Technology, Gravity and Global Income Distribution*

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Abstract

Does asymmetric growth, like tides, raise boats in one region of the world while stranding them in others? How large a role does economic distance to and from markets play in explaining income per capita differences and their changes? We provide answers in a world economy where distance and borders impose significant barriers to trade. Income shocks raise wages in the region near the shock but lower them far away. The benefit of increased variety tends to offset most of the losses.

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Does asymmetric growth, like tides, raise boats in one region of the world while stranding them in others? How large a role does economic distance to and from markets play in explaining income per capita differences and their changes? We provide answers in a world economy where distance and borders impose significant barriers to trade. In this setting, shifts in supply alter the incidence of trade costs borne by sellers and buyers and do so differentially across countries. Causation importantly goes the other way too as changing sellers' incidence shifts the supply of goods and changing buyers' incidence shifts the demand for goods. We sort these forces out and quantify their importance in a general equilibrium simulation model that retains an attractive intuitive structure.

The empirical gravity model literature establishes that trade costs are high and vary significantly with bilateral distance and bilateral frictions associated with differences in language, culture and openness to inclusion of strangers. Empirical results of Anderson and Yotov (2009, 2010) show that changes in global supply shares over the last 20 years have significantly different effects across countries on the incidence of trade costs borne by sellers and buyers. This translates into impacts on real output that differ in sign across countries and do so significantly. The Anderson-Yotov analysis takes as given the output and expenditure shares observed in the data for each year: the upper level general equilibrium determination of these shares includes the changing incidence of trade costs and changing factoral terms of trade, but is not modeled. These channels may be important, because Anderson and Yotov's results indicate churning in the world economy characterized by negative correlation between output shares and sellers' incidence. This paper embeds gravity in a general equilibrium production model that endogenizes the output and expenditure shares as a platform for a complete analysis of the effect of productivity shocks.

The structural gravity model of this paper is embedded in in a one good-many varieties Krugman-Dixit-Stiglitz monopolistic competition production and preferences structure. Using national product and trade data for 161 countries in 2000, the model is applied to simulate the real income effects of technology shocks on real incomes. Applying realistic

bilateral trade costs that vary by large amounts, closely linked partners gain while more remote partners lose as as growth in the region near an initial shock raises the incidence of trade costs falling on more remote regions. With realistic parameters for bilateral trade costs, and technology levels calibrated to reflect observed income per capita levels, most of the enormous observed differences in income per capita are explained by technology, not geographic location.

This paper analyzes the effects of growth shock propagation including the two way causality between incidence on the one hand and production and expenditure on the other hand. We follow recent literature in focusing on wage changes (Fujita, Krugman, and Venables,2001; Redding and Venables, 2004). We show that the real welfare gains can be quite different from the wage gains. The production structure is Ricardian but with fixed costs for each variety. The world general equilibrium determines the range of varieties produced by each country, the vector of wages (the factoral terms of trade) and the vectors of buyers' and sellers' incidences of trade costs. Real income of the representative agent in each economy is given by the wage deflated by buyers' incidence. Analytic results are limited to special cases, but the simulations are based on a simple intuitive structure that is easy to interpret.

The simulations reveal substantial negative as well as positive responses of the world's economies to technology shocks in key countries.

1. In the initial equilibrium, for reasonable parameter values of trade costs and elasticities, trade costs can account for roughly 5% of the variation in per capita GDP. The other 95 percent is from technology differences. With parameter values consistent with the upper bound of trade costs and agents' love of variety, trade costs account for 19% of the variation in per capita GDP

2. A 20% improvement in technology in the United States results in 11 countries that have higher wages. The total gain in world GDP for these countries is $2.05 trillion. Roughly 5% of these gains occur from a redistribution of income away from the 150 countries that have falling wages. In short, the higher technology growth increases the

pie by $1.95 trillion. The countries that gain receive an extra boost of 0.10 trillion from a redistribution of income.

3. Despite the wage declines, almost all countries benefit on balance due to the increase in variety of goods sold by the US.

4. In an emerging markets, such as Brazil, rapid technology growth that would lead to a doubling of technology would boost the annual per capita wage growth by 0.25 percent for countries that have strong trade ties with the emerging markets. Wages rise in all countries.

5. A uniform reduction in external trade costs, would tend to benefit countries that are relatively remote. A 25 percent reduction in trade costs would increases wages in Africa by more than 10%. Developed countries such as the United States and Japan would see wage reductions of more than 5%.

6. Despite the wage declines, most countries would experience an increase in real GDP because the falling transport costs would mean there are fewer goods lost in transit and so the price index for countries falls enough to offset the loss in wages.

7. A reduction in external trade costs for the US would result in US wages rising by more than 4%. However, they are not the biggest beneficiaries in terms of wage gains. Once again the countries that are relatively remote would tend to benefit the most. They would experience wage gains well over 10 percent.

Our simulation approach complements and contrasts with the econometric approach of Redding and Venables (2004) using a closely related model. They find larger effects of economic geography variables on factor incomes than we do in Results 1 and 2. They regress factor incomes on constructed 'market access' and 'supplier access' variables and interpret the coefficients as structural. Theory implies that all these variables are jointly determined in a highly nonlinear simultaneous equation system as we explain below. Despite Redding

and Venables' skillful use of econometric techniques to try to deal with joint determination, we regard the problem as intractable. While calibration is 'zero degrees of freedom econometrics', the complementary method at least provides a useful alternative perspective on the relative importance of geography and technology. Our main focus is on analyzing the response of the model to technology and trade cost shocks using the calibrated computational model as a basis, which we regard as more readily interpretable than analogous simulation results in Redding and Venables.

The general equilibrium model contrasts with the endowments model of Anderson and van Wincoop (2003), in which the number of varieties is fixed, but retains much of its simplicity. Goods market adjustment to shocks is done here mostly on the extensive margin, in contrast to adjustment on the intensive margin by price changes in the endowments model. An active extensive margin is consistent with the empirical literature on trade of firms.

Section 1 develops the basic model. Section 2 presents the world distribution of wages and its comparative statics with respect to technological change. Section 3 sets out the setup of the simulation model and its calibration. Section 4 presents the comparative statics of technology shocks. Section 5 does the same for trade cost changes. Section 6 concludes.

1 The Model with Monopolistic Competition

In each country, there exists a fixed number of consumers that have Dixit-Stiglitz preferences over varieties. For an individual in country j, the preferences over the consumption goods are given by

$$U_j = \Big(\sum_{i=1}^{R_j} \int_0^{Ni} c_{ij}(z)^{\frac{\sigma-1}{\sigma}} dz \Big)^{\frac{\sigma}{\sigma-1}}$$

where $c_{ij}(z)$ is a good produced by firm z in country i shipped to a consumer in country j and R_j is the set of countries j imports from. We assume that all firms operating in a country have access to the same technology. With this assumption, we can write the preferences of

the representative consumer in country j as

$$U_j = \Big(\sum_{i=1}^{R_j} N_i c_{ij}^{\frac{\sigma-1}{\sigma}} \Big)^{\frac{\sigma}{\sigma-1}}$$

whre N_i is the number of firms producing varieties in country i, and R_j is the set of countries that country j imports from. Given these CES preferences, the demand for good i consumed by the representative agent in country j is given by $c_{ij} = \Big(\frac{p_{ij}}{P_j}\Big)^{-\sigma} \Big(\frac{w_j}{P_j}\Big)$ and aggregate demand is given by [1].

$$c_{ij} = \Big(\frac{p_{ij}}{P_j}\Big)^{-\sigma} \Big(\frac{Y_j}{P_j}\Big) \tag{1}$$

where

$$P_j = \Big(\sum_{i=1}^{R} N_i p_{ij}^{1-\sigma} \Big)^{\frac{1}{1-\sigma}} \tag{2}$$

where we sum over all R countries.

