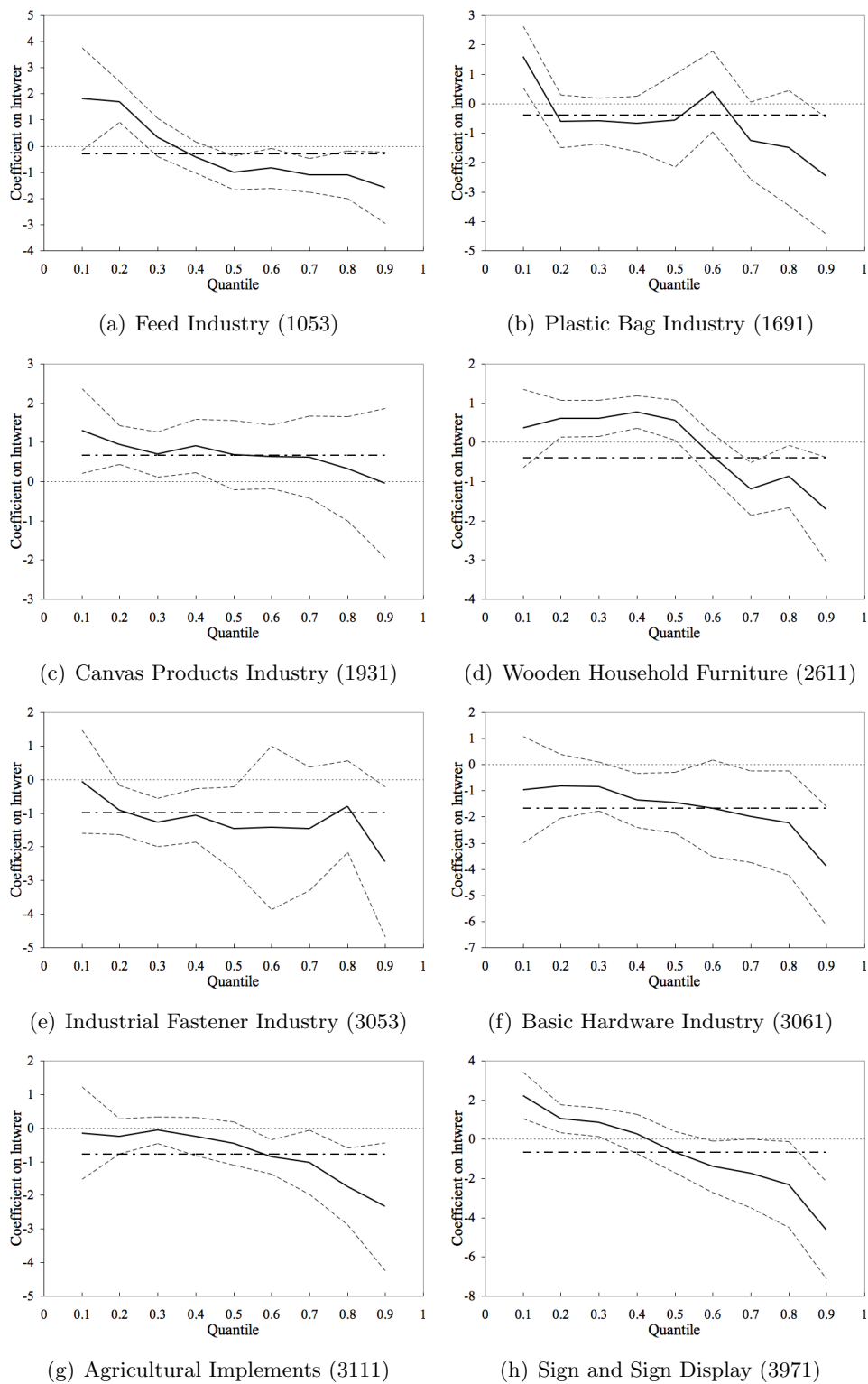
(h) Sign and Sign Display (3971)

Figure 5: OLS and Quantile Regression Estimates on the Exchange Rate

Note: The solid line is the quantile regression curve and the dotted lines represent the 90% confidence bands. The dash and dot line is the OLS estimate. For the quantile regression estimates, the standard errors are calculated using the bootstrap method with between-quantile blocks.

with our hypotheses about industry dynamics.

