Export Variety and Country Productivity:
ESTIMATING THE MONOPOLISTIC COMPETITION MODEL WITH ENDOGENOUS PRODUCTIVITY

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Abstract

This paper provides evidence on the monopolistic competition model with heterogeneous firms and endogenous productivity. We show that this model has a well-defined GDP function where relative export variety enters positively, and estimate this function over 48 countries from 1980 to 2000. Average export variety to the United States increases by 3.3% per year, so it nearly doubles over these two decades. The total increase in export variety is associated with a 3.3% average productivity improvement for exporters over the two decades. Overall, the model can explain 31% of the within-country variation in productivity (or 52% for the OECD countries), but only a very small fraction of the between-country variation in productivity.

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1. Introduction

Empirical research in international trade (as well as other fields) has made it clear that productivity levels differ a great deal across countries.[1] This conclusion begs the question of where the technology differences come from. While various explanations have been proposed that do not depend on international trade,[2] our interest here is whether trade itself can explain the productivity differences across countries. This conclusion is suggested by recent models of monopolistic competition and trade in which productivity levels are endogenous.

Two examples of this recent literature are Eaton and Kortum (2002) and Melitz (2003). Eaton and Kortum allow for stochastic differences in technologies across countries, with the lowest cost country becoming the exporter of a product variety to each location. In that case, the technologies utilized in a country will depend on its distance and trade barriers with other countries. Melitz allows for stochastic draws of technology for each firm, and only those firms with productivities above a certain cutoff level will operate. A subset of these firms – the most productive – also become exporters. Melitz shows how the average productivity in a country is affected by changes in trade barriers and transport costs. A reduction in trade barriers, for example, pushes the less efficient firms to exit the market while draws more firms into exporting. It follows that average country productivity rises.

Empirical testing of this class of models can proceed by utilizing firm-level data and inferring the productivity levels of firms. That approach is taken by Bernard *et al* (2003) for U.S. firms; Eaton, Kortum and Kramarz (2003, 2004) for French firms; Helpman, Melitz and Yeaple (2004) for U.S. multinationals operating abroad; and Demidova, Kee and Kala (2006) for Bangladeshi garment exporters. When firm level data are available, it is highly desirable to make

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[1] See, for example, the work of Trefler (1993, 1995), and Davis and Weinstein (2001).
[2] Explanations for the aggregate productivity differences across countries include geography/climate (Sachs, 2001), colonial institutions (Acemoglu, et al, 2001), or social capital (Jones and Hall, 1999).

use of it like these authors do. But for many countries such data are not available, and in those cases, we are still interested in determining the extent to which openness to trade can explain country productivity. That is our objective in this paper, using a broad cross-section of advanced and developing nations and disaggregating across sectors.

In section 2 we review the monopolistic competition model with heterogeneous firms, from Melitz (2003), Bernard, Redding and Schott (2004) and Chaney (2005). We emphasize some features of that model that these authors do not: for example, the "cutoff" productivity of firms producing for either the domestic or export markets are both at the socially optimal level. This means that we can use a GDP function for the economy, similar to the competitive case. In each sector, only a subset of firms become exporters, and these are the most productive firms. It follows that when the share of exporting firms rises, or equivalently, the share of exported varieties rises, then average productivity and GDP increase. Therefore, relative export variety is positively related to GDP.[3]

Our empirical specification is developed in section 3. We draw on Harrigan (1997), who estimates a translog GDP function in a competitive model allowing for industry productivity differences across countries. In our case, the export variety of each industry enters the GDP function instead. A goal of the empirical work is to determine what amount of the productivity differences across countries and over time are determined by variation in export variety, which is treated as an endogenous variable. The instrumental variables used to determine export variety are those suggested by our model: tariffs, trade agreements and distance. The index of export variety we use draws on Feenstra (1994), and has been employed recently by Hummels and Klenow (2005) and Broda and Weinstein (2006). Using this measure, average export variety to

[3] With a Pareto distribution for firm productivities, we also show that relative export variety enters with an exponent related to the elasticity of substitution and the Pareto productivity parameter. This result is similar to the formulation of the gravity equation in Chaney (2005).

the U.S. has increased by 3.3% per year over 1980-2000, so export variety nearly doubles over the two decades.

In section 4 we estimate the GDP function using data on 44 countries from 1980 to 2000, distinguishing the sectoral outputs of seven sectors. Parameter estimates of the GDP function show that expansion of export variety over 1980-2000 explains a 3.3% increase in exporters' productivity. Since average export variety also grew 3.3% per year, a rule of thumb is that a x% per annum *sustained* growth in export variety over two decades leads to an overall productivity improvement for the exporter of x%. This is an estimate of the endogenous portion of productivity gains. In the time series, export variety explains 31.1% of within-country variation in productivity, and 52.2% for just the OECD countries. But this linkage between export variety and productivity is not enough to explain the enormous cross-country differences in productivity. Allowing for country fixed effects, export variety explains only 0.3% of the between-country variation in productivity, or 3.3% for the OECD countries. We conclude that export variety in the monopolistic competition model with heterogeneous firms is quite effective at accounting for the time-series variation in productivity within countries, but cannot explain the large absolute differences in productivity between them.

2. Monopolistic Competition with Heterogeneous Firms

We assume some familiarity with the monopolistic competition model of Melitz (2003), and outline here a two-country, multi-factor, multi-sector version that also draws upon Bernard, Redding and Schott (2005) and Chaney (2005). We focus on the home country H, while denoting foreign variables with the superscript F.

In each sector $i = 1,\ldots,N$ at home, there is a mass of M_i firms operating in equilibrium. Each period, a fraction δ of these firms go bankrupt and are replaced by new entrants. Each new entrant pays a fixed cost to receive a draw φ_i of productivity from a cumulative distribution $G_i(\varphi_i)$, which gives rise to the marginal cost of m_i/φ_i. Only those firms with productivity above a cutoff level φ_i^* find it profitable to actually produce (the cutoff level will be determined below). Letting M_{ie} denote the mass of new entrants in sector i, then $[1-G_i(\varphi_i^*)]M_{ie}$ firms successfully produce. In a stationary equilibrium, these should replace the firms going bankrupt, so that:

$$[1-G_i(\varphi_i^*)]M_{ie} = \delta M_i \ . \tag{1}$$

Conditional on successful entry, the distribution of productivities for firms in sector i is then:

$$\mu_i(\varphi_i) = \begin{cases} \dfrac{g_i(\varphi_i)}{[1-G_i(\varphi_i^*)]} & \text{if } \ \varphi_i \geq \varphi_i^*, \\ \\ 0 & \text{otherwise,} \end{cases} \tag{2}$$

where $g_i(\varphi_i) = \partial G_i(\varphi_i)/\partial \varphi_i$.

Home and foreign consumers both have CES preferences that are symmetric over product varieties. Given home expenditure of E_i^H in sector i, it follows that the revenue earned by a home firm from selling in the domestic sector i at the price $p_i(\varphi_i)$ is:

$$r_i(\varphi_i) = p_i(\varphi_i)q_i(\varphi_i) = \left[\frac{p_i(\varphi_i)}{P_i^H}\right]^{1-\sigma_i} E_i^H, \quad \sigma_i > 1, \tag{3}$$

where $q_i(\varphi_i)$ is the quantity sold and P_i^H is the home CES price index for sector i:

$$P_i^H = \left[\int_{\varphi_i^*}^{\infty} p_i(\varphi_i)^{1-\sigma_i} M_i \mu_i(\varphi_i) d\varphi_i + \int_{\varphi_{ix}^{F*}}^{\infty} p_i^F(\varphi_i)^{1-\sigma_i} M_i^F \mu_i^F(\varphi_i) d\varphi_i\right]^{\frac{1}{1-\sigma_i}} . \tag{4}$$

The first integral in this expression is taken over home firms, with prices $p_i(\varphi_i)$ and mass M_i, selling in the domestic market. The second integral is taken over foreign firms, with prices $p_i^F(\varphi_i)$ and mass M_i^F, exporting to the home market.

In our analysis below it will be convenient to treat revenue as a function of quantity. Using the second equality in (3) to solve for price as a function of quantity, and substituting this back into (3), we obtain:

$$r_i(\varphi_i) = A_{id}\, q_i(\varphi_i)^{\frac{\sigma_i - 1}{\sigma_i}}, \text{ where } A_{id} \equiv P_i^H \left(\frac{E_i^H}{P_i^H} \right)^{\frac{1}{\sigma_i}}. \qquad (3')$$

We introduce the notation A_{id} as shift parameter in the demand curve facing home firms for their domestic sales. It depends on the CES price index P_i^H, and also on domestic expenditure E_i^H in sector i. Home firms takes both these as given when maximizing profits.

While firms with productivities $\varphi_i \geq \varphi_i^*$ find it profitable to produce for the domestic market, those with productivities $\varphi_i \geq \varphi_{ix}^* \geq \varphi_i^*$ find it profitable to export. A home firm exporting in sector i faces the iceberg transport costs of $\tau_i \geq 1$ meaning that τ_i units must be sent in order for one unit to arrive in the foreign country. Letting $p_{ix}(\varphi_i)$ and $q_{ix}(\varphi_i)$ denote the price received and quantity shipped at the *factory-gate*,[4] the revenue earned by the exporter is:

$$r_{ix}(\varphi_i) = p_{ix}(\varphi_i) q_{ix}(\varphi_i) = \left[\frac{p_{ix}(\varphi_i)\tau_i}{P_i^F} \right]^{1-\sigma_i} E_i^F, \qquad (5)$$

where P_i^F is the aggregate CES price for sector i in the foreign country, and E_i^F is foreign expenditure in sector i. Once again, it is convenient to treat revenue as a function of quantity,

[4] Notice that we are measuring export price and quantity at the factory-gate, or f.o.b., net of any transport costs. The c.i.f. prices would instead be $\tau_i p_{ix}$, and the quantity inclusive of the amount lost in transit would be q_{ix}/τ_i. It would be equivalent to use these c.i.f. prices and quantities, but we find it convenient to use the f.o.b. variables since they show how the transport costs τ_i enter the export shift parameter in (5').

which is determined from (5) as:

$$r_{ix}(\varphi_i) = A_{ix} q_{ix}(\varphi_i)^{\frac{\sigma_i - 1}{\sigma_i}}, \text{ where } A_{ix} \equiv \left(\frac{P_i^F}{\tau_i}\right)\left(\frac{\tau_i E_i^F}{P_i^F}\right)^{\frac{1}{\sigma_i}}. \tag{5'}$$

We introduce the notation A_{ix} as shift parameter in the demand curve facing home firms for their export sales. It depends on the foreign CES price index P_i^F, foreign expenditure E_i^F, and the transport costs in sector i.