The market structure is assumed to be monopolistically competitive. Therefore, each firm produces and sells a single variety and the production takes place under increasing returns to scale technology. The production technology is the standard Krugman (1980) production technology where there is a fixed cost assocoated with production. We write this technology as:

$$q_i = A_i l_i - f_i$$

where f_i is the fixed cost associated with production, l_i are the number of workers employed in the *representative* firm in country i, and A_i is marginal productivity of the firm operating in country i.

International trade introduces additional costs which we model as iceberg trading costs. As is standard, the icerberg costs imply that if one unit of the good is shipped from country i to destination j only $\frac{1}{\tau_{ij}}$ $(\tau_{ij} > 1)$ arrives.

[1] It will be shown below that each good producer in country i produces the same quantity. Therefore, for ease of notation, we assume this here.

Total firm profits can be expressed as

$$\pi_i = \Big(\sum_{j=1}^{Z_{ii}} p_{ij} q_{ij} - w_i \frac{\tau_{ij} q_{ij}}{A_i} \Big) - w_i \frac{f_i}{A_i}$$

where $q_{ij} = c_{ij} L_j$. Using the demand equation, operating profits are positive if

$$\sum_j \Big(\frac{p_{ij}}{P_j} \Big)^{1-\sigma} Y_j - \sum_j \frac{w_i \tau_{ij}}{A_i} \Big(\frac{p_{ij}}{P_j} \Big)^{-\sigma} \Big(\frac{Y_j}{P_j} \Big) - \frac{w_i}{A_i} f_i$$

Profit maximization implies that prices are marked up over factory gate prices. More specifically, the landed price in country j is given by

$$p_{ij} = \frac{\sigma}{\sigma - 1} \frac{w_i}{A_i} \tau_{ij}$$

Summing over countries, total profits for the firm are given by

$$\pi_i = \sum_{j=1}^{R} \pi_{ij} - \frac{w_i}{A_i} f_i = \sum_{j=1}^{R} \frac{1}{\sigma - 1} \frac{w_i}{A_i} q_i - \frac{w_i}{A_i} f_i$$

where we have used $q_i = \sum_{i=1}^{Z_i} \tau_{ij} q_{ij}$. Monopolistic competition implies that there are zero economic profits so that the zero profit condition pins down the quantity of output produced by a firm in country i and is given by

$$\pi_i = 0 \Rightarrow q_i = f_i(\sigma - 1)$$

Labor market clearing implies $L_i = \sum_{i=1}^{N_i} l_i = \sum_{i=1}^{N_i} \Big(\frac{q_i}{A_i} - \frac{f_i}{A_i} \Big) = N_i A_i^{-1} f_i \sigma \Rightarrow N_i = \frac{A_i L_i}{\sigma f_i}$

Thus, the number of varieties produced by country i is increasing in the labor ednowment (L_i), the marginal productivity of labor (A_i), and is decreasing in the fixed costs (f_i) and the elasticity of sustitution.

Market clearing for a variety produced in country i is given by

$$q_i = \sum_{j=1}^{R} t_{ij} c_{ij} L_i = \sum_{j=1}^{R} t_{ij} \Big(\Big(\frac{p_i t_{ij}}{P_j} \Big)^{-\sigma} \Big(\frac{Y_j}{P_j} \Big) \Big)$$

Multiplying through by $N_i p_i$ and noting $N_i p_i q_i = Y_i$ yields

$$Y_i = \sum_{j=1}^{R} N_i \Big(\frac{p_i t_{ij}}{P_j} \Big)^{1-\sigma} Y_j \tag{3}$$

Dividing through by world GDP we obtain

$$\theta_i = N_i p_i^{1-\sigma} \Big[\sum_{j=1}^{R_i} \Big(\frac{t_{ij}}{P_j} \Big)^{1-\sigma} \theta_j \Big] \tag{4}$$

The term in brackets represents a GDP share weighted measure of trade cost resistance that exporters in country i face when they ship their goods to the other potential R markets. Accordingly, Anderson and van Wincoop define *outward multilateral resistance* (OMR) as this CES -aggregate of the trade costs; that is, OMR is given by

$$\Pi_i = \Big[\sum_{j=1}^{R} \Big(\frac{t_{ij}}{P_j} \Big)^{1-\sigma} \theta_j \Big]^{\frac{1}{1-\sigma}} \tag{5}$$

and we can re-express equation (5) as

$$\theta_i = N_i (p_i \Pi_i)^{1-\sigma} \tag{6}$$

The left hand side of (6) is country $i's$ share of world GDP. On the right hand side, N_i is the number of varieties produced in location i while $(p_i \Pi_i)^{1sv}$ is the share of world spending on a single variety from i. Π_i is the outward multilateral resistance from country i, as if goods

went to a world market at uniform markup P_i. Summing over all countries yields

$$1 = \sum_i N_i (p_i \Pi_i)^{1-\sigma} \tag{7}$$

Using (6), substitute for $N_i p_i^{1-\sigma}$ in the CES price index to obtain inward multilateral resistance

$$P_j^{1-\sigma} = \Big(\sum_{i=1}^{R_i} \Big(\frac{t_{ij}}{\Pi_i} \Big)^{1-\sigma} \theta_i \Big)$$

The inward multilateral resistance term can be then be used to find the indirect utility function for an individual in country j is given by

$$V_j = \frac{w_j}{P_j}$$

In the next section, we use the general equilibrium structure of the gravity framework to solve for the multilateral resistance terms. Once we have solved for these terms we can decompose differences in output into differences that can be attributed to tastes, technology, and labor differences, and market access.

2 Trade Costs and the Distribution of World Income

Summarizing results, from monopolistic competition and CES preferences, the first order condition yields the markup equation on factory gate costs as where factory gate prices are

$$p_i = \frac{\sigma}{\sigma - 1} \frac{w_i}{A_i} \tag{8}$$

while free entry drives profits to zero, implying

$$N_i = \frac{A_i L_i}{\sigma f_i} \tag{9}$$

trade balance implies

$$\theta_i = \frac{w_i L_i}{\sum_j w_j L_j} \tag{10}$$

the inward multilateral resistance

$$P_j = \Big[\sum_{i=1}^{R_i} \Big(\frac{t_{ij}}{\Pi_i} \Big)^{1-\sigma} \theta_i \Big]^{1-\sigma} \tag{11}$$

and outward multilateral resistance

$$\Pi_i = \Big[\sum_{j=1}^{R_i} \Big(\frac{t_{ij}}{P_j} \Big)^{1-\sigma} \theta_j \Big]^{\frac{1}{1-\sigma}} \tag{12}$$

Substituting from (8) and (9) into (6) and using (10) we obtain

$$\frac{A_i L_i}{\sigma f_i} \Big(\frac{\sigma}{\sigma - 1} \frac{w_i}{A_i} \Pi_i \Big)^{1-\sigma} = \frac{w_i L_i}{\sum_j w_j L_j} \tag{13}$$

Summing (13) gives a reduced form of (7), implying a restriction on the vector of $\{w_i \Pi_i\}$. The scalar indeterminacy is resolved by imposing a normalization on the price system. It is analytically convenient to normalize by the world GDP:

$$1 = \sum_i w_i L_i. \tag{14}$$

Under normalization (14), (13) can be solved for the equilibrium efficiency wage:

$$\frac{w_i}{\widetilde{A}_i} = \phi(\sigma) \Pi_i^{(1-\sigma)/\sigma} \tag{15}$$

where

$$\phi(\sigma) \equiv \sigma^{-1} (\sigma - 1)^{\frac{(1-\sigma)}{\sigma}}$$

and $\widetilde{A}_i = A_i / f_i^{1/\sigma}$. A country's equilibrium wage is proportional to its productivity and falls with its sellers' incidence of trade costs with elasticity $1/\sigma - 1$. Using (15) the reduced form

GDP shares can be expressed as

$$\theta_i = \frac{\tilde{A}_i L_i \Pi_i^{\frac{(1-\sigma)}{\sigma}}}{\sum_j \tilde{A}_j L_j \Pi_j^{\frac{(1-\sigma)}{\sigma}}} \tag{16}$$

The general equilibrium of production and distribution can be solved in a reduced form for $P's$ and $\Pi's$ by substituting (16) for each θ_i in in (11)-(12) and using the normalization (14) to pin down the $\Pi's$ and P's. No closed form solution is possible but the system solves easily numerically.