In many industries, the lower quantile regression coefficients are greater than zero, while the coefficient estimates at the upper quantiles are negative (SIC 1053, 1691, 2611 and 3971). For these industries, it is likely the case that the effect of plant exit dominates the scale effect at the lower end of the productivity distribution, resulting in an increase in productivity when there is an appreciation of the *twrer*. At the upper end of the productivity distribution, the scale effect dominates, and an appreciation of the *twrer* decreases productivity.

For SIC 3053, 3061 and 3111, the coefficient estimates are all negative. In these industries, it is likely that the scale effect dominates the effect of plant exit at the lower end of the productivity distribution, but that plant exit still has an effect on productivity. That is, although an appreciation of the exchange rate may lead to the exit of less productive plants, continuing plants at the lower end of the productivity distribution may face a decrease in sales and thus measured productivity as a result of the appreciation, which will reduce productivity at the lower end of the productivity distribution. However, this reduction in productivity at the lower end of the distribution will be dampened by the exit of very low productivity producers.

The one anomaly in the group of eight is the sawmill and planing mill products industry (SIC 1931), where both the OLS estimate and the entire quantile regression curve are above zero. That is, an appreciation of the *twrer* has a positive effect on labour productivity, and this effect is more pronounced at the lower end of the productivity distribution. This may be an industry where surviving plants, and not foreign producers, are absorbing the market share of exiting plants. This will result in an increase in productivity for surviving plants, and result in a quantile regression curve that is above zero. The exit of less productive plants will only increase productivity further at the lower end of the distribution. Alternatively, this may be an industry that relies heavily of foreign intermediate inputs and technology. Therefore, an appreciation will decrease the cost of imports, thus enabling plants to increase productivity through increased foreign intermediate inputs and technology. If the appreciation still forces less productive plants from the market, we would see a downward sloping quantile regression curve that lies entirely above the zero line. Our empirical model does not allow us to distinguish between these competing, but complementary explanations.

5.3 Tariff Parameter Estimates and Other Issues

In addition to the exchange rate, it could also be interesting to examine the results of Canada and U.S. tariff reductions on the conditional distribution of productivity. However, our estimates of α_i^{CA} and α_i^{US} are difficult to interpret for a number of reasons. First, because we are running the quantile regressions industry by industry, we lose out on any cross-industry variation in the tariff rates that are important for identifying their effects. Of course, we do not have cross-industry variation in our measure of the exchange rate either, but there is much more variation in industry-specific exchange rates across time than in tariff rates. Most industries had their bilateral tariff rates reduced to zero linearly either over five or ten years beginning in 1989. For this reason, some of the effects of the tariff reductions may be indistinguishable from the time trend. Moreover, some industries saw no change in tariff rates over the period being studied since the bilateral rates we effectively zero from the start of our sample period. Figure 6 summarizes the Canadian tariffs against the U.S. and the U.S. tariffs against Canada for the 128 industries. For the most part, the coefficient estimates on the tariff variables are statistically insignificant, and those that are significant show no discernible pattern.[19] In the end, our framework may not be suitable for analyzing the effects of tariff reductions, and therefore we do not attempt to interpret these results, using Canada and U.S. tariff rates as control variables only (see Trefler (2004) and Lileeva (2008) for alternative frameworks for examining the effects of tariff reductions on productivity).

When developing our hypotheses, the underlying assumption is that all the factors of production are domestic; however, imported inputs are often used in production. As the home currency appreciates, for instance, imported inputs become cheaper and this can lower production costs and mitigate, or even reverse the adverse exchange rate effect on productivity. We do not have access to data on plant-level imported inputs, and therefore cannot control for the effects of exchange rates on imported inputs and productivity.[20] However, because this mechanism works in the opposite direction of the scale effect and we still see a significant number of industries exhibiting downward sloping quantile regression curves, we can only assume that our results would be stronger if we could control for imported inputs.

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[19]Nevertheless, full regression results for any industry are available upon request.