Integrating (3') and (5'), we obtain revenue from domestic and export sales in sector i:

$$R_{id} \equiv M_i A_{id} \int_{\varphi_i^*}^{\infty} q_i(\varphi_i)^{\frac{\sigma_i - 1}{\sigma_i}} \mu_i(\varphi_i) d\varphi_i, \tag{6}$$

$$R_{ix} \equiv M_i A_{ix} \int_{\varphi_{ix}^*}^{\infty} q_{ix}(\varphi_i)^{\frac{\sigma_i - 1}{\sigma_i}} \mu_i(\varphi_i) d\varphi_i. \tag{7}$$

Notice that the mass of domestic firms or varieties is $\int_{\varphi_i^*}^{\infty} M_i \mu_i(\varphi_i) d\varphi_i = M_i$, which we are aggregating over in (6). But the mass of exporting firms or varieties that we are aggregating over in (7) is $M_{ix} \equiv \int_{\varphi_{ix}^*}^{\infty} M_i \mu_i(\varphi_i) d\varphi_i \leq M_i$. It will be convenient to denote the range of *export varieties relative to domestic varieties* by:

$$\chi_i \equiv \left(\frac{M_{ix}}{M_i}\right) = \left(\int_{\varphi_{ix}^*}^{\infty} \mu_i(\varphi) d\varphi\right) = \left(\frac{1 - G(\varphi_{ix}^*)}{1 - G(\varphi_i^*)}\right) \leq 1. \tag{8}$$

On the resource side, firms producing for the domestic market have fixed costs of f_i, and firms who are exporters have the added fixed cost of f_{ix}. We allow for multiple factors of production, and assume that these fixed costs use the resources in the same proportion as do variable costs in each sector. The resource constraints for the economy as detailed in the Appendix. Total GDP in the economy is obtained by summing revenue over the sectors:

$$R = \sum_{i=1}^{N} R_{id} + R_{ix} . \tag{9}$$

Consider now a social planner's problem of maximizing GDP in (9), subject to the resource constraints for the economy. In maximizing GDP we will hold fixed the shift parameters A_{id} and A_{ix} , i = 1,…,N, which is analogous to holding product prices constant in a conventional GDP function. Then we show in the Appendix that:

Proposition 1

Choose $q_i(\varphi_i)$, $q_{ix}(\varphi_i)$, φ_i^*, φ_{ix}^*, and M_i for i = 1,…,N, to maximize GDP in (9), subject to the resource constraints for the economy. Holding fixed the shift parameters $A_d = (A_{1d},..., A_{Nd})$ and $A_x = (A_{1x},..., A_{Nx})$, the first-order conditions for an interior maximum are identical to the equilibrium conditions for the monopolistically competitive economy. Then GDP can be written as a function $R(A_d, A_x, V)$, which is homogeneous of degree one in (A_d, A_x) and in V.

The proof of Proposition 1 proceeds by setting up the Lagrangian and obtaining the first-order conditions. Details are provided in the Appendix, and here we simply describe the results. The first-order conditions to maximize GDP specify that marginal revenue equal marginal cost in each sector for both the domestic and export market:

$$\left(\frac{\sigma_i - 1}{\sigma_i}\right) p_i(\varphi_i) = \frac{c_i}{\varphi_i}, \quad \text{and} \quad \left(\frac{\sigma_i - 1}{\sigma_i}\right) p_{ix}(\varphi_i) = \frac{c_i}{\varphi_i}, \tag{10}$$

where c_i represents marginal costs. Using (10), we can calculate profits from domestic and export sales as $r_i(\varphi_i) - (c_i / \varphi_i) q_i(\varphi_i) = r_i(\varphi_i) / \sigma_i$, and $r_{ix}(\varphi_i) - (c_i / \varphi_i) q_{ix}(\varphi_i) = r_{ix}(\varphi_i) / \sigma_i$. In addition, the first-order condition specify that the productivity cutoffs φ_i^* and φ_{ix}^* are:

$$r_i(\varphi_i^*) / \sigma_i = c_i f_i, \quad \text{and} \quad r_{ix}(\varphi_{ix}^*) / \sigma_i = c_i f_{ix}, \tag{11}$$

which are the zero-cutoff-profit conditions of Melitz (2003).[5]

Proposition 1 shows that the optimal choices for quantities and cutoff-productivities by individual firms are identical to the constrained social optimum, where we hold constant the shift parameters in demand.[6] As discussed more fully in the Appendix, this GDP function satisfies similar properties as in the competitive case, but estimating this function will be more difficult than in the competitive case for several reasons. First, the shift parameters are endogenous, since they depend on the country price indexes in (3') and (5') which are endogenous. Second, the shift parameters are not directly observed, so we will need to develop some proxies for them. Third, we still need to determine the appropriate functional form for the GDP function. We address these issues in the next section, using a Pareto distribution for firm productivities.

2.2 Functional Form for GDP

Following Helpman, Melitz and Yeaple (2004) and Chaney (2005), we assume the Pareto distribution for productivities, defined by:

$$G_i(\varphi_i) = 1 - \varphi_i^{-\theta_i}\text{, with } \theta_i > \sigma_i - 1. \qquad (12)$$

The parameter θ_i is a measure of dispersion of the Pareto distribution, with lower θ_i having more weight in the upper tail. Using this distribution, we calculate export relative to domestic variety in (8) as:

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[5] Fixed costs are multiplied by c_i in (11) because we use the same factor proportions in fixed and marginal costs.

[6] Helpman and Krugman (1985, p. 139) also derive a GDP function for a two-sector economy with monopolistic competition (and symmetric costs) in one sector. Because of the constraint we have used that the shift parameters are hold constant, we cannot necessarily interpret our solution as an unconstrained social optimum. Nevertheless, Dixit and Stiglitz (1977) argue that by adding the constraint that firms do not earn negative profits in autarky, then the equilibrium of the symmetric monopolistic competition model is also the constrained first-best for consumers. Further, once we add international trade, then the constraint that the export shift parameter is constant can be interpreted as a "small country" assumption: there are many varieties in the world, so that the additional varieties of this country have a negligible effect on the world price index.

$$\chi_i = \left(\frac{1-G(\varphi_{ix}^*)}{1-G(\varphi_i^*)} \right) = \left(\frac{\varphi_i^*}{\varphi_{ix}^*} \right)^{\theta_i}. \tag{13}$$

Relative export variety can be further simplified by using (3) and (5) to compute $r_i(\varphi_i^*)$ and $r_{ix}(\varphi_{ix}^*)$, together with the equilibrium conditions (10) and (11). Then we obtain:

$$\frac{r_{ix}(\varphi_{ix}^*)}{r_i(\varphi_i^*)} = \left(\frac{\varphi_{ix}^* P_i^F / \tau_i}{\varphi_i^* P_i^H} \right)^{\sigma_i - 1} \frac{E_i^F}{E_i^H} = \frac{f_{ix}}{f_i}.$$

Raising this expression to the power ($1/\sigma_i$), and re-arranging, we have:

$$\left(\frac{A_{ix}}{A_{id}} \right) = \chi_i^{\frac{\sigma_i - 1}{\sigma_i \theta_i}} \left(\frac{f_{ix}}{f_i} \right)^{1/\sigma_i}, \qquad 0 < \frac{\sigma_i - 1}{\sigma_i \theta_i} < 1. \tag{14}$$

Thus, the ratio of the export/domestic shift parameters in demand equals relative export variety raised to a positive power, adjusted for a term involving fixed costs. This means that relative export variety can be used as a proxy for (A_{ix}/A_{id}).

The Pareto distribution further enables us to aggregate domestic and export sales in each sector. In particular, we shown in the Appendix that the Pareto distribution, along with condition (11), allows us to write export sales relative to domestic sales in each sector as:

$$\frac{R_{ix}}{R_{id}} = \chi_i \left(\frac{f_{ix}}{f_i} \right). \tag{15}$$

As one might expect, relative export variety is directly related to relative export sales. Then substituting from (14), the ratio of export to domestic sales becomes:

$$\frac{R_{ix}}{R_{id}} = \left(\frac{A_{ix}}{A_{id}} \right)^{\frac{\sigma_i \theta_i}{(\sigma_i - 1)}} \left(\frac{f_{ix}}{f_i} \right)^{1 - \frac{\theta_i}{(\sigma_i - 1)}}. \tag{16}$$

Thus, the sales ratio is a constant-elasticity function of the relative export shift parameters. This implies that: first, the shift parameters (A_{ix}, A_{id}) for sector i are weakly separable from all other variables in the GDP function; and second, the appropriate aggregator for (A_{ix}, A_{id}) is a CES function. These results are summarized by:

Proposition 2

Assume that the distribution of firm productivity in Pareto, as in (12). Then the domestic and export shift parameters (A_{id}, A_{ix}) can be aggregated into a CES function:

$$\psi_i(A_{id}, A_{ix}) \equiv \left[A_{id}^{\frac{\sigma_i\theta_i}{(\sigma_i - 1)}} + A_{ix}^{\frac{\sigma_i\theta_i}{(\sigma_i - 1)}} (f_{ix}/f_i)^{1 - \frac{\theta_i}{(\sigma_i - 1)}} \right]^{\frac{(\sigma_i - 1)}{\sigma_i\theta_i}}. \tag{17}$$

GDP can be written as a function $R(\psi_1, ..., \psi_N, V)$, and if R is differentiable then:

$$\frac{\partial \ln R}{\partial \ln \psi_i} = \frac{(R_{id} + R_{ix})}{R}, \tag{18}$$

which is the share of sector i in GDP.