In a frictionless world, $\Pi_i = P_i = 1 \,\forall\, i$ and so normalized wages in (15) become

$$\frac{w_i}{\tilde{A}_i} = \phi.$$

Relative wages are determined by productivity alone. This stark result is because of the Ricardian production structure combined with the Armington nature of demand in symmetric monopolistic competition equilibrium.

2.1 Comparative Statics

It is useful to benchmark the comparative statics of the model with the frictionless trade case. A rise in country 1's productivity results in an equiproportionate rise in country 1's normalized wage and no change in the normalized wage of any other country. No price will change for any variety produced by any country. But, because country 1 is effectively bigger, $A_1 L_1$ rises, it produces more varieties, N_1 rises. Therefore all countries in the world gain due to an increase in the number of varieties. *In a frictionless trading world of the Krugman-Dixit-Stiglitz type of preferences and technology, technological progress anywhere benefits all with increased variety and benefits the source country with a rise in its wage equal to the technological improvement.*

Trade costs make a dramatic difference. The incidence of the trade costs is divided

unevenly between sellers and buyers, and technological shocks alter the incidences. This creates the potential for gainers and losers among the source country's trading partners.

In the presence of trade costs, the comparative statics of the model are derived from substituting (16) into (11)-(12). In general, this system is too complex for enlightening analytic conditions. Anderson and Yotov (2009) provide some insight for intuitive guidance based on the simple case where trade costs are uniform border barriers: $t_{ij} = t > 1, i \neq j; t_{ii} = 1$. For this case they prove that larger world output shares imply lower multilateral resistance. The intuition is that larger countries naturally have a smaller fraction of their trade crossing their borders. This prediction (in the sense of correlation) is borne out for outward multilateral resistance in their empirical work on Canada's provinces trade (2009) and on world manufacturing trade (2010). Their work indicates that inward multilateral resistance has much less strong correlation with supply or expenditure shares (outward and inward multilateral resistance differ because they deal with unbalanced sectoral trade data).

Applying these insights in the model of this paper, differentiating (15) and (16),

$$\widehat{w}_j = \delta_{ij}\widehat{A}_i - \frac{\sigma - 1}{\sigma}\widehat{\Pi}_j, \tag{17}$$

and

$$\widehat{\theta}_j = (1 - \theta_i)\widehat{w}_i \tag{18}$$

where δ_{ij} is the Kronecker delta. The factory gate price changes by, differentiating (8),

$$\widehat{p}_j = \widehat{w}_j - \delta_{ij}\widehat{A}_i = -\frac{\sigma - 1}{\sigma}\widehat{\Pi}_i. \tag{19}$$

The number of varieties changes by

$$\widehat{N}_i = \widehat{A}_i$$

based on differentiating (9).

A rise in country 1's technology parameter raises its wage and its share directly, the first

term on the right hand side of (17), and indirectly via the fall in its outward multilateral resistance, the second term on the right hand side of (17). For all other countries, their wages and shares tend to fall indirectly due to rises in their outward multilateral resistance. But these are tendencies only, based on empirical observation and the intuition from a very special unrealistic theoretical case. All countries benefit from an increase in variety, tending to raise real wages.

Changes in the set of bilateral trade costs change the Π's directly in (17)-(19) and lead to equal changes in the wages and prices. The changes in the shares induce further changes in the Π's. In the full general equilibrium the real wages change asymmetrically even if the trade cost changes are symmetric.

The simulation results for technology shocks below indicate that when one country receives a technology improvement wage decreases in receiving countries predominate, associated with the negative but imperfect correlation of outward multilateral resistance and output share observed by Anderson and Yotov. The change in factory gate prices is relatively small for the originating country, while the change in the number of varieties $\widehat{N}_i = \widehat{A}_i$ confers substantial benefits widely by reducing inward multilateral resistance, the CES price index. We regard the model and its simulation as providing a clean general equilibrium mechanism that should be at work in more complex production and market structures that feature adjustment on the extensive margin. We separately report wage and real income effects below because the benefit of more variety may be overstated in the CES preferences structure (though less adjustment in variety would force more benefit to consumers through lowering the price of existing varieties).

Simulation results for trade cost shocks below indicate that symmetric trade cost reductions lead to quite similar real income improvements, despite the initial asymmetry of trade costs. Thus a uniform fall in distance (associated with a drop in fuel costs) tends to raise real incomes close to equiproportionately, even though induces a non-uniform reduction in trade costs because bigger countries have much smaller proportions of their trade incurring border

costs. Under the normalization (14), sellers' incidence and wages are essentially constant and the incidence of the trade cost reduction accrues to buyers.

2.2 Graphical Analysis

It is helpful in understanding the model and its properties to develop a graphical analysis. For the determination of GDP's, (12) is equivalently the trade-cost-bill-minimizing allocation of world efficiency labor at given outward multilateral resistances, where the cost function has constant elasticity of substitution. To see this, define $\tilde{\Pi}_i = \Pi_i^{1-\sigma}$. The hypothetical minimized total trade cost bill is

$$C(\tilde{\Pi}, \sum_i \tilde{A}_i L_i) = \Big[\sum_i (\tilde{\Pi}_i / f_i)^{-1/\sigma} \Big] \sum_i \widetilde{A}_i L_i \tag{20}$$

Using Shephard's Lemma, it is readily verified that the cost shares implied by (20) are given by (16), provided that the allocation (the 'demand' for efficiency labor) $C_{\widetilde{\Pi}}$ is equal to the endowment actually given to each origin $\widetilde{A}_i L_i$. By duality, then, the equilibrium $\widetilde{\Pi}$'s for given allocations are uniquely generated as hyperplanes supporting the trade cost bill for the world at the point where the allocation ray intersects a normalized isocost curve.

3 General Equilibrium and Model Calibration

In order to quantify how trade costs and the distribution of labor and technology influence the distribution of world income, we calibrate the model using data on population, per capita GDP and standard estimates of trade costs implied from the gravity equation. We use data on per capita GDP as our measure of wages. The data for population and per capita GDP are from the World Development Indicators for the year 2000. To construct the $P's$ and the $\Pi's$ we use estimates of trade costs from the gravity equation on bilateral trade flows. As Anderson and van Wincoop note the solution to the $P's$ and $\Pi's$ are not unique;

that is, for the vectors of the $P's$ and $\Pi's$ that solve equations (11)and (12) so to will any $\lambda P^{1-\sigma}$ and $\frac{\Pi^{1-\sigma}}{\lambda}$. We show that the general equilibrium structure of the gravity model and the normalization on the vector of wages pins down the values of the inward and outward multilateral resistance terms. To see this more clearly, consider an arbitrary solution to (11) and (12) plug these solutions and per capita income into the relative wage equation, where each country is compared relative to the US, then technologies relative to the United States are given by

$$a_{i,US} = \frac{\tilde{A}_i}{\tilde{A}_{US}} = \frac{w_i}{w_{US}} \Big(\frac{\Pi_i^{1-\sigma}}{\Pi_{US}^{1-\sigma}} \Big)^{\frac{-1}{\sigma}}$$