[20]See Ekholm et al. (2009) for an analysis of the impact of imported inputs on productivity.
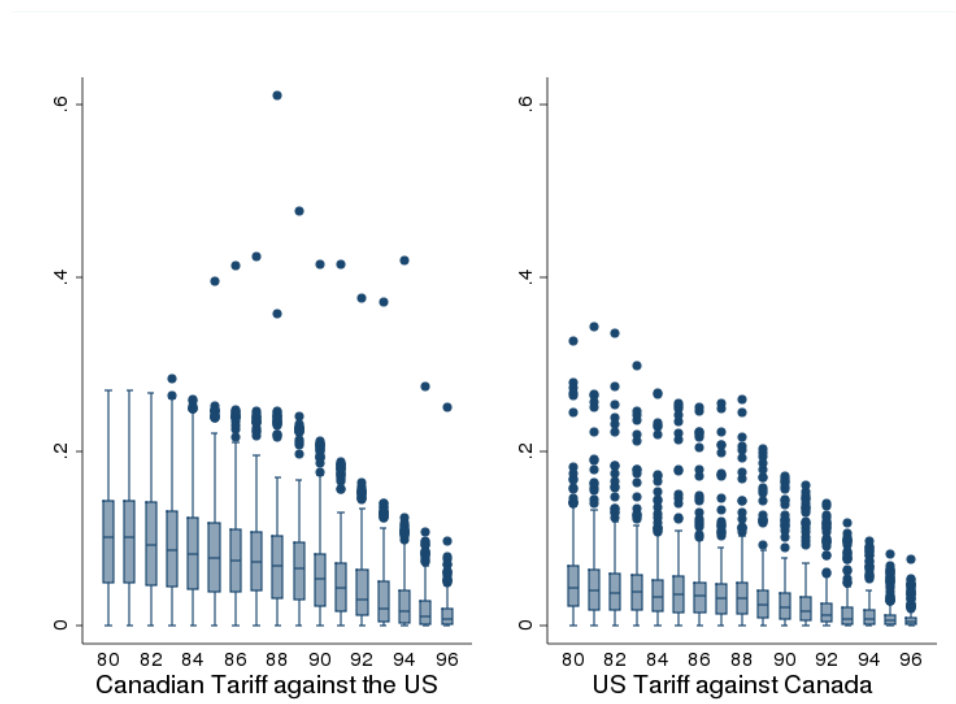
Figure 6: Canadian Tariff against the US and US Tariff against Canada, 1980-1996

Source: Trefler (2004) and Lileeva (2008)

Note: The centre of the shaded boxes is the median tariff rate for the 128 industries. The top of the box represents the 75th percentile and the bottom of the box is the 25th percentile. The thin vertical lines represent the observations within the upper adjacent value (the value of the third quartile plus 1.5 times the distance between the first and third quartiles) and the lower adjacent value (the value of the first quartile minus 1.5 times the distance between the first and third quartiles, or zero), while the dots represent values outside this range. The year is on the x-axis and the y-axis is the tariff per dollar of shipment.

Another issue that needs to be addressed relates to the lack of plant-specific price data. Studies such as Klette and Griliches (1997), Hall and Mairesse (1995) and Bernard et al. (2003) point out that in imperfectly competitive industries, plant-level prices may deviate from the industry level prices. If this is the case, then our measure of output—sales deflated using an industry-level price deflator—may include a markup, which is then included in our measure of productivity. Because markups can be positively correlated with the degree of competition, and the degree of competition can be affected by the exchange rate, movements in the exchange rate can affect observed sales, and thus labour productivity, without actually affecting output. In the absence of observable plant-level prices, we use a price deflator at the 3-digit SIC level—the most detailed deflator data available— and in our empirical work we control for market concentration (which may be positively related

to markups) using a Herfindahl-Hirschman Index. These measures will partially control for the influence of markups on our measure of productivity.

5.4 Economic Significance of Results

Our empirical findings indicate that the relationship between the exchange rate and productivity quantiles differs across industries and that many industries exhibit downward sloping quantile regression curves. Three important questions remain: (1) how large is the economic magnitude of the exchange rate effect?; (2) to what extent do these effects vary across different groups of industries?; and (3) how large is the overall effect for the Canadian manufacturing sector? To explore these questions, we calculate the economic magnitude of the exchange rate effect by comparing the predicted productivity of hypothetical plants at different quantiles of the productivity distribution at different levels of the trade-weighted real exchange rate, while holding all other variables at their means.