Our finding that the Pareto distribution leads to a CES function between domestic and exported varieties is related to the results in Chaney (2005), who derives a gravity equation for country exports to different destination markets. For the case of a single export market, we can obtain his results by substituting for A_{id} and A_{ix} from (3') and (5') into (16), obtaining:

$$\frac{R_{ix}}{R_{id}} = \chi_i \left(\frac{f_{ix}}{f_i} \right) = \left(\frac{P_i^F / \tau_i}{P_i^H} \right)^{\theta_i} \left(\frac{E_i^F}{E_i^H} \right)^{\frac{\theta_i}{(\sigma_i - 1)}} \left(\frac{f_{ix}}{f_i} \right)^{1 - \frac{\theta_i}{(\sigma_i - 1)}}. \tag{19}$$

Thus, the export/domestic share is negatively related to the transport costs, with an exponent of $-\theta_i$ in (19), just as in the gravity equation derived by Chaney. The fixed costs in (19) also have the same exponent as found by Chaney (2005). The gravity equation in (19) gives us some instruments that we can use to explain relative export variety, namely: country size, as measured by factor endowments, and transport costs, as measured by distance and tariffs.

3. Empirical Specification

3.1 Translog GDP Function

Following Harrigan (1997) we assume a translog functional form for GDP across sectors, and then use the CES function in (18) within each sector. Introducing the country superscript h=1,…,H and time subscript t, let $\psi_{it}^{h} = \psi_i(A_{idt}^{h}, A_{ixt}^{h})$ denote the value of that CES function. Define the vector $\psi_t^h = (\psi_{1t}^h,...,\psi_{Nt}^h,\psi_{N+1,t}^h)$ to also include a price $\psi_{N+1,t}^h$ for the non-traded sector N+1. Denoting factor endowments by the vector $V_t^h = (v_{1t}^h,...,v_{Kt}^h)$, the translog GDP function is:

$$\begin{aligned} \ln R_t^h\left(\psi_t^h, V_t^h\right) = {} & \alpha_0^h + \beta_{0t} + \sum_{i=1}^{N+1} \alpha_i \ln \psi_{it}^h + \sum_{k=1}^{K} \beta_k \ln v_{kt}^h + \tfrac{1}{2} \sum_{i=1}^{N+1}\sum_{j=1}^{N+1} \gamma_{ij} \ln \psi_{it}^h \ln \psi_{jt}^h \\ & + \tfrac{1}{2} \sum_{k=1}^{K}\sum_{\ell=1}^{K} \delta_{k\ell} \ln v_{kt}^h \ln v_{\ell t}^h + \sum_{i=1}^{N+1}\sum_{k=1}^{K} \phi_{ik} \ln \psi_{it}^h \ln v_{kt}^h . \end{aligned} \tag{20}$$

We allow this function to differ across countries based on the fixed-effects α_0^h, which reflect exogenous technology differences, and also allow for the year fixed-effects β_{0t}, which are equal across countries. In treating all other parameters of the translog function as common across both countries and time, we are assuming that the distribution function $G_i(\varphi_i)$ and the fixed costs f_i and f_{ix} do not vary over these dimensions.

To satisfy homogeneity of degree one in prices and endowments, we test the restrictions:

$$\gamma_{ij}=\gamma_{ji},\delta_{k\ell}=\delta_{\ell k},\ \sum_{i=1}^{N+1}\alpha_n=\sum_{k=1}^{K}\beta_k=1,\ \sum_{i=1}^{N+1}\gamma_{ij}=\sum_{i=1}^{N+1}\phi_{ik}=\sum_{k=1}^{K}\delta_{k\ell}=\sum_{k=1}^{K}\phi_{ik}=0. \qquad (21)$$

As stated in Proposition 2, the share of sector i in GDP equals the derivative of $\ln R_t^h(\psi_t^h, V_t^h)$ with respect to $\ln \psi_{it}^h$:

$$s_{it}^h=\alpha_i+\sum_{j=1}^{N+1}\gamma_{ij}\ln\psi_{jt}^h+\sum_{k=1}^{K}\phi_{ik}\ln v_{kt}^h,\quad i=1,...,N+1. \qquad (22)$$

Also, the share of factor k in GDP equals the derivative of $\ln R_t^h(\psi_t^h, V_t^h)$ with respect to $\ln v_{kt}^c$:

$$s_{kt}^h=\beta_k+\sum_{\ell=1}^{K}\delta_{k\ell}\ln v_{\ell t}^h+\sum_{i=1}^{N+1}\phi_{ik}\ln P_{it}^h,\quad k=1,...,K. \qquad (23)$$

3.2 CES Sectoral Aggregates

Key to the empirical work is to measure the CES aggregates $\psi_{it}^h=\psi_i(A_{idt}^h, A_{ixt}^h)$ in each sector. To this end, we will difference the GDP and share equations with respect to a comparison country denoted by F. The CES aggregate in each sector will also be differenced with respect to country F in log form, which means we take the log of the ratio ψ_{it}^h/ψ_{it}^F. To evaluate the ratio of CES functions, we can apply the index number formula due to Sato (1976) and Vartia (1976). Assuming that the fixed costs f_{ix} and f_i appearing in (17) are the same across countries, the CES ratio in sector i equals:

$$\frac{\psi_i(A_{idt}^h, A_{ixt}^h)}{\psi_i(A_{idt}^F, A_{ixt}^F)}=\left(\frac{A_{idt}^h}{A_{idt}^F}\right)^{1-W_{it}^h}\left(\frac{A_{ixt}^h}{A_{ixt}^F}\right)^{W_{it}^h}=\left(\frac{A_{idt}^h}{A_{idt}^F}\right)\left(\frac{A_{ixt}^h/A_{idt}^F}{A_{ixt}^h/A_{idt}^F}\right)^{W_{it}^h}=\frac{A_{idt}^h}{A_{idt}^F}\left(\frac{\chi_{it}^h}{\chi_{it}^F}\right)^{\frac{(\sigma_i-1)}{\sigma_i\theta_i}W_{it}^h} \qquad (24)$$

where W_{it}^h is the logarithmic mean of the export shares in countries h and F.[7]

[7] Let S_{it}^h denote export/(export + domestic) sales in sector i and country h. Then W_{it}^h is constructed as: $[(S_{it}^h - S_{it}^F)/(\ln S_{it}^h - \ln S_{it}^F)]/\{[(S_{it}^h - S_{it}^F)/(\ln S_{it}^h - \ln S_{it}^F)] + [(1-S_{it}^h)-(1-S_{it}^F)]/[\ln(1-S_{it}^h)-\ln(1-S_{it}^F)]\}$.

The first equality in (24) follows directly from the Sato-Vartia formula, which allows us to evaluate the ratio of CES functions without knowledge of the fixed costs (f_{ix}/f_i), but using the data on export shares instead. The second equality follows by algebra; and the third equality follows by using (14) to replace the export/domestic shift parameters with relative export variety.

The decomposition in (24) is as far as the theory can take us, and to measure this formula, we rely on two assumptions. First, we have no data to measure the domestic shift parameters A^h_{idt} in each sector appearing in (24), and will assume that they reflect *country-level* prices P^h_t plus a sectoral error term:

$$\ln\left(\frac{A^h_{idt}}{A^F_{idt}}\right) = \ln\left(\frac{P^h_t}{P^F_t}\right) + u^h_{1it}. \tag{25}$$

This simplification in (25) is justified by the idea that prices are the usual variables that appear in a GDP function under perfect competition, so we are using prices in place of the domestic shift parameters, though the prices are measured at the country (rather than sector) level.

Second, as discussed in the next section, we will be measuring export variety in country h relative to country F, which is (M^h_{ixt}/M^F_{ixt}). In contrast, the term appearing in (24) is the export variety relative to domestic variety, $(\chi^h_{it}/\chi^F_{it})$, in country h compared to F. Once again, we have no data that would allow us to measure the domestic product varieties, so we will be using export variety instead of export/domestic variety:

$$\ln\left(\frac{\chi^h_{it}}{\chi^F_{it}}\right) = \ln\left(\frac{M^h_{ixt}}{M^F_{ixt}}\right) - u^h_{2it}. \tag{26}$$

where $u^h_{2it} \equiv \ln(M^h_{it}/M^F_{it})$ are the omitted domestic varieties.

Substituting (25) and (26) into (24), we obtain the sectoral CES functions:

$$\ln\left[\frac{\psi_i(A^h_{idt}, A^h_{ixt})}{\psi_i(A^F_{idt}, A^F_{ixt})}\right] = \ln\left(\frac{P^h_t}{P^F_t}\right) + \frac{(\sigma_i - 1)}{\sigma_i\theta_i} W^h_{it}\left(\frac{M^h_{ixt}}{M^F_{it}}\right) + u^h_{1it} - \frac{(\sigma_i - 1)}{\sigma_i\theta_i} W^h_{it} u^h_{2it}. \qquad (27)$$

Differencing the share equation (22) with respect to country F and using (27), we obtain:

$$s^h_{it} = s^F_{it} + \sum_{j=1}^{N} \rho_j \gamma_{ij} W^h_{jt} \ln\left(\frac{M^h_{jxt}}{M^F_{jxt}}\right) + \gamma_{iN+1} \ln\left(\frac{\psi^h_{N+1t}/P^h_t}{\psi^F_{N+1t}/P^F_t}\right) + \sum_{k=1}^{K} \phi_{ik} \ln\left(\frac{v^h_{kt}}{v^F_{kt}}\right) + \varepsilon^h_{it}, \qquad (28)$$

where $\rho_j = (\sigma_j - 1)/\theta_j\sigma_j$ and the error ε^h_{it} in (28) consists of the errors $(u^h_{1it} - \rho_j W^h_{it} u^h_{2it})$ times γ_{ij} and summed across the all sectors j=1,…,N. Notice that the country-level prices P^h_t deflate the non-traded prices ψ^h_{N+1t} in (28), but do not appear otherwise by using $\sum_{j=1}^{N+1} \gamma_{ij} = 0$.