Note that the scalar λ cancels out. Given these relative technologies, we use the normalization on wages to solve for US technology; that is, $\tilde{A}_{US} = \frac{\sum w_i L_i}{\sum a_{i,US} L_i}$. This implies $\tilde{A}_i = a_{i,US} A_{us}$. Once these are obtained, the $P's$ that are consistent with conditional general equilibrium are given by

$$P_j^{1-\sigma} = \{ \sum_{i=1}^{R_i} \phi(\sigma) (\tilde{A}_i / w_i)^{\sigma} (w_i L_i) (t_{ij})^{1-\sigma} \}$$

and the $\Pi's$ are given by

$$\Pi_j^{1-\sigma} = \Big(\sum_i (\frac{t_{ji}}{P_i})^{1-\sigma} \theta_i \Big)$$

As a check, the solution for the $\Pi's$ are substituted into $\sum_i \tilde{A}_i L_i \phi(\sigma)^{\sigma} (w_i \Pi_i)^{1-\sigma} = 1$ to ensure this identity holds.[2]

Accounting for Trade Costs and the Variation of Income Across Countries

Given the solution to the $P's$and $\Pi's$, the wage equation (15) can be used to account for the variation in wages across countries that can be attributed to trade costs and technology. In particular, we can use a variation of the Klenow and Rodriguez-Claire (1997) decomposition to account for the fraction of the variation in log wages that is accounted for by technology

[2]Another check of the model is to make sure the correlations final $P's$ and $\Pi's$ and the price vectors used at the outset is unity.

differences and trade costs. That is we write the wage equation (15) in logs as

$$\ln(w_i) = \psi + \ln(A_i) + \frac{1}{\sigma}\ln(\Pi^{1-\sigma})$$

or in terms of the variance of log wages (15) can be expressed as

$$var(\ln(w_i)) = cov(\ln(A_I), ln(w_i)) + 1/\sigma cov(\ln(w_i), \ln(\Pi_i^{1-\sigma}))$$

and so $\frac{cov(\ln(A_I),\ln(w_i)}{var(\ln(w_i))}$ is the fraction of the variance of log wages that is accounted for by productivity and $\frac{1/\sigma cov(\ln(w_i),\ln(\Pi_i^{1-\sigma})}{var(\ln(w_i))}$ is the fraction of the variance of log wages that is accounted for by trade costs.[3]

The table below reports the fraction of the variance in log wages that can be accounted for by technology and trade costs. For the distance elasticity, we choose numbers that represent the high and the low end of the empirical estimates obtained from a gravity equation ($\rho = \{-0.50,\ -100,\ -1.50\}$) for the border effect we choose a value of $\alpha = 0.75$. The only other variable that is not pinned down by the model is the elasticity of substitution across goods. For this parameter, we also choose a range of estimates that include values on the high and low end; $\sigma = \{2,\ 6,\ 10\}$.

[3]While this is a nice 'closed form' solution, multilateral resistance terms depend on wages and so there is an endogeneity issue. However, if viewed from the aspect of each agent is small relative to the market size, what matters for the agents are how close she is to all market participants including her own domestic market. Thus, it is not obvious that one would want to not include the domestic market in this calculation. In Section xx, when we look at technology growth, this endogeneity more appropriately accounted for.

Table 1. Variation in Log Wages Explained By Technology and Trade Costs

	Technology	Trade Costs	Technology	Trade Costs	Technology	Trade Costs
	ρ=−0.50		ρ=−1.00		ρ=−1.50	
σ=2	0.94	0.06	0.88	0.12	0.81	0.19
σ=6	0.98	0.02	0.95	0.05	0.94	0.06
σ=10	0.99	0.01	0.98	0.02	0.96	0.04

The bulk of variation in log per capita GDP across country is accounted for by technology. Trade costs account for as much as 20% when the cost of distance is high and consumers have a strong love of variety. When trade costs are low and consumers do not have a strong love of variety trade costs account for only one percent of the cross country variance in per capita GDP. With $\sigma = 6$ and a distance elasticity of -1.00, commonly used estimates, trade

costs account for roughly 5% of the variation in log wages.

These calibration results differ from the findings of Redding and Venables (2004), who use a similar theoretical model to infer econometrically a relationship between wages and measures of average outward and inward trade costs they call market access and supplier access. Compared to Redding and Venables, in our results technology is more important and geography less important in explaining international variation in income per capita. Even though Redding and Venables use econometric techniques that attempt to control for simultaneity between trade cost aggregates and wages, our results and the theoretical model suggest that their instruments are not successful in doing so. In terms of our model, effectively Redding and Venables estimate something like (15) multiplied through by $\widetilde{A}_i$, but replacing sellers' general equilibrium incidence Π_i with their constructed market access and supplier access variables (see their equation (14)). Either form of the wage equation is a relationship between endogenous variables. Attempts to control for simultaneity with instrumenting seem unlikely to pick up the full general equilibrium dependence of Π's or of markt access and supplier access on *all* bilateral trade costs, wages and output shares in the world. It is at least worthwhile for comparison and perhaps more believable to learn something about the relative importance of geography and technology from calibration. Of course, calibration is open to the obvious jibe that it is 'zero degrees of freedom econometrics'. A more satisfactory approach would be to derive separate, more or less independent productivity estimates to combine with estimated Π's on the right hand side of (15), and compare them to income per capita see how closely the constructed variable matches the data. Two minor reasons for the difference in findings may have some power. First, the Redding and Venables distance elasticity of trade costs is at the upper end (in absolute value) of those in the literature, thus raising the importance of geography. Second, Redding and Venables use a traded intermediate goods setup.

4 Technology Shocks, Incidence and Incomes

In order to assess how technological growth in one region can impact the distribution of world income, we continue to employ the one sector many varieties gravity model. The three key *sets* of equations determine the impact of changes in technology on wages and welfare are given by:

- The set of wage equations which are given by

$$w_i = A_i \phi(\sigma) \Big(\Pi_i^{1-\sigma} \Big)^{1/\sigma} \text{ for } i = 1, 2, ...R \tag{21}$$

- The set of *outward-multilateral resistance* equations which are given by

$$\Pi_i^{1-\sigma} = \Big[\sum_j \Big(\frac{t_{ij}^{1-\sigma}}{P_j^{1-\sigma}} \Big) \Big(\frac{w_j L_j}{\sum_k w_k L_k} \Big) \Big] \text{ for } i = 1, 2, ...R \tag{22}$$

- The *inward-multilateral resistance* equations which are given by

$$P_i^{1-\sigma} = \Big[\sum_j \Big(\frac{A_j L_j}{\sigma f} \Big) \Big(\frac{\sigma}{\sigma - 1} \frac{w_j}{A_j} \Big)^{1-\sigma} t_{ji}^{1-\sigma} \Big] \text{ for } i = 1, 2, ...R \tag{23}$$

where we have substituted $\theta_j = \Big(\frac{w_j L_j}{\sum_k w_k L_k} \Big)$, $N_j = A_j L_j / \sigma f$, and $p_j = \frac{\sigma}{\sigma - 1} \frac{w_j}{A_j}$.

The comparative static effects of changes in technology are too complex to yield easily interpreted results even in this simple stylized model. But the intuition from Section 2.1 gives some help in interpreting a simulation based on a one sector model with 161 countries and gravity coefficients and elasticities taken from the empirical gravity literature.

We use standard estimates from the empirical gravity literature for our parameter estimates. In particular, common estimates of the elasticity of trade with respect to distance range between -0.75 and -1.25. We use a value of -1.00 in our baseline estimates. The estimated effect of common shared border is between 0.50 and 1.00; we use 0.75 in our baseline case. For the elasticity of substitution, estimates range between 3 and 10; we set $\sigma = 6$.

Distance measures are taken from Head and Mayer (xxxx). These estimates of distance take into consideration population centers and provide a better measure of internal distance. Adjacency measure come from the CIA factbook. GDP shares are 2000 estimates of GDP taken from the World Development Indicators.

