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Putting industries into the Eaton–Kortum model

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The article introduces the industry dimension into the Eaton-Kortum model of trade. Industries are linked with each other by domestic and international trade in intermediate goods. The model is parametrized using data for eight industries in 1989. It is used to perform several counterfactual simulations that are relevant to today's policy debates. First, the model is used to study the effects of the US–EU trade wars. It is found that trade wars have a greater negative effect on countries with large initial net export positions. It is also found that some trade war scenarios are more beneficial to the US while others to the EU. Second, the model is used to study the effects of trade barrier reductions between the high-income and middle-income countries. The results show that this trade liberalization tends to reinforce the pattern of trade according to technological comparative advantages. The results also show which industries should be targeted for barrier reductions depending on policy goals. The third set of simulations investigates spillovers from the technological growth in the US machinery industry. The results show how geography, technology, and industry links affect the propagation of this growth across countries and industries.

Keywords: international trade; specialization; comparative advantage; technology; computable models; trade policy

JEL Classifications: F1, F11, F13, F17

1. Introduction

This article extends the Eaton and Kortum (2002) model of trade by adding the industry dimension. In addition to producing final goods, industries supply each other with intermediate goods. This creates forward and backward linkages between industries in the sense of Hirschman (1958). These linkages mean that price changes in one industry affect costs of production and output in other industries.

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The model makes industry the central unit of analysis, similar to the traditional empirical trade literature. Other significant features of the model, which come from using the Eaton and Kortum's (EK) methodology, are producer heterogeneity within industry, two-way trade, transportation costs, and endogenous prices. As in the Ricardian model, countries have different technologies and trade with each other to exploit their competitive advantages. As in gravity model, distance between countries is an obstacle to international trade and creates a wedge between goods prices in different countries. Allowing for producer heterogeneity within industries makes two-way trade a natural outcome of the model.

The model is estimated for 8 two-digit industries in 19 OECD (Organization for Economic Co-Operation and Development) countries in 1989. The article suggests a two-step procedure for estimating industry-level technology parameters, taking into account inter-industry trade in intermediate goods. These parameters are measures of technology derived from international competitiveness.

The model makes it possible to simulate changes in technology and trade barriers and see the effects of these changes on prices, costs of production, employment, specialization, and welfare. The model is used to perform several counterfactual simulations that are interesting because they address issues relevant to current policy debates. The simulation results demonstrate how technology, trade costs, and industry linkages interact to determine the complex pattern of trade and specialization.

In the first exercise, the model is used to simulate trade wars between the European Union (EU) and the United States (US). It is found that the employment changes resulting from a trade war are negatively correlated with the initial net export position. For example, the EU is a net exporter of textile products to the US So, a trade war in the textile industry would reduce textile employment in the EU and increase it in the US.

There are also interesting cross-industry effects of trade wars due to the forward and backward linkages between industries. For example, a trade war in the metals industry would have significant negative effects on the machinery industry, which uses intermediate goods made in the metals industry. The results of the exercise are linked with several recent trade disputes between the US and EU.

The second exercise looks at the effects of trade barrier reductions between high-income and middle-income countries. It is found that following such trade liberalizations employment tends to shift from less to more productive countries, thus following technological comparative advantages. The results suggest which industries should be targeted for barrier reductions, depending on policy goals. These goals may include maximizing world manufacturing employment, maximizing world welfare, or increasing manufacturing employment in the poorer countries while minimizing manufacturing employment losses in the richer countries.

The third exercise investigates the spillovers from the technological growth in the US machinery industry. It describes the effects of this growth on prices and employment in other US industries and other countries. It also describes the effects on specialization and welfare. It shows which countries and industries benefit the most from this technological growth and why.

The model of this article focuses on industry as the unit of observation and analysis and has implications for specialization, which connects it to the literature that studies the determinants of specialization.[1] However, while the traditional literature on specialization considers each industry having a homogeneous technology, the model of this article allows for producer heterogeneity within industries.

The model explicitly incorporates trade costs and uses them to explain the home bias in consumption and cross-country price differentials. Therefore, it is well suited to study the effects of changes in trade costs, such as trade wars or trade liberalizations. By comparison, the traditional computable models of trade are based on the Armington (1969) assumption which uses demand-side parameters to explain the pattern of trade (including the home bias) instead of trade costs.