One problem with the share equations (28) is that the parameters $\rho_j = (\sigma_j - 1)/\theta_j\sigma_j$ cannot be separately identified from the translog parameters γ_{ij}. To overcome this, we estimate the share equations jointly with a country-level productivity equation, obtained by differencing the GDP equation (20) with respect to country F:

$$\ln\left(\frac{R^h_t(\psi^h_t, V^h_t)}{R^F_t(\psi^F_t, V^F_t)}\right) = \alpha^h_0 + \beta_{0t} + \sum_{i=1}^{N+1} \tfrac{1}{2}\left(s^h_{it} + s^F_{it}\right) \ln\left(\frac{\psi^h_{it}}{\psi^F_{it}}\right) + \sum_{k=1}^{M} \tfrac{1}{2}\left(s^h_{kt} + s^F_{kt}\right) \ln\left(\frac{v^h_{kt}}{v^F_{kt}}\right). \qquad (29)$$

The right-hand side of (29) equals fixed effects, plus a share-weighted index of relative prices, plus a share-weighted index of relative endowments.[8] These terms provide a decomposition of relative GDP into its price and factor-endowment components.[9]

We can simplify (29) by using the ratio of CES aggregates (27), and moving the factor endowments and non-traded prices to the left:

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[8] The country fixed-effect and time trend appearing in (29) should actually be the *difference* between the country h fixed-effect or time trend and the corresponding term for the comparison country F.

[9] The decomposition in (29) is a special case of results in Diewert and Morrison (1986), which are summarized by Feenstra (2004, Appendix A, Theorem 5).

$$TFP_t^h \equiv \ln\left(\frac{RGDP_t^h}{RGDP_t^F}\right) - \sum_{k=1}^{K} \tfrac{1}{2}(s_{kt}^h + s_{kt}^F)\ln\left(\frac{v_{kt}^h}{v_{kt}^F}\right) - \tfrac{1}{2}(s_{N+1t}^h + s_{N+1t}^F)\ln\left(\frac{\psi_{N+1t}^h / P_t^h}{\psi_{N+1t}^F / P_t^F}\right)$$
$$= \alpha_0^h + \beta_{0t} + \sum_{i=1}^{N} \tfrac{1}{2}(s_{it}^h + s_{it}^F)\rho_i W_{it}^h \ln\left(\frac{M_{ixt}^h}{M_{ixt}^F}\right) + \varepsilon_t^h, \qquad (30)$$

where real GDP is $RGDP_t^h \equiv R_t^h(\psi_t^h, V_t^h)/P_t^h$. The left-hand side of (30) is interpreted as total factor productivity (TFP) differences between country h and country F, with an adjustment for non-traded good prices. These TFP differences across countries are explained by differences in export variety on the right, plus an error term obtained from the sectoral errors ε_{it}^h.

3.3 Measuring Export Variety

The measure of export variety we use is derived from a CES utility function by Feenstra (1994), and has been employed recently by Hummels and Klenow (2005), who call it the "extensive margin," and by Broda and Weinstein (2005). Rather than indexing prices by the continuous productivity φ_i in sector i, we instead indexes prices by the discrete variable $j \in J_{it}^h$. So $p_{it}^h(j)$ is the export price for variety j in sector i, year t and country h, with quantity $q_{it}^h(j)$.

Suppose that the set of exports from countries h and F differ, but have some product varieties in common. Denote this common set by $J \equiv \left(J_{it}^h \cap J_{it}^F\right) \neq \varnothing$. From Feenstra (1994), an inverse measure of export variety from country h is:

$$\lambda_{it}^h(J) \equiv \frac{\sum_{j\in J} p_{it}^h(j) q_{it}^h(j)}{\sum_{j\in J_{it}^h} p_{it}^h(j) q_{it}^h(j)} \quad . \qquad (31)$$

Notice that $\lambda_{it}^h(J) \leq 1$ in (31) due to the differing summations in the numerator and denominator. This term will be strictly less than one if there are goods in the set J_{it}^h that are *not found* in the common set J. In other words, if country h is selling some goods in period t that are *not sold* by country F, this will make $\lambda_{it}^{h}(J) < 1$. The more unique goods that are exported by country h and not country F, the lower is the value of $\lambda_{it}^{h}(J)$, so it is an *inverse measure* of country h export variety. The ratio, $[\lambda_{it}^{F}(J)/\lambda_{it}^{h}(J)]$ therefore measures the export variety of country h relative to country F. It increases with the variety of goods exported from country h, decreases with the variety of goods exported from country F.

We use $[\lambda_{it}^{F}(J)/\lambda_{it}^{h}(J)]$ in place of $(M_{ixt}^{h}/M_{ixt}^{F})$ in (28) and (30). Furthermore, we shall measure the ratio $[\lambda_{it}^{F}(J)/\lambda_{it}^{h}(J)]$ using exports of countries to the United States. While it would be preferable to use their worldwide exports, our data for the U.S. are more disaggregate and allows for a finer measurement of "unique" products sold by one country and not another. Specifically, for 1980 – 1988 we use the 7-digit Tariff Schedule of the U.S. Annotated (TSUSA) classification of U.S. imports, and for 1989 – 2000 we use the 10-digit Harmonized System (HS) classification.

To measure the ratio $[\lambda_{it}^{F}(J)/\lambda_{it}^{h}(J)]$, we need a consistent comparison country F. For this purpose, we shall use the *worldwide exports* from all countries to the U.S. as the comparison. Furthermore, we take the union of all products sold in any year, and we average real export sales of each product over years. Denote this comparison country by F, so that the set $J_{i}^{F} = \bigcup_{h,t} J_{it}^{h}$ is the *total set of varieties* imported by the U.S. in sector i over all years, and $p_{i}^{F}(j)q_{i}^{F}(j)$ is the *average real value of imports* for product j (summed over all source countries and averaged across years). Then comparing country h=1,…,H to country F, it is immediate that the common set of goods exported is $J \equiv J_{it}^{h} \cap J_{i}^{F} = J_{it}^{h}$, or simply the set of goods exported by country h. Therefore, from (31) we have that $\lambda_{it}^{h}(J) = 1$, and export variety by country h is measured by:

$$\Lambda_{ixt}^{h} \equiv \frac{\lambda_{it}^{F}(J)}{\lambda_{it}^{h}(J)} = \frac{\sum_{j \in J_{it}^{h}} p_{i}^{F}(j) q_{i}^{F}(j)}{\sum_{j \in J_{i}^{F}} p_{i}^{F}(j) q_{i}^{F}(j)} . \quad (32)$$

Notice that the measure of export variety in (32) changes over time or across country *only* due to changes in the set of goods sold by that country, J_{it}^{h}, which appears in the numerator on the right. The denominator is constant across countries and time. Therefore, (32) is a measure of product variety of exports that is consistent across countries and over time. Broda and Weinstein (2006) and Hummels and Klenow (2005) each use a similar formula to (31) or (32), but with different "comparison cases": Broda and Weinstein focus on the time-series growth in import varieties in the U.S., so the comparison is import variety in a base year; whereas Hummels and Klenow focus on cross-sectional variety in a given year, so the comparison is worldwide variety in that year. Each of these formulations are appropriate for the question being asked, and by taking the union of all imported products in the U.S. over years and source countries, we obtain a consistent comparison across both dimensions.[10]

Summary statistics for the measure of export variety in (32) are provided in Table 1. There is a strong correlations with real GDP in the exporting countries, shown in the third row. In the next rows we show export variety in each sector for 1980, 1988, 1989 and 2000. There is a discrete fall in export variety from 1988 to 1989, due to the changing classification of U.S. import statistics from the TSUSA to the HS classification. We will account for that discrete fall

[10] We thank a referee for pointing this out that this consistency was needed. If we instead use the worldwide exports to the U.S. in *each* year as the comparison, then the measures of export variety obtained are somewhat higher than those reported in Table 1.

by including year fixed-effects in all our estimating equations. Taking the growth rate of export variety over 1980-1988 and 1989-2000, the average growth is 3.3% per year, which means that export variety increases by 1.9 times over the two decades.[11] That average growth and total increase are shown in the final rows of Table 1, and are lower in the agriculture sector, wood and paper, and mining and metals, but higher in the electronics industry.

3.4 Other Data

Our data set is an unbalanced panel of 48 countries from 1980 to 2000, a total of 532 observations. The GDP and endowment data are obtained from World Development Indicators (World Bank, 2005). Real GDP is measured in constant 2000 U.S. dollars (converted at nominal exchange rates that year), so we are using GDP deflators to measure P_t^h and $RGDP_t^h$. There are three primary factor endowments: labor, capital and agriculture land. Labor is defined as the number of persons in the labor force of each country. Capital is constructed from real investment using the perpetual inventory method.[12] Endowments of the comparison country F are measured by the sum of endowments for all sample countries, $v_{kt}^F = \sum_{h=1}^{H} v_{kt}^h$.