The set of exercises we conduct is to assume that a country experiences an increase in technology. We simulate the effect of technological growth in a country on the world distribution of income by iterating on the system of equations as described by the social planner in Section xxx. Given an initial set of P's and $\Pi's$, we increase the technology in one country. We assume that this increases their GDP by the amount of the technology increase. With the new level of world technology, then recalculate an new vector of price indices (Π^{new} and P^{new}) . This implies a new set of wages given by (15) and a new distribution of world income. We then repeat these steps until the change in per capita GDP converges.[4]

The simulation exercises attempt to quantify the extent that technological growth impacts other countries. The comparative statics above highlight the different channels for the gains and losses from technology growth. Below we summarize the effects for country j when there is technological growth in country k:

- **Negative sellers' incidence effect:** Country j's output share falls as country k has a larger share of the world economy. This tends to raise sellers' incidence in j, an effect that is mitigated or reversed as j is economically close to k. Wages are falling in sellers' incidence by (15) with elasticity $1/\sigma - 1$.

- **Ambiguous buyers' incidence effect**: The effectively larger country size of k has an ambiguous effect on inward multilateral resistance (buyers' incidence) in Anderson and Yotov's data. In our simulations, there is essentially no effect. This is because the general equilibrium structure of monopolistic competition puts adjustment to technology change on the extensive margin — more varieties are produced at essentially

[4]The cut off rate for the change in the per capita GDP is that the largest change from the between per capita GDP's in two consecutive iterations is less than \$0.01

constant price in the growing country. In the endowments model of Anderson and van Wincoop (2003), a rise in endowment forces down the price and buyers' incidence falls.

- **Positive variety effects:** Country k's growth increases its equilibrium number of varieties, benefitting all consumers.

- The net effect is positive for almost all countries, redeemed only by the variety effect. Holding variety constant, the majority of countries lose from k's growth.

In all the simulations, we assume that the distance elasticity is -1.00 and the presence of a common border increases log trade by 0.75. We use $\sigma = 6$ as the elasticity of substitution. The first simulation is to assume there is a 20% increase in US technology. In order to present the results from the simuations for 161 countries, we present some of the results by regions. The countries are placed in regions based primarily based on the geography of the country. The regions are listed in table 2.

Table 2: Countries

North America
Canada
Mexico
United States

Central America
Aruba
Barbados
Belize
Costa Rica
Dom Republic
El Salvador
Guatemala
Guyana
Haiti
Honduras
Jamaica
Nicaragua
Panama
St Kitts & Nevis
The Bahamas
Trinidad & Tobago

South America
Argentina
Bolivia
Brazil
Chile
Colombia
Ecuador
Paraguay
Peru
Suriname
Uruguay
Venezuela

Asia pacific
Australia
Fiji
Kiribati
Micronesia Fed Sts
New Caledonia
New Zealand
Papua New Guinea
Samoa

Central & South. Asia
Hong Kong
Indonesia
Japan
Korea (Republic of)
Malaysia
Singapore
Thailand

Developing Asia
Afghanistan
Armenia
Azerbaijan
Bangladesh
Bhutan
Cambodia
China
Kazakhstan
Kyrgyz (Republic of)
Lao PDR
Macao (China)
Mongolia
Nepal
Pakistan
Philippines
Sri Lanka
Tajikistan
Turkmenistan
Uzbekistan
Vietnam

Middle East
Bahrain
Iran (Islamic Republic of)
Israel
Jordan
Kuwait
Lebanon
Oman
Qatar
Saudi Arabia
Syrian Arab Republic
Turkey
United Arab Emirates
Yemen (Republic of)

Northern Africa
Algeria
Egypt
Libya
Morocco
Tunisia

Southern Africa
Angola
Benin
Burkina Faso
Burundi
Cameroon
Central African Republic
Chad
Comoros
Congo (Republic of)
Djibouti
Equatorial Guinea
Ethiopia
Gabon
Ghana
Guinea
Guinea Bissau
Ivory Coast
Kenya
Liberia
Madagascar
Malawi
Mali
Mauritius
Mozambique
Mauritania
Niger
Nigeria
Rwanda
Senegal
Seychelles
Sierra Leone
South Africa
Sudan
Tanzania
The Gambia
Togo
Uganda
Zaire
Zambia
Zimbabwe

Western Europe
Austria
Belgium
Cyprus
Denmark
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
United Kingdom

Central Europe &
Ālbanià
Belarus
Bosnia & Herzegovina
Bulgaria
Croatia
Czech Republic
Estonia
Georgia
Hungary
Latvia
Lithuania
Macedonia FYR
Malta
Moldova
Poland
Romania
Russian Federation
Slovak Republic
Slovenia
Ukraine

The increase in technology pushes up US wages by 21.40%. Because US expenditure share on its own goods is approximately 75%, the trade costs and the large internal US market provides additional support for the rise in wages as workers within the US increase

their consumption of US produced goods. The rise in the US wage by more than 20 percent implies that wages in some other countries must decline. There are also countries that will benefit from the US growth as the US consumers by more imported goods. For example, Canada's wages rise by 0.78 percent and Canada's wages rise by nearly one-half a percent. Both of these markets have large distribution shares to the US; therefore, as the US grows the increased demand by US consumers has the largest effect on these countries. In all, there are 26 countries whose wages rise in response to the growth in US technology. There are 135 countries that experience a decline in wages. The largest decline is in Libya; their wage falls by 0.66%. We can integrate the effects of a 20% increase in US technology by adding up the effect on world GDP. The growth in US technology implies that world GDP rises by nearly $1.95 trillion dollars. For the 26 countries that benefit, the increase in wages sum to nearly $2.05 trillion. The 135 countries experience a fall in wages of nearly $100 billion. Therefore, nearly 5% of wage income gains for the benefiting countries occurs because there is a redistribution from the 136 countries countries.

The impact on wages for each of the regions is depicted in Table 3. We see that for most regions the average impact on wages is that wages fall by about 0.40 percent.

Table 3. US 20% Growth in Technology

US 20% Growth in Technology

Region ID	Region	Average Growth	Minimum	Maximum
Region 1	North America*	0.64	0.49	0.78
Region 2	Central America	0.23	-0.08	0.56
Region 3	South America	-0.25	-0.45	0.39
Region 4	Asia Pacific	-0.15	-0.47	0.25
Region 5	Central and Southern Asia	-0.50	-0.53	-0.46
Region 6	Developing Asia	-0.38	-0.53	-0.3
Region 7	Middle East	-0.44	-0.53	-0.33
Region 8	Northern Africa	-0.44	-0.38	-0.57
Region 9	Southern Africa	-0.17	-0.43	0.17
Region 10	Western Europe	-0.47	-0.52	-0.18
Region 11	Central and Eastern Europe	-0.44	-0.5	-0.38
	*Excludes US			

In terms of measuring the impact of US technology growth on utility, the increased varieties produced by the US may enhance consumer welfare enough to offset the fall in

wages for the countries that experience a decline in wages. Measuring the impact of the gain in US productivity this we find that all but two countries benefit. The 20% rise in US technology results in an increase in US welfare by nearly 24%. Canada's experiences an increase in utility of 2.85%. Because Mexico's, who experienced the firth highest gains in wages, has the second highest gain in utility. This occurs because Mexico has a high expenditure share on US goods, so the growth in the US implies that that Mexico will have access to many more varieties and this increases their welfare.

The second example involves the case of the fast growing BRIC countries. We focus on two examples. In the first example, we assume that technology in Brazil increases by 20%. Thus, the experiment is similar to the US experiment above. However, Brazil differs in that it is a much smaller country compared to the US and because their own expenditure and distribution shares are much lower than the US [5]; that is, as a share of GDP, Brazil trades more with other countries. The 20% increase in technology in Brazil causes wages to rise by more than 21%. Because Brazil's trade share is higher, there a 141 countries experience an increase in their wages. The countries that benefit the most are Paraguay and Bolivia whose wages rise 0.65% and 0.35% respectively. The Mauritius stands to lose the most as their wages fall by a modest -0.04%. In terms of utility, Brazil's real wages rise by more than 22%. Paraguay and Bolivia's real wages rise by 1.53% and 1.23% respectively. In this case, 12 countries experience modest declines in utility.