Table 5 summarizes the median of predicted relative productivity by different industry groups and by quantiles.[21] We examine predicted productivity at three levels of the trade-weighted real exchange rate: 85, 100 and 115. For reasons of confidentiality, we normalize the predicted level of productivity when the $twrer = 100$ to 100 for each quantile, and then present the productivity results for $twrer = 85$ and $twrer = 115$ as productivity relative to that normalize value. Columns 1 to 3 summarize the predicted relative productivity when industries are divided into three groups based on the slope of their quantile regression curves and the sign of coefficient estimates. Group 1 includes industries with coefficient estimates of $\hat{\beta}_{10}$ and $\hat{\beta}_{90}$ that are consistent with our hypotheses (i.e. positive $\hat{\beta}_{10}$ and negative $\hat{\beta}_{90}$). Group 2 consists of plants with negative $\hat{\beta}_{10}$ and $\hat{\beta}_{90}$, but $\hat{\beta}_{10} > \hat{\beta}_{90}$. Finally, group 3 comprises all other industries. When the exchange rate is low, the median of productivity in group 1 is around 85 percent of productivity when $twrer = 100$ at the 10th percentile and 120 percent at the 90th percentile. When the exchange rate moves from the lower to the higher level (a 35 percent appreciation), the median of productivity in group 1 increases by 34 percent at the 10th percentile and reduces by 28 percent at the 90th percentile.[22] For group

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[21]The median of industries within a group for each quantile is used instead of mean to reduce the influence of extreme values.

[22]Note that a 35 percent increase in the exchange rate is not unusual for Canada. The most recent example is that

2, an increase in the *twrer* from 85 to 115 is associated with a 12 percent decrease in productivity at the 10th percentile and a 51 percent decrease at the 90th percentile. For group 3, the increase in the *twrer* is associated with 0.6 and 11 percent increases in productivity at the 10th and 90th percentiles, respectively.

For both groups 1 and 2, a real currency appreciation *reduces* productivity at the 75th and 90th percentiles. These results are consistent with the scale effect hypothesis that a real currency appreciation reduces output scale, which in turn reduces productivity. Since this is based on the assumption that production technology has increasing returns to scale (Fung, 2008), we would expect these results to be driven by those industries that do exhibit increasing returns to scale. To confirm this, we divide industries into industries thought to exhibit increasing returns to scale (IRS) and those thought to exhibit constant returns to scale (CRS) based on the returns to scale estimates from Lee (2007) that are based on U.S. plant level data.[23] The classifications are at the 2-digit SIC level. Columns 4 and 5 of Table 5 report the median of predicted relative productivity for IRS and CRS industries, respectively. For both groups, a real currency appreciation increases productivity at the 10th percentile of the productivity distribution, however the IRS industries experienced a *smaller* increase (10 percent) as compared to the CRS industries (21 percent). It is likely that the level of competition is more intense in CRS industries than in IRS industries. In general, IRS industries are characterized by a smaller number of plants producing larger quantities of output, which is consistent with imperfectly competitive markets, while CRS industries have a larger number of smaller plants competing. As a result, plants in IRS industries have more room for adjustment in the face of movements in the exchange rate. That is, entry and exit of plants may be less of a factor in IRS industries, which would mitigate the selection effect at the lower end of the productivity distribution as compared to CRS industries.

At the 90th percentile, a real currency appreciation is associated with a *larger* reduction in productivity (25 percent) across IRS industries as compared to CRS industries (15 percent). This patterns persists, but with a smaller difference, at the 75th percentile. This would suggest that the

the Canadian dollar appreciated by approximately 47 percent in nominal terms against the U.S. dollar between 2002 and 2007. (Source: Bank of Canada monthly exchange rate, expressed as US dollars per Canadian dollar, noon).