We aggregate goods into N = 7 sectors, as shown in Tables 1 and 2. The value added of these sectors are available in a UNIDO data set, used to construct the value added share of each sector, s_{it}^h. The 8th sector is the nontraded good, with price ψ_{8t}^h obtained by netting the prices of traded goods, both export and import, from the country GDP deflators. This procedure may

[11] The highest growth rates of export variety are shown by Turkey, Iceland, Bulgaria, and Thailand, which start with very low variety. The lowest growth rates are shown by Peru, Canada, Sweden, the U.K. and Japan, which start with high variety (except for Peru). Israel, South Korea, Costa Rica, Ireland and Singapore have growth rates of export variety to the U.S. of 2.5%, 2.7%, 3.3%, 3.9% and 4.6% per year, respectively.

[12] Real investment is obtained by deflating the gross domestic capital formation of countries with that item's GDP deflator. In addition, we construct the base year capital stock using an infinite sum series of investment prior to the first year, assuming that the growth rate of investment in the first five years proxy investment prior to the first year.

introduce some errors into the nontraded price, which we address using instrumental variables.[13]

In Table 2 we show the sectoral shares for each traded sector, which jointly account for 20% of GDP on average. Instruments used to address the endogeneity of export variety, as well as measurement error in the nontraded prices, consist of U.S. tariffs with each partner country, free trade agreements and distance to the U.S. The U.S. tariffs vary by sector, countries and years, and are summarized in Table 2. The textiles and garments sector has the highest tariffs, and a correlation of –0.16 with export variety. In the final rows of Table 2 we also show the drop in tariffs from 1980-2000, which are modest in size: –5.4 percentage points in electronics, and less than that in all other sectors. The small cuts in U.S. tariffs means that this variable will not be able to account for the large growth in export variety.

3.5 Estimating Equations

Substituting for export variety Λ_{ixt}^{h} and the relative nontraded price $(\psi_{8t}^{h} / P_{t}^{h})$ in (28), the share equations become:

$$s_{it}^{h} = s_{it}^{F} + \sum_{j=1}^{7} \gamma_{ij} \rho_i W_{jt}^{h} \ln(\Lambda_{jxt}^{h}) + \gamma_{i8} \ln\left(\frac{\psi_{8t}^{h} / P_{t}^{h}}{\psi_{8t}^{h} / P_{t}^{F}} \right) + \sum_{k=1}^{3} \phi_{ik} \ln\left(\frac{v_{kt}^{h}}{v_{kt}^{F}} \right) + \varepsilon_{it}^{h} . \qquad (33)$$

We allow for year fixed effects when estimating (33). Homogeneity of degree zero in prices and endowments is tested by $\sum_{j=1}^{8} \gamma_{ij} = 0$ and $\sum_{k=1}^{3} \phi_{ik} = 0$, respectively.

Testing homogeneity of the TFP equation is slightly more complicated, because with the shares of sectors and factors summing to unity in (30), it is automatically homogeneous of degree one in both. To test that TFP is homogeneous of degree one in prices, we rewrite the non-traded

[13] The nontraded goods price for the comparison country is a weighted average of the country nontraded goods price indexes. As discussed in section 4, instruments include U.S. tariffs, a NAFTA dummy, distance and its squares between exporting countries and the U.S., and relative factor endowments.

share in (30) as $-\frac{1}{2}(s^h_{N+1t}+s^F_{N+1t})=\frac{1}{2}\sum_{i=1}^{7}(s^h_{it}+s^F_{it})-1$. Keep $\frac{1}{2}\sum_{i=1}^{7}(s^h_{it}+s^F_{it})\ln\left(\frac{P^h_{8t}/P^h_t}{P^F_{8t}/P^F_t}\right)$ on

the left but move $\ln\left(\frac{P^h_{8t}/P^h_t}{P^F_{8t}/P^F_t}\right)$ to the right of (30), while introducing the coefficient η_1 this term.

Then $\eta_1 = 1$ tests that the TFP equation is homogeneous of degree one in prices.

We use a similar approach to test that TFP is homogeneous of degree one in endowments. In this case we do not have the separate capital and land shares, though we do have the labor share of GDP.[14] So letting η_2 denote the average share of land, the weighted endowments appearing on the left of (30) can be written as:

$$-\sum_{k=1}^{K}\frac{1}{2}\left(s^h_{kt}+s^F_{kt}\right)\ln\left(\frac{v^h_{kt}}{v^F_{kt}}\right)=-\frac{1}{2}\left(s^h_{Lt}+s^F_{Lt}\right)\ln\left(\frac{\ell^h_t}{\ell^F_t}\right)-\left[1-\frac{1}{2}\left(s^h_{Lt}+s^F_{Lt}\right)-\eta_2\right]\ln\left(\frac{k^h_t}{k^F_t}\right)-\ln\left(\frac{T^h_t}{T^F_t}\right),$$

where we measure the labor/land and capital/land endowments as $\ln\ell^h_t\equiv\ln(L^h_t/T^h_t)$ and $\ln k^h_t\equiv\ln(K^h_t/T^h_t)$, respectively. Those two terms continue to appear on the left of (30), but we move $-\eta_2\ln(k^h_t/k^F_t)$ and $\ln(T^h_t/T^F_t)$ to the right. We introduce the coefficient η_3 on the latter term, where $\eta_3 = 1$ tests that the TFP equation is homogeneous of degree one in endowments.

To implement these homogeneity tests we define "adjusted" TFP as:

$$\text{Adj. TFP}^h_t\equiv\ln\left(\frac{RGDP^h_t}{RGDP^F_t}\right)-\frac{1}{2}(s^h_{Lt}+s^F_{Lt})\ln\left(\frac{\ell^h_t}{\ell^F_t}\right)-\left[1-\frac{1}{2}(s^h_{Lt}+s^F_{Lt})\right]\ln\left(\frac{k^h_t}{k^F_t}\right)+\frac{1}{2}\sum_{i=1}^{7}(s^h_{it}+s^F_{it})\ln\left(\frac{\psi^h_{8t}/P^h_t}{\psi^F_{8t}/P^F_t}\right)$$

Then the TFP equation (30) is rewritten as:

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[14] We thank Ann Harrison for providing this data.

$$\text{Adj. TFP}_t^h = \alpha_0^h + \beta_{0t} + \eta_1 \ln\left(\frac{\psi_{8t}^h / P_t^h}{\psi_{8t}^F / P_t^F}\right) - \eta_2 \ln\left(\frac{k_t^h}{k_t^F}\right) + \eta_3 \ln\left(\frac{T_t^h}{T_t^F}\right)$$
$$+ \sum_{i=1}^{7} \tfrac{1}{2}(s_{it}^h + s_{it}^F)\rho_i W_{it}^h \ln(\Lambda_{ixt}^h) + \varepsilon_t^h. \qquad (34)$$

With the estimated parameters from (34), we can reconstruct the country TFP differences as:

$$\text{Estimated TFP}_t^h \equiv \text{Adj. TFP}_t^h - \hat{\eta}_1 \ln\left(\frac{\psi_{8t}^h / P_t^h}{\psi_{8t}^F / P_t^F}\right) + \hat{\eta}_2 \ln\left(\frac{k_t^h}{k_t^F}\right) - \hat{\eta}_3 \ln\left(\frac{T_t^h}{T_t^F}\right)$$
$$= \hat{\alpha}_0^h + \hat{\beta}_{0t} + \sum_{i=1}^{7} \tfrac{1}{2}(s_{it}^h + s_{it}^F)\hat{\rho}_i W_{it}^h \ln(\Lambda_{it}^h) + \hat{\varepsilon}_t^h, \qquad (35)$$

which shows how estimated TFP is related to export variety and an error term.

We need to use nonlinear system estimation to estimate equations (33) and (34). In the next section, we proceed by estimating a full nonlinear 3SLS estimation with instrumental variables. A series of specification tests are performed: for homogeneity in prices, $\sum_{j=1}^{8} \gamma_{ij} = 0$ in (33) and $\eta_1 = 1$ in (34); homogeneity in endowments, $\sum_{k=1}^{3} \phi_{ik} = 0$ in (33) and $\eta_3 = 1$ in (34); symmetry, $\gamma_{ij} = \gamma_{ji}$ in (33); as well as the over-identifying restrictions on the instruments.

Given that the system is highly complex and nonlinear, we need to estimate the parameters by stages. We first de-mean (34) to remove country fixed effects. Next we estimate the time fixed effects of (33) and (34) by holding all the rest of parameters at some starting values. The estimated time fixed effects is then held constant while we estimate all the rest of the parameters. We repeat the process to make sure that the time fixed effects converge to the same points (where the sum of the differences in the estimated time fixed effects is less than 0.5%). From then on, we hold the time fixed effects constant to estimate the rest of the parameters by the following iterations.

As ρ_i and γ_{ij} enters (33) multiplicatively, we first estimate all the γ_{ij} holding ρ_i constant. Subsequently we estimate all the ρ_i holding all the γ_{ij} at the level we have just estimated. We repeat the process and calculate the distance between the objective functions of the two rounds. We repeat the process until convergence occurs, which is when the distance is less than 0.5%.

4. Estimation Results

Table 3 presents the result of the nonlinear system of share equations (33) with the country TFP equation (34), estimated using three stage least squares regressions (3SLS). For brevity we report only one set of results: with the symmetric and homogeneity constraints in prices and endowments imposed in the share equations, [15] but testing for homogeneity in the TFP equations by allowing for $\eta_1 \neq 1$ and $\eta_3 \neq 1$. Columns (1) to (7) of the table show the estimated coefficients of each of the sectoral share equations, and the last column shows the estimated coefficients of the TFP equation.

In the top part of Table 3 in columns (1) to (7) we report γ_{ij}, which are the partial price effects due to export variety changes of the industry in the rows on the share of industries in the columns. All the own-price effects γ_{jj} are positive and most are highly significant. In other words, the underlying supply curves of these industries are positively sloped. The bottom part of Table 3 in columns (1) to (7) presents the Rybczynksi effects of endowments on the share of each industry. Positive point estimates indicate industry share expansions due to the increases in that endowments. For example, an increase in the labor endowment relative to land benefits the electronics industry.