A more dramatic exercise is to assume that Brazil's technology doubles. One way to think about this thought experiment is to assume Brazil's technology grows roughly 7 percent faster than the world average for a decade. After this time period, we take stock how this growth impacts the world distribution of in. The growth in technology in Brazil tends to benefit the countries that have the lowest trading costs with Brazil; that is, the countries that trade the most with Brazil. Obviously, Brazil benefits from a large internal market and this will increase the demand for Brazil's own goods. As a result, of the doubling of

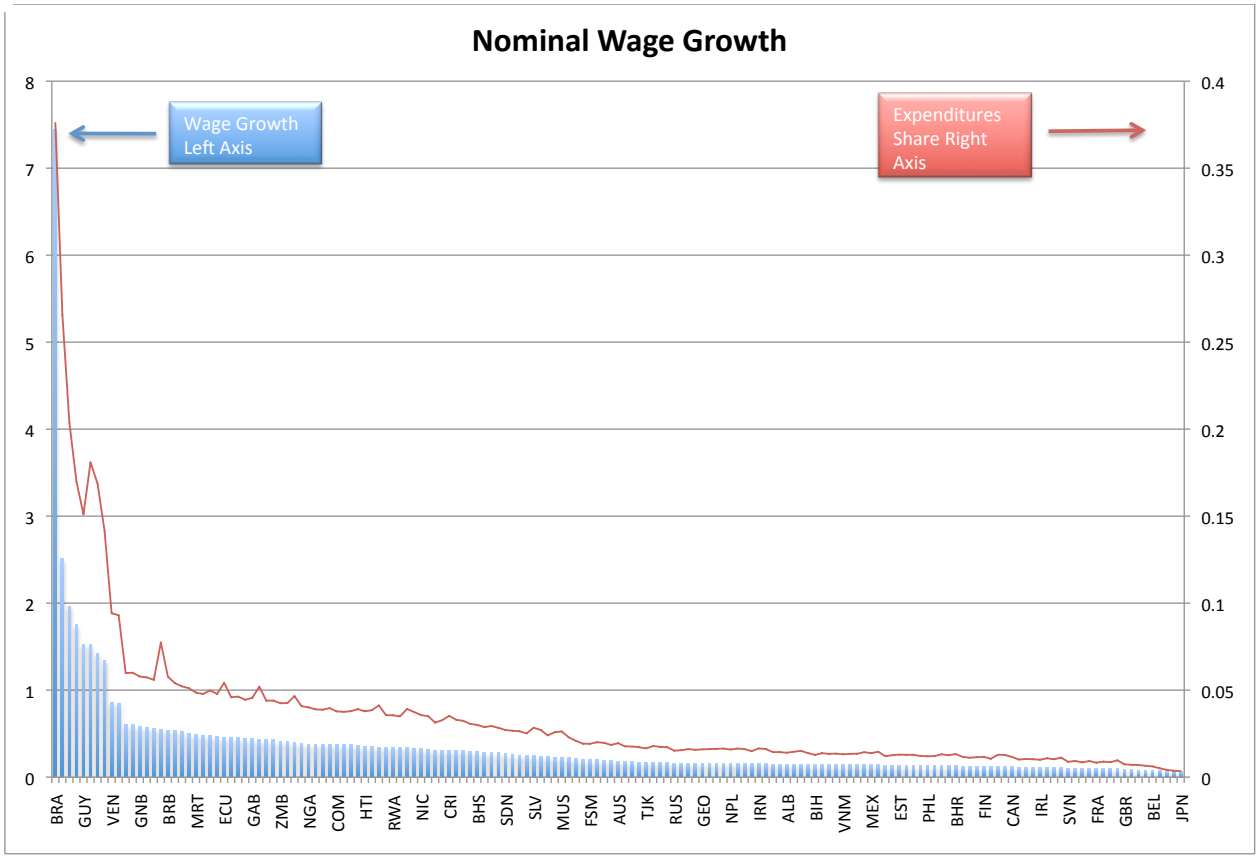
[5]Brazil's distribution and expenditure shares on its own output is notably less than the the US–roughly 40 percent.

technology in Brazil, per capita income in Brazil increases by nearly 109%. This implies that the the annual 7 percent faster technology growth implies Brazil's wage will grow by slightly more than 7.8% per year; that is, the trade costs will push up the growth rate of wages by an additional one-half percentage point. The gains for countries that trade intensively with Brazil are more notable as well. For example, Paraguay's wages increase by more than 2.76%. This implies the faster technological growth in Brazil increase the demand for goods produced in Paraguay and their GDP growth over this 10 year period, wage growth will be roughly 0.27% higher on a per year basis than it would have been otherwise.[6] Paraguay stands to benefits the most since the model implies Paraguay sends nearly 40% of its output (its distribution share) to Brazil. This high demand tends to push up Paraguay's nominal wage. Bolivia, Uruguay, Argentina, and Peru all experience one percent faster growth in wages due to the growth in Brazil's technology. In total, 98 countries end up with higher per capita GDPs because of the faster technological growth in Brazil. This implies that there are 116 countries whose per capita GDP declines. Most of the declines in per capita GDP growth are quite modest. The country that stands to lose the most, in terms of percent fall in the wage rate, is Mauritius. Their wage falls by nearly -0.2 percent. Surprisingly, the country that stands to lose the second most is Guyana. The wage in Guyana contracts by a modest 0.19% over the period. The reason for this is that according to the data Guyana does not send any of its output to Brazil and, as a result, it does not experience and increase in demand and wages do not rise. Figure 2 depicts the growth percent change in wages due to the doubling of Brazil's technology as well as each country's share of output that is shipped to Brazil (its distribution share).[7] Clearly,there is a positive relationship between the country's wage growth and Brazil's demand for its production.

[6]For example, from 1999 to 2009 this implies Paraguay's growth rate would have been 10% higher.

[7]In all cases, we depict the growth in real wages net of the technology growth. The figures capture the wage impact from the changing distribution of world GDP.

Figure 2. Wage Growth and Technological Growth in Brazil



The effect on real GDP are noticeably larger. This occurs because countries that have lower trading costs with Brazil have easier access to Brazil's expanded production. Brazil real wage rises by more than 115% If this growth was over the course of ten years it implies that annual growth more nearly 8% at an annual rate. This is almost a full percentage point above technological growth. For Bolivia and Paraguay, their real income rises by more than 5%. If this growth occurred over a 10 year period, Bolivia and Paraguay would real wage would increase annually by about 0.5% faster than they would have otherwise. The easier access to goods produced in Brazil ends up pushing up Guyana's real wage by more than 3