[23]Consistent with Fung, Baggs and Beaulieu (2010), an industry is classified as having increasing returns to scale if its returns to scale estimates are above 1.1. To the best of our knowledge, there are few studies estimating returns to scales for Canadian manufacturing industries. Therefore, we use returns to scale estimates from the U.S. as a proxy.

Table 5: Predicted Relative Labour Productivity

| | | Labour Productivity | | | | | |
| | Trade-Weighted | (1) | (2) | (3) | (4) | (5) | (6) |
Quantile	Real Exchange Rate	Group 1	Group 2	Group 3	IRS	CRS	Overall
0.10	85	85.51	107.32	99.70	94.98	90.32	92.55
	115	114.40	94.11	100.26	104.53	109.15	106.89
0.25	85	94.61	111.37	101.53	101.82	96.90	99.13
	115	104.88	91.15	98.71	98.46	102.75	100.76
0.50	85	105.24	108.29	99.90	107.10	100.60	102.75
	115	95.71	93.38	100.08	94.27	99.48	97.70
0.75	85	111.81	118.70	100.53	109.41	105.66	106.25
	115	90.85	86.29	99.55	92.56	95.38	94.92
0.90	85	119.98	146.52	94.39	116.70	108.91	110.05
	115	85.50	72.00	105.09	87.56	92.92	92.10

Notes: Results are relative to the predicted value for *twrer* = 100, normalized to 100. We use median relative productivity to limit the influence of outliers.
Group 1: Industries with downward sloping quantile regression curves (i.e. $\hat{\beta}_{10} > \hat{\beta}_{90}$) and $\hat{\beta}_{10} > 0$ & $\hat{\beta}_{90} < 0$.
Group 2: Industries with downward sloping quantile regression curves (i.e. $\hat{\beta}_{10} > \hat{\beta}_{90}$) and $\hat{\beta}_{10} < 0$ & $\hat{\beta}_{90} < 0$.
Group 3: All other industries.
Group 1 contains 52 industries, group 2 consists of 19 industries and group 3 includes 57 industries.
    There are 57 increasing returns to scale (IRS) industries and 71 constant returns to scale (CRS) industries.

reduction in productivity at higher percentiles reflects the scale effect—plants reducing their output and thus productivity.[24] The fact that CRS industries also experience a reduction in productivity at the upper of the productivity distribution may be a result of heterogeneity of 4-digit SIC industries within the 2-digit SIC industries. That is, although a 2-digit industry is classified as CRS, it may still contain some IRS 4-digit SIC industries, which could be driving the observed results at the upper end of the productivity distribution for CRS industries.

Although the sign of the coefficient estimates and the slope of the quantile regression curves varies across industries, the median levels of productivity across all industries for each quantile reported in the last column suggest that the overall quantile regression curve is downward sloping (see Table 5 column 6). More specifically, a 35 percent appreciation is associated with a 15 percent increase in median productivity at the 10th percentile and a 16 percent decrease at the 90th percentile. Finally, median productivity at the 50th percentiles decreases by 5 percent as the *twrer* movements from 85 to 115.

[24]Empirical results in Fung, Baggs and Beaulieu (2010) show that a real currency appreciation reduces the scale of production, which, in turn, reduces productivity. A real currency depreciation has the opposite effect. They also find that this effect is larger for IRS industries.

6   Conclusions

Theory predicts that movements in the exchange rate will have differing effects on plants depending on their placement within the industry productivity distribution. Our empirical results show that movements in the exchange rate do, indeed, have distributional effects on productivity, but it depends on the industry. Although it is not the case for all industries, we find a number of industries that exhibit downward sloping quantile regression curves for the exchange rate, which is evidence of two mechanism at play: the selection effect and the scale effect.

We find that the scale effect is larger for those industries broadly defined as having increasing returns to scale, which supports the hypothesis that surviving plants are adjusting their scale of production, and hence productivity, in the face of movements in the exchange rate. We also find that the effect of movements in the exchange rate on the lower end of the productivity distribution is larger for industries that exhibit constant returns to scale production technology.

As more and more countries open their borders to trade, and their economies become integrated with the world economy, the focus of study for many international economists will shift from the effects of trade liberalization to other determinants of international competition, such as real exchange rates. These results suggest that this is an important area of study.

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