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[15] Homogeneity in endowments means that (33) can be written as depending on the labor-land ratio and the capital-land ratio. Since the share equations sum to unity across sectors, their errors sum to zero. So one equation should be omitted for estimation, and we omit the share equation for the nontraded sector.

The top half of column (8) in Table 3 presents the 3SLS estimates of $\rho_i = (\sigma_i - 1)/\theta_i\sigma_i$ for each sector. All the point estimates are positive, and are smaller than one, implying that the elasticities of substitution exceed unity and that the restriction $\theta_i > \sigma_i - 1$ in (12) holds. The industry with the highest value of $\rho_i = 0.791$ is electronics, so that increases in export variety contribute the most to country productivity, whereas the industry with the lowest value of $\rho_i = 0.206$ is agriculture, so export variety contributes little to productivity. While we cannot separately identify the elasticity of substitution from the Pareto parameter θ_i, one interpretation of these findings is that agriculture has a high value of σ_i, or a high value of θ_i as compared to $(\sigma_i - 1)/\sigma_i$. High σ_i means homogeneous products, whereas high θ_i means there is little dispersion in firm productivities, both of which seem appropriate for agriculture. The low value of ρ_i for electronics can be explained by heterogeneous products (low σ_i) or a wide dispersion of productivities (low θ_i as compared to $(\sigma_i - 1)/\sigma_i$), which again seem reasonable.

The coefficient of the capital-land ratio in the lower part of column (8) in Table 3, which has the interpretation of the negative share of land in GDP is about 11 percent. The coefficient on the relative land size (shown in the labor-land row) is statistically less than one, which implies that homogeneity in factor endowments is rejected. Likewise, the coefficient η_1 on the price of nontraded goods is significantly less than one, which violates the homogeneity constraint on prices in the TFP equation.

Instruments used in Table 3 consisting of U.S. tariffs for textiles and apparels (the industry are among most protected) varying by source country and year, a NAFTA dummy, distance and its squares between exporting countries and the U.S. (in kilometers), and relative endowments. We did not include transport costs to the U.S. due to their potential endogeneity.[16] Given that the above nonlinear 3SLS estimation involves minimizing the criterion function, the minimized value provides a test statistic for hypothesis testing. The difference between the values of the criterion functions of the restricted and unrestricted models is asymptotically chi-squared distributed with degree of freedom equal to the number of restrictions. According to Davidson and MacKinnon (1993, p. 665), it is important that the same estimate of variance-covariance matrix be used for both the restricted and unrestricted estimations, in order to ensure that the test statistic is positive. We use the variance-covariance matrix of the unrestricted model.

Table 4 presents the test statistics and the associated p-values of the hypothesis tests. First, we test the homogeneity constraints on prices and endowments in the share equations, along with the homogeneity constraint in endowments in the TFP equation. As shown in the first row of Table 4, these homogeneity constraints are not rejected. If we also test the homogeneity constraint on prices in the TFP equation (i.e. $\eta_1 = 1$), that constraint is easily rejected, possibly due to measurement errors in nontraded good prices. So that constraint is not imposed.

Next, the twenty-one symmetry constraints on the cross-price effects are tested on the whole system, which are not rejected. Third, we test for the 8 over-identifying restrictions due to the extra instruments, which are not rejected. Finally, the overall specification of the system is tested by jointly testing all these 36 constraints. This is done by comparing the value of criterion function of the restricted model to a just-identified model with no symmetry constraints and no extra instruments. The whole set of restriction are again not rejected, which supports the symmetry and homogeneity constraints and the validity of instruments. In the next section we explore the instruments further by reporting their regressions with export variety.

[16] Countries that trade more with the U.S. may have lower transport costs as a result, as noted by a referee.

4.1 Effects of Tariffs and Distance on Export Variety

Table 5 presents least squares (LS) estimation linking export variety to all instruments and exogenous variables of the nonlinear 3SLS system presented in Table 3. This is similar but not identical to the first-stage estimation of the nonlinear system, which involves regressing the derivatives of each equation with respect to the parameters of the system on all the instruments and exogenous variables. In comparison, the regressions we present in Table 5 just uses the export variety index $\ln \Lambda_{it}^{h}$ as a dependent variable, which allows us to see the relationship between export variety and the tariff and distance variables.

The top part of Table 5 shows the effects of U.S. tariffs on the export variety of the industry in the columns. We expect industry export variety to decrease with its own tariff, while there may exist some positive effects (due to reallocation of resources among industries) when there is a tariff increase in *other* industries. All industry export variety indexes are negatively correlated with own tariffs except for the textiles & garments and the electronics industries. For textiles & garments, the positive effect of tariffs on export variety could be due to the influence of MFA quotas, which are known to be more restrictive and binding than tariffs. For the electronics industry, it could be the case that other features (such as non-tariff barriers and skilled labor endowments) are more important in explaining expansion in export variety than tariffs.

A one percentage point increase in U.S. tariffs on petroleum and plastics lowers export variety of that industry by 17%, at the highest, and a similar increase in the wood and paper tariff lowers export variety of the industry by 3.8%, at the lowest. While these semi-elasticities show that tariffs have a statistically significant impact on product variety in most industries, the economic magnitude of this effect is very modest. From the last rows of Table 2, we know that the observed drop in U.S. tariffs over 1980-2000 are quite small. Using these tariff reductions and the semi-elasticities in Table 5, we can calculate that the drop in U.S. tariffs has increased export variety by only 8.3% over the two decades (or 28% if we ignore the estimates for the textiles and garments and electronics industries). Recalling that average export variety increased by 1.9 times over 1980-2000 (from Table 1), we conclude that fall in U.S. tariffs explains only a very small part of export variety growth.

The next section of Table 5 shows the marginal effects of NAFTA on export variety. Given that we already control for tariffs, these variables capture the effect of the reduction in non-tariff barriers due to the signing of such agreements on export variety. NAFTA is shown to have significant positive effects on the export variety of agriculture, textiles & garments and machinery and transport equipment, and has a significant negative effect on the export variety of the petroleum and plastics industry.

The third section of Table 5 relates distance (in log of kilometers) and its squares to the export variety of the industries. Overall, the further a country is from the U.S., the less variety is exported. Such negative effects are particularly significant for the machinery and transport equipment industry, as well as the electronics industry. However, the effects are not linear since the coefficients on distance squares are mostly positive, which indicates that that marginal effect of each addition kilometer diminishes with the overall distance between the two countries. Other than tariffs, distance and its squares, we have also included all the right-hand side exogenous variables in Table 3 in the regressions. These variables are a full set of year fixed effects, the labor-land ratio, capital-land ratio, non-traded goods prices, and land area. The vast majority of the increase in export variety over time is explained by the year fixed effects, while the other variables explain its variation across countries. This result could indicate that the falling fixed costs of exporting that are common across countries, such as the modernization of container ports, faster and better shipping lines, are the main factors behind the expansion in export variety. We leave an exploration of that possibility for future research.

4.3 Productivity Decomposition

To gain additional insight into the links between export variety and country productivity, we performed panel regressions of estimated productivity on export variety (constructed from the estimates in Table 3). As in (35), we regress estimated country TFP to that portion due to export variety, $\sum_{i=1}^{7} \frac{1}{2}(s_{it}^{h} + s_{it}^{F})\hat{\rho}_i W_{it} \ln(\Lambda_{it}^{h})$. Figure 1 plots the scatter graph of country TFP against industry export variety. Both variables are averaged over time so this scatter plot is equivalent to a "between" regression. It is evident that export variety has significant explanatory power for the variation of the country productivity differences: R^2=0.48 for this univariate regression. The problem with this "between" regression, however, is that it *omits* country fixed-effects, which should be included to reflect exogenous technological progress across countries.

Running panel regressions including country and time fixed effects, as in (34), in Table 6 we report the amount of variance explained by each term. In the total sample, export variety can explain 1% of the overall variation in country TFP, along with 31.1% of within-country TFP variation, but only 0.3% of the between-country variation. Thus, export variety is strongly correlated with the variation in country TFP over time, but explains only a tiny fraction of the variation in TFP across countries. This finding continues to hold if we investigate only the OECD countries (using the same parameters estimates as in Table 3). In that case, export variety explains 6.2% of the overall variation in country TFP, and 52.2% of the within-country TFP variation, but just 3.3% of the between-country variation.

To further illustrate the effects of export variety on country productivity, according to (34), a 1% increase in the export variety of each industry would increase country productivity by

$\frac{1}{2}(s_{it}^{h} + s_{it}^{F})\hat{\rho}_i W_{it}^{h}$ percent. Thus, we can compute that at the sample mean, a doubling of export varieties of all industries could lead to 3.6% increase in country productivity. This effect is significant both statistically and economically. It implies that the 1.9 times expansion of export variety over 1980-2000 explains a 3.3% increase in exporters' productivity. Recall that average export variety itself also increased by 3.3% per year. So as a rule-of-thumb, our estimates show that a *sustained* increase of x% per annum in export variety over two decades leads to a x% overall productivity improvement for the exporter.[17] This is an estimate of the endogenous portion of productivity gains that is consistent with the monopolistic competition model. As noted above, however, the variety increase itself is not well-explained by the marginal trade costs such as tariff cuts or other variables that change over countries and time; instead, the increase in export variety is predicted mainly by the time fixed effects. In this sense, our results do not give a full account of the mechanism of increased export activity and resulting productivity growth in the monopolistic competition model.