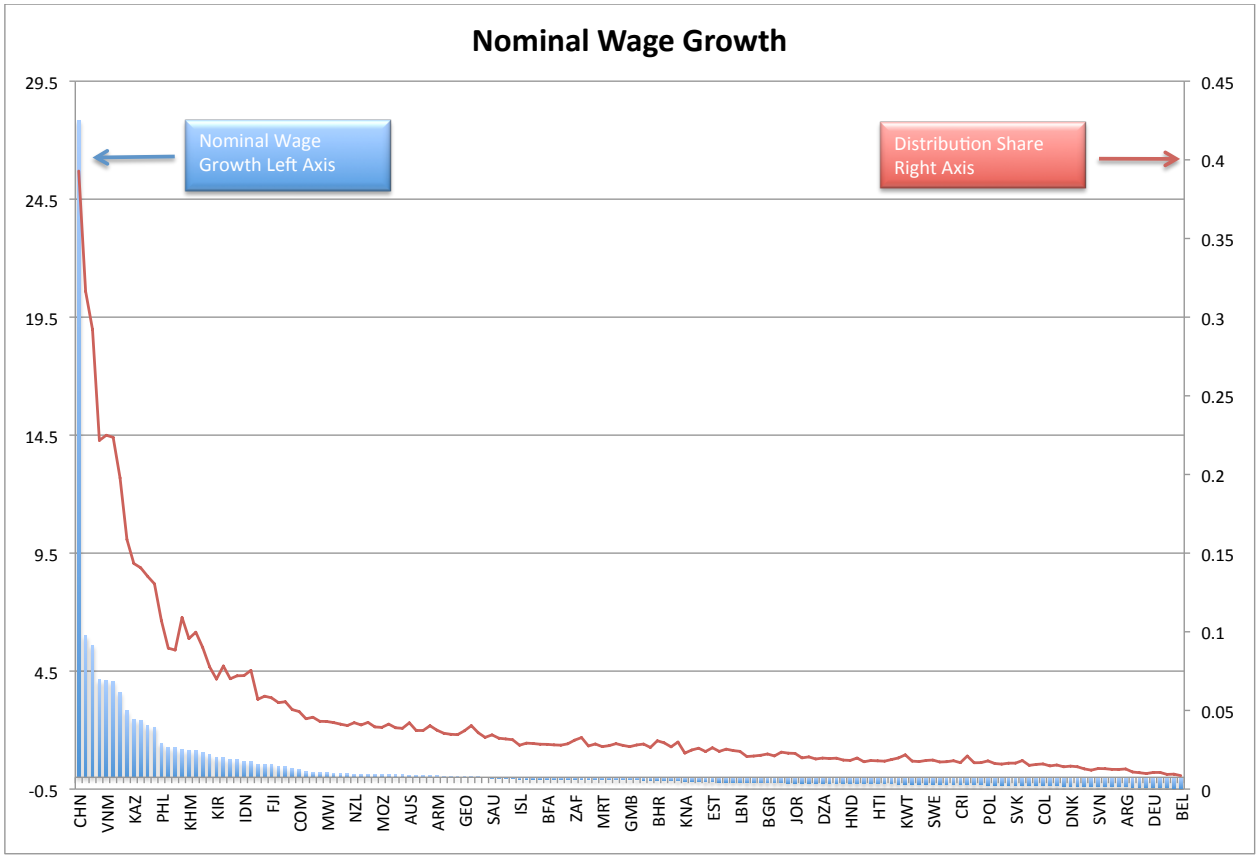
percent. The country that now stands to have the largest fall in real GDP is Niger. Their real GDP contracts by a modest 0.14%. The growth in real wages can be attributed to the access to Brazil's market. The countries with the higher expenditure share will stand to benefit the most. This is depicted in Figure 3. In all only 11 countries stand to lose in terms of real wages.

Figure 3. Real Wage Growth and Technological Growth in Brazil

A recent concern that has gained a lot of attention in the popular press is China's growth and how will their rapid growth rate impact the structure world demand. To capture these effects in this simplified toy model, assume that China's technology growth increases at such

a pace that its technology increases from 2.64% of the U.S technology to ten percent of United States technology; this amounts to a 378% increase in technology! As above the growth in China's technology tends to push up the wages of the countries that have the highest distribution shares. China's own wages grow by more than 40 percent above the rate of technology increase ($420 - 378 = 42$). Mongolia and Macao wages rise by more than eight percent due to the increase in China's technology. Western Samoa and New Caledonia stand to lose the most; their real GDP falls by more than 2%. Again this is due to the fact, that neither of these countries export to China. The wage rate in the US and Western Europe all fall by nearly 0.7% Figure 4 depicts the growth in wages and the country's distribution share to China.

Figure 4. Wage Growth and Technological Growth in China



In terms of real wage growth, China the growth in internal demand pushes China's real wage up by nearly an additional 108%. Countries such as Macao, Mongolia, Bhutan all experience an increase in the purchasing power in real terms by roughly 20%. There are six other countries whose real income increases by more than 10%. In terms of real purchasing power, the only country that stands to lose is Comoros, because they have weak trading ties with China in terms of exports and imports.

5 Income, Trade Cost and Incidence

In order to assess how changes in transport costs impact the distribution of world income, we continue to employ the one sector many varieties gravity model. We reproduce the three key *sets* of equations that determine the influence of trade costs on wages and welfare:

- The set of wage equations which are given by

$$w = \widetilde{A}_i \phi(\sigma) \Big(\Pi_i^{1-\sigma} \Big)^{1/\sigma} \text{ for } i = 1, 2, ...C;$$

- the set of GDP share equations which are given by

$$\theta_i = \frac{\widetilde{A}_i L_i \Pi_i^{(1-\sigma)/\sigma}}{\sum_i \widetilde{A}_i L_i \Pi_i^{(1-\sigma)/\sigma}};$$

- the set of *outward-multilateral resistance* equations which are given by

$$\Pi_i^{1-\sigma} = \Big[\sum_j \Big(\frac{t_{ij}^{1-\sigma}}{P_j^{1-\sigma}} \Big) \theta_j \Big] \text{ for } i = 1, 2, ...C;$$

- and the *inward-multilateral resistance* equations which are given by

$$P_i^{1-\sigma} = \sum_j \left(\frac{t_{ji}}{\Pi_j} \right)^{1-\sigma} \theta_j, i = 1, 2, ...C.$$

Before turning to the simulations, it is useful to analyze a special case to show the impact of a fall in trade costs. Consider the special case where $\hat{t}_{omr} = \hat{t}_{imr} = \hat{t}$, all trade costs, including local ones t_{ii} fall by a uniform amount. In this case, there is no change in the trade pattern or the distribution of GDP in the world, and real GDP rises by $\widehat{t}$ because less resources are used up in distribution; more of the icebergs survive to be consumed at their destinations. Such a uniform reduction might accompany a technological improvement that reduced distance related trade costs proportionately, as if the world literally became

smaller.