The time series linkage between export variety and productivity can be seen from Figures 3 and 4. Figure 3 compares Canada to the sample mean in terms of productivity, and average export variety, from 1980 to 2000. The relative export variety index is measured on the vertical left-hand scale, while relative country TFP index is measured on the right-hand scale. It is clear that these two series move together closely. In the years just after the Canada-U.S. free trade agreement in 1989, Canada has a boost in its export variety to the U.S. and in its TFP, but afterwards experienced a decline in both indexes relative to other countries. Figure 4 compares Japan to South Korea. Similar to the previous figure, average export variety is measured on the

[17] The countries with highest growth of export variety to the U.S., of 7.4 – 11% per year, are listed in note 11, and the countries with lowest variety growth (0.8% for Peru and 1.0 – 1.6% for the others) are also listed there. The implied country productivity growth over 1980-2000 will differ from these magnitudes to the extent that the export and value-added shares of these countries deviate from the sample averages.

left-hand scale, while the productivity of Japan relative to Korea is measured on the right-hand scale. The movements of the two lines suggest that over the twenty year period, South Korea is catching up in terms of export variety as well as country productivity.

5. Conclusions

Current research in international trade (Melitz, 2003) has stressed that productivity is endogenous through the self-selection of exporters: exporters are more productive on average than domestic firms, so an increase in export activity is associated with rising productivity. In this paper we have attempted to estimate the relation between export variety and productivity using a GDP function across countries and over time. We have shown that a CES measure of export variety enters the GDP function like a sectoral "price". We have treated export variety as an endogenous variable, and as instruments use those suggested by Melitz (2003): tariffs, trade agreements and distance.

The measure of export variety we use is constructed to be consistent across countries and over time. It shows an average 3.3% per annum increase in export variety to the U.S. over 1980-2000. Only a small amount of that increase is explained by observed cuts in U.S. tariffs. Corresponding to the 3.3% sustained growth in export variety over two decades is a 3.3% productivity gain in the exporting countries. That estimate is larger than the *gains to the U.S.* from increased import variety over 1972-2001, which amount to 2.6% of GDP in 2001 according to Broda and Weinstein (2005). Our estimate can be interpreted as the endogenous portion of productivity gains for exporters (with the caveat that the variety increase itself is not well-explained by tariff cuts). Overall, the model can explain 31.1% of the within-country variation in productivity (or 52.2% for the OECD countries), but only a very small fraction of between-country variation. We conclude that export variety in the monopolistic competition model with heterogeneous firms is quite effective at accounting for the time-series variation in productivity, but not the large absolute differences in productivity between countries.

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Table 1: Summary Statistics for Export Variety

	Overall Industry	Agriculture	Textiles & Garments	Wood & Paper	Petroleum & Plastics	Mining & Metals	Machinery & Transport	Electronics
				Export Variety (percent)				
Mean	34.2	27.8	47.6	37.9	31.6	25.1	26.0	37.4
Stan.Dev.	19.1	14.4	22.6	21.0	26.4	19.9	23.6	23.3
Correlation with GDP	0.54	0.35	0.42	0.49	0.31	0.59	0.59	0.44
1980	25.1	26.1	29.8	28.0	22.3	21.7	19.2	27.0
1988	32.2	30.7	37.4	31.6	41.4	23.0	18.1	34.7
1989	30.5	23.4	50.9	38.8	30.1	22.4	25.5	27.5
2000	44.3	27.5	61.1	45.9	37.2	29.1	36.6	51.8
Annual Growth, 1980-	3.1	2.0	2.9	1.5	7.8	0.8	-0.7	3.1
Annual Growth, 1989-	3.4	1.5	1.7	1.5	1.9	2.4	3.3	5.7
Average	3.3	1.7	2.2	1.5	4.4	1.7	1.6	4.6
$\frac{\text{Variety 2000}}{\text{Variety 1980}}$	1.9	1.4	1.5	1.4	2.4	1.4	1.4	2.5

Notes:
1. Correlations with exporter country real GDP are computed across years and countries.
2. Export variety falls from 1988 to 1989 due to the change in classification of U.S. imports, from the TSUSA classification to the Harmonized System.
3. Annual growth is computed as the difference in log varieties, divided by the number of years in the interval.
4. Average growth = [(annual growth, 1980-1988)×8.5 + (annual growth, 1989-2000) ×11.5]/20. This calculation attributes average growth in export variety for the 1988-1989 year, when growth is not observed.
5. (Variety 2000/Variety 1980) = exp(average growth×20).

Table 2: Summary Statistics for Traded Sectors

	Overall Industry	Agriculture	Textiles & Garments	Wood & Paper	Petroleum & Plastics	Mining & Metals	Machinery & Transport	Electronics
				Value Added Share in GDP (percent)				
Mean	2.8	4.0	2.2	2.2	3.6	2.2	2.6	3.0
Stan. Dev.	0.8	1.8	1.5	1.1	1.8	1.1	1.7	2.1
				U.S. Tariffs (percent)				
Mean	3.5	2.6	13.0	2.3	2.3	3.4	2.4	3.2
Stan. Dev.	3.5	3.3	7.5	5.0	3.4	5.5	3.2	5.0
Correlation with Variety	-0.25	-0.13	-0.16	-0.14	-0.19	-0.05	-0.09	-0.21
1980	4.1	3.7	14.7	3.1	2.4	4.4	3.1	5.9
2000	2.1	1.4	10.3	0.7	1.0	1.7	1.0	0.5
Difference	-2.0	-2.3	-4.3	-2.4	-1.5	-2.7	-2.1	-5.4

Notes:
1. Correlations between U.S. tariffs and export variety in that sector are computed across years and countries.

Table 3: Dependent Variables - Industry Shares in Columns (1) to (7), and Adjusted TFP in Column (8)

Estimation method: Non-linear Three Stage Least Squares Regressions

Total system observations: 4256

Observations per equation: 532

	Independent Variables:	(1) Agriculture	(2) Textiles & Garments	(3) Wood & Paper	(4) Petroleum & Plastics	(5) Mining & Basic Metals	(6) Machinery & Transports	(7) Electronics	(8) Adj. TFP
Log of Relative Export Variety in:	Agriculture	**0.158*****	-0.122*	-0.075**	0.070***	0.003	0.020*	-0.052***	0.206***
		(0.059)	(0.069)	(0.033)	(0.022)	(0.015)	(0.011)	(0.011)	(0.049)
	Textiles & Garments	-0.122*	**0.312*****	-0.025	-0.098**	0.084**	-0.176***	0.031	0.333***
		(0.069)	(0.112)	(0.065)	(0.040)	(0.033)	(0.025)	(0.020)	(0.051)
	Wood & Paper	-0.075**	-0.025	**0.063**	0.002	-0.063**	0.125***	-0.030**	0.667***
		(0.033)	(0.065)	(0.059)	(0.030)	(0.025)	(0.017)	(0.014)	(0.059)
	Petroleum & Plastics	0.070***	-0.098**	0.002	**0.052****	0.008	0.019**	-0.049***	0.209***
		(0.022)	(0.040)	(0.030)	(0.022)	(0.013)	(0.009)	(0.011)	(0.029)
	Mining & Basic Metals	0.003	0.084**	-0.063**	0.008	**0.028**	-0.058***	0.000	0.785***
		(0.015)	(0.033)	(0.025)	(0.013)	(0.017)	(0.011)	(0.008)	(0.061)
	Machinery & Transports	0.020*	-0.176***	0.125***	0.019**	-0.058***	**0.056*****	0.011	0.726***
		(0.011)	(0.025)	(0.017)	(0.009)	(0.011)	(0.009)	(0.007)	(0.047)
	Electronics	-0.052***	0.031	-0.030**	-0.049***	0.000	0.011	**0.090*****	0.791***
		(0.011)	(0.020)	(0.014)	(0.011)	(0.008)	(0.007)	(0.010)	(0.039)
Log of Relative:	Labor-Land Ratio[1]	0.001	-0.015***	0.012***	0.004***	-0.006***	0.005***	0.006***	0.643***
		(0.001)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.046)
	Capital-Land Ratio	-0.004***	0.007***	-0.005***	-0.001	0.003***	0.003***	0.003***	-0.109***
		(0.001)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.037)
	Non-Traded Goods Prices								0.250***
									(0.016)
	Year Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Country Fixed-Effects								Yes
	R-squared	0.1359	0.0003	0.0219	0.0436	0.0297	0.1749	0.5849	0.8993

Note: For (1) to (7), each coefficient of the log of relative export variety in the row industry is the partial price effect of that industry on the share of the column industry. These are the point estimates of γ_{ij}. Own price effects are in bold.

For (8), each coefficient of the log of relative export variety in the row industry is the point estimate of ρ_i of that industry.

[1] Relative land area for (8).

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels respectively, and White-robust standard errors are in parentheses.

Instruments: effective tariffs, NAFTA dummy, distance, and distance squares, relative land, labor and capital endowments.