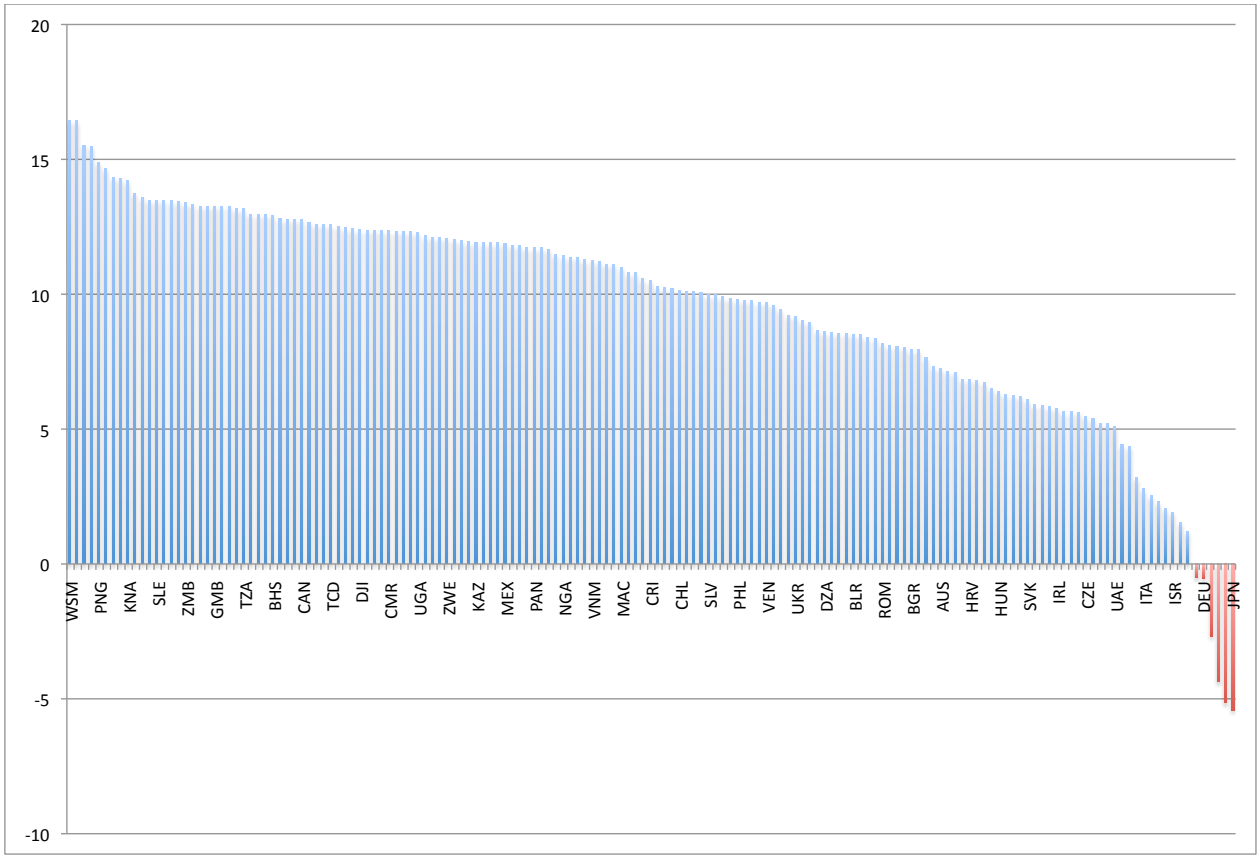
Reductions in bilateral trade costs that are non-uniform, as when national border barriers fall uniformly but distance related costs remain constant,[8] will have some of the global gain aspect of the first case, but will also have non-uniform impacts on incidence, including the possibility that some countries can lose.

The model of trade costs utilized in the simulations below includes only variable costs. We exclude the fixed export costs that have become a staple of the literature since Melitz (2003) for two reasons. First, while in principle the action on the extensive margin induced by fixed costs could be important, the empirical literature in our view is not well enough matured to give parameter values that are believable for our simulation purposes. Second, Anderson and Yotov (2010) report that estimated trade costs with OLS, PPML and the Helpman, Melitz and Rubinstein (2008) fixed export cost/selection model all imply the same relative trade costs, so that for purposes of tracing the implications of changing trade costs on multilateral resistance and its implications for real output changes, the use of fixed export costs does not matter.

In the first experiment we assume that there is a 25% decline in external transport costs. Here we assume that the distance elasticity falls from -1.00 to -0.75. In this instance it seems likely, that the countries that benefit from their proximity to the large markets are like to have the largest decline in wages. Those countries that are more remote would be the countries that are most likely to gain. In fact, this precisely what occurs. Western Samoa and Kiribati experience wage gains of 16.45 and 16.43 percent respectively. Many of the countries in Africa experience wage gains of more than 10%. There are seven countries that experience declines in the wage rate. The largest losses occur in Japan and the US (5.43% and 5.15% . Singapore's wage declines by 4.37% . Hong Kong, Singapore, Germany and Great Britain are the other countries that stand to lose from the declining transport costs. Figure 6 depicts these losses.

[8]The bilateral trade costs are affected unevenly because border barriers affect only some trade, with a proportion that varies widely across countries.

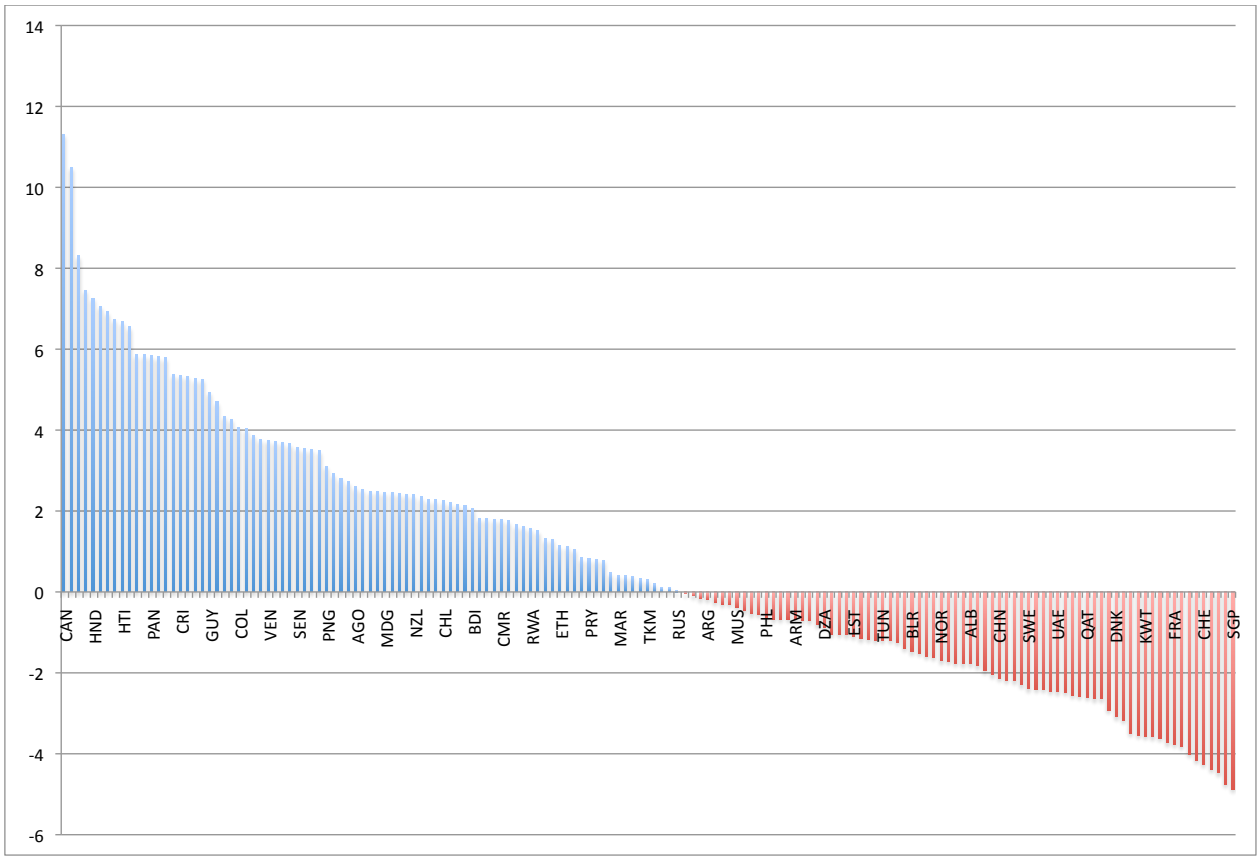
Figure 6. Transport Cost Declines



Comment on real wage gains

In the next experiment, it is assumed that only external transport costs declines for the United States (The internal trade costs for the US do not change). In this case, the increased world demand for US products increases their wage by nearly 4%. However, in terms of wage growth they are not the biggest beneficiary. There are 2 countries that experience wage gains above 10% , Canada and Mexico, with a further 20 countries experiencing gains above 5%. In terms of real wages, all countries experience gains with 125 countries enjoying gains above 10%. These gains are depicted in Figure 7.

Figure 7. US Reduction in Transport Costs



6 Conclusion

This paper demonstrates an important mechanism through which income shocks propagate asymmetrically through the world economy: closely linked partners gain and more distant ones lose. In the presence of large trade costs, churning is inevitable in a world economy where the members grow unevenly because one region's gain tends to be another region's loss. The methods illustrate a practical and insightful way to integrate gravity models into

general equilibrium trade models.

7 Appendix