Table 4: Hypothesis Testing

Null Hypotheses	Degree of Freedom	Test Statistics	P-values
Homogeneity	7	1.140	0.992
Symmetry	21	11.715	0.947
Over Identifying Restrictions	8	7.650	0.468
Overall Specification	36	32.483	0.637

Table 5: Dependent Variables - Export Variety Index

Estimation method: Ordinary Least Squares

Observations per equation: 509

	Independent Variables:	Eq (1) Agriculture	Eq(2) Textiles & Garments	Eq(3) Wood & Paper	Eq(4) Petroleum & Plastics	Eq(5) Mining & Basic Metals	Eq(6) Machinery & Transports	Eq(7) Electronics
Log of 1+ Effective Tariff of :	Agriculture	**-6.282*****	4.701***	-2.453*	-14.056***	0.766	2.013	-1.412
		(1.535)	(1.381)	(1.370)	(2.534)	(1.674)	(1.771)	(1.376)
	Textiles & Garments	2.273***	**3.732*****	0.522	-2.017	-0.147	1.149	-1.058
		(0.752)	(1.039)	(0.554)	(1.666)	(0.849)	(1.025)	(0.632)
	Wood & Paper	0.641	-1.788	**-3.817*****	-5.648*	-3.174	-3.762*	-2.199
		(1.697)	(1.914)	(1.287)	(3.028)	(1.958)	(2.228)	(1.572)
	Petroleum & Plastics	-7.796***	-0.573	-1.916	**-17.063*****	-2.264	1.812	0.231
		(1.870)	(1.739)	(1.379)	(3.461)	(2.391)	(1.801)	(1.843)
	Mining & Basic Metals	-0.014	1.821	0.731	-6.919**	**-3.219**	5.292***	3.474**
		(1.909)	(1.580)	(1.289)	(2.944)	(2.211)	(1.982)	(1.731)
	Machinery & Transports	-3.348*	-1.867	-1.729	-2.725	-6.686**	**-10.983*****	-6.330***
		(1.895)	(2.334)	(1.706)	(4.287)	(2.690)	(2.771)	(2.103)
	Electronics	0.203	-4.734**	2.165	14.817***	5.123**	4.814**	**1.347**
		(1.725)	(2.135)	(1.528)	(3.808)	(2.410)	(2.127)	(1.938)
	North America Free Trade Agreement	0.309***	0.254**	0.010	-0.565***	0.099	0.363**	0.031
		(0.109)	(0.106)	(0.090)	(0.158)	(0.086)	(0.172)	(0.124)
	Log of Distance	-0.335	-0.281	-0.713**	3.021***	-0.967**	-2.786***	-2.314***
		(0.369)	(0.458)	(0.349)	(1.108)	(0.443)	(0.462)	(0.350)
	$(\text{Log of Distance})^2$	0.006	0.010	0.034	-0.209***	0.053*	0.160***	0.138***
		(0.023)	(0.028)	(0.022)	(0.069)	(0.027)	(0.029)	(0.022)
	Endowment controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	R-squared	0.4967	0.6240	0.7202	0.6135	0.7397	0.8044	0.7246

Note: All figures in bold are the own partial effects of effective tariffs. White robust standard errors are in parentheses.
Effective tariffs are the ratios of duties paid over industry exports.
Endowment controls included are the right-hand side variables of Table 3, which are log of relative labor-land ratio, capital-land ratio, relative land area and nontraded good prices
*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels respectively.

Table 6: Productivity Decompositions

	Overall Variation (in %)		Between-Country Variation (in %)		Within-Country Variation (in %)	
	Full Sample	OECD	Full Sample	OECD	Full Sample	OECD
Variance of Estimated Country TFP	0.636 (100)	0.303 (100)	0.653 (100)	0.298 (100)	0.045 (100)	0.033 (100)
Explained by Country Fixed Effects	0.511 (80.3)	0.177 (58.3)	0.590 (90.4)	0.222 (74.3)		
Explained by Average Variety	0.006 (1.0)	0.019 (6.2)	0.002 (0.3)	0.010 (3.3)	0.014 (31.1)	0.017 (52.2)

Source: Authors calculation based on regression results of Table 3.

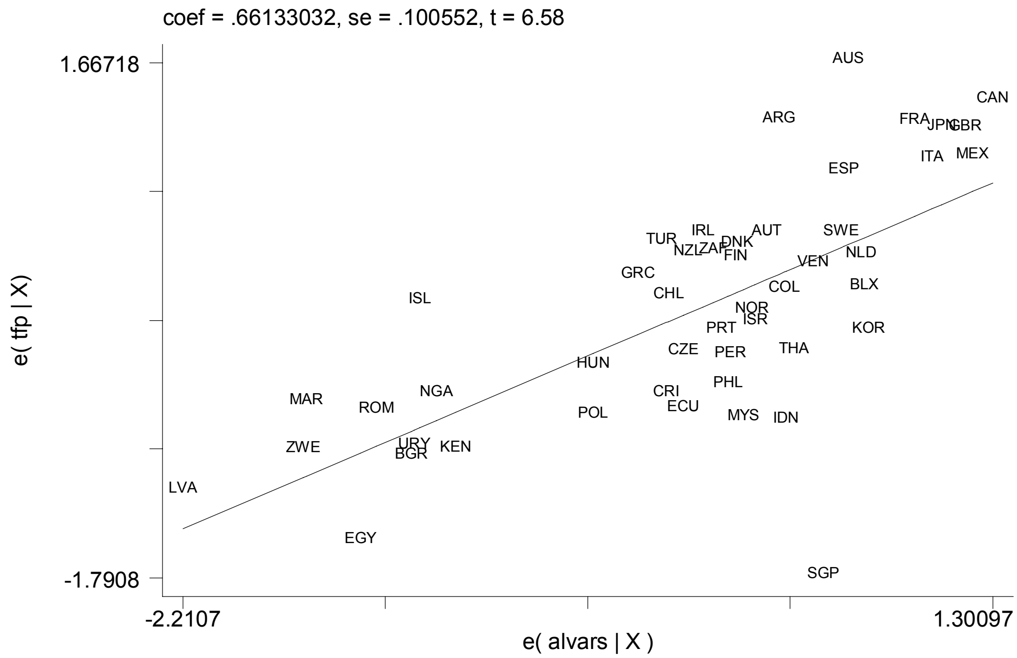

Figure 1: Country Productivity versus Average Export Variety

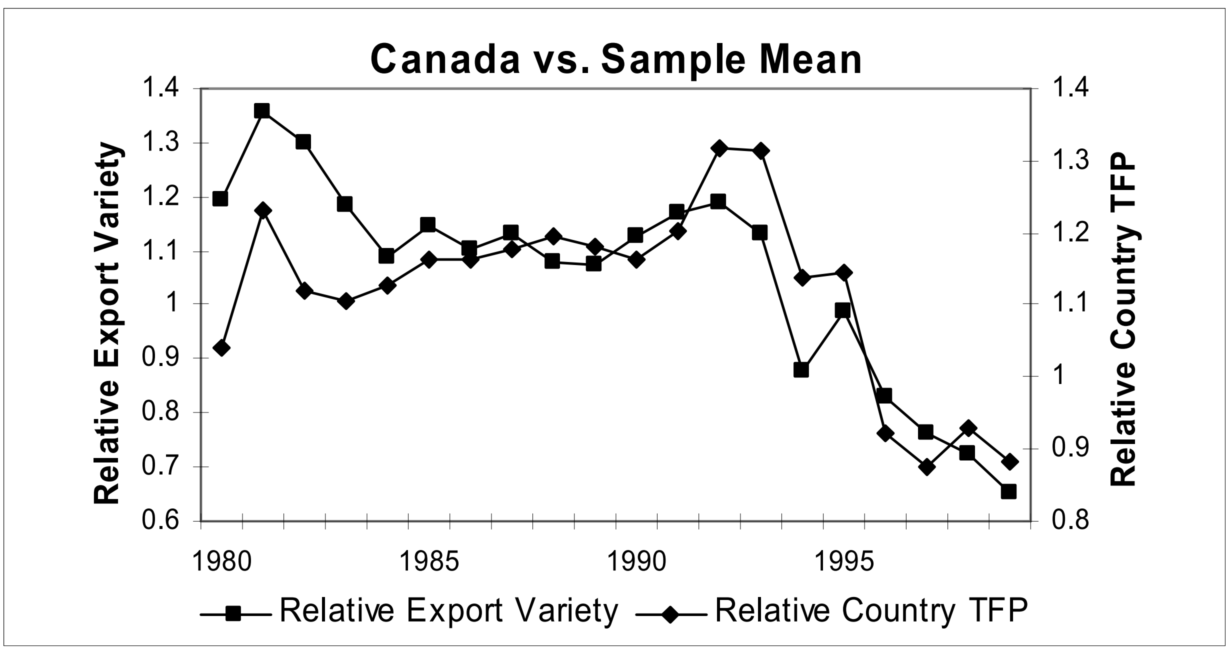

Figure 2: Canada compared to Sample Mean

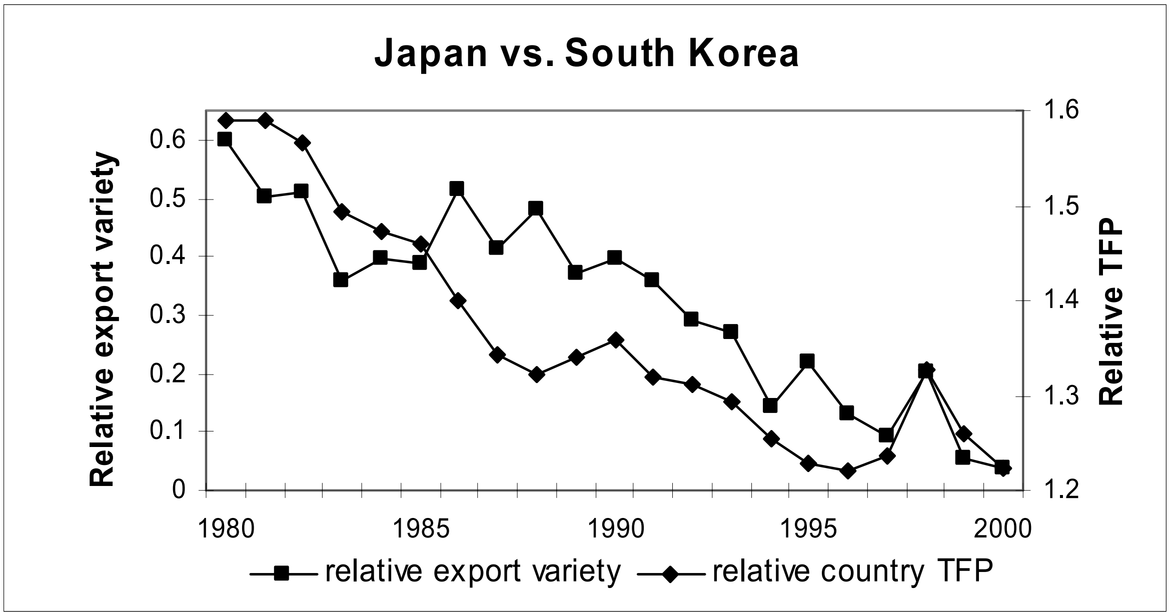

Figure 3: Japan Compared to South Korea