The model also explicitly incorporates technological differences across industries and countries. It is an extension of the Ricardian model, so technology and technological comparative advantage play important roles in the model. Therefore, the model is particularly suitable for a study of how technological change is propagated around the world through trade.

Since the model makes inter-industry linkages as one of its main components, it has connections to the literature on forward and backward linkages and location of industry.[2] The model allows simulation of technological spillovers across industries and countries, which connects it to the vast literature on that topic.[3] Eaton and Kortum (2001) use their model to study the effect of reducing trade barriers on the price of machinery. However, they consider machinery industry in isolation and do not take into account inter-industry trade, a fact that they discuss in the appendix to their paper.[4]

This article is organized as follows. Section 2 describes the model. Section 3 explains the procedure for obtaining model parameters, including the industry technology parameters. Section 4 describes the data. Section 5 discusses the estimated distance and technology parameters. Section 6 explains the simulations and presents their results. Section 7 concludes.

2. Model

There are N countries and J industries. The focus on the empirical application of this model is on the manufacturing industries. The first $J-1$ industries produce manufacturing products, while the last industry produces nonmanufactures. Subscripts i and n refer to countries while subscripts j and m refer to industries.

As in the Ricardian and EK models, labor is the only factor of production. Labor is mobile across industries, but not across countries. The industry cost function is

$$c_{ij} = w_i^{\beta_j} \rho_{ij}^{1-\beta_j} \tag{1}$$

where w_i is the wage, ρ_{ij} is the price of the intermediate goods, and β_j is the share of labor. It is assumed that industries mix intermediate inputs in a Cobb–Douglas fashion, so the price of inputs ρ_{ij} is a Cobb–Douglas function of industry prices:

$$\rho_{ij} = \prod_{m=1}^{J} p_{im}^{\eta_{jm}} = \prod_{m=1}^{J-1} p_{im}^{\eta_{jm}} \tag{2}$$

where η_{jm} is the share of industry m goods in the input of industry j, such that $\sum_{m=1}^{J} \eta_{jm} = 1, \forall j$. The second equality in equation (2) holds because following Eaton and Kortum (2002) we assume that (at least some of) nonmanufacturing output can be traded costlessly and use it as the numeraire: $p_{iJ} \equiv 1$. Note that industries that make manufacturing goods can use nonmanufacturing intermediate goods.[5]

Intra-industry production, trade, and prices are modeled using the framework of Eaton and Kortum (2002). Each industry $j < J$ has a continuum of goods indexed by $l \in [0, 1]$ and produced with its own productivity $z_{nj}(l)$. These productivities are the result of the R&D process and probabilistic, drawn independently from the Fréchet distribution with parameters $T_{ij} > 0$ and $\theta > 1$. The cumulative distribution function (CDF) of this distribution is $F_{ij}(z) = e^{-T_{ij} z^{-\theta}}$.[6] Consumers have constant elasticity of substitution (CES) preferences over the continuum of goods within an industry with the elasticity of substitution $\sigma > 0$.

The price of each good l of industry j produced in country i and delivered to country n is $p_{nij}(l) = c_{ij}\, d_{nij}/z_{ij}(l)$, where d_{nij} is the Samuelson's ('iceberg') transportation cost.[7] The distribution of prices p_{nij} is described by the following CDF: $G_{nij}(p) = 1 - F_{ij}\left(c_{ij} d_{nij}/p\right) = 1 - e^{-T_{ij}\left(c_{ij} d_{nij}\right)^{-\theta} p^{\theta}}$.

Country n consumers buy from the lowest-cost supplier, so the price of good l in country n is $p_{nj}(l) = \min\ \{p_{nij}(l), i = 1, \ldots, N\}$. The distribution of p_{nj} is $G_{nj}(p) = 1 - \prod_{i=1}^{N} \left[1 - G_{nij}(p)\right] = 1 - e^{-\Phi_{nj} p^{\theta}}$, where $\Phi_{nj} = \sum_{i=1}^{N} T_{ij}\ \left(c_{ij} d_{nij}\right)^{-\theta}$ summarizes technology, input costs, and transport costs around the world.

The exact price index for the within-industry CES objective function is $p_{nj} = \gamma\, \Phi_{nj}^{-1/\theta}$, where $\gamma \equiv \Gamma((\theta + 1 - \sigma)/\theta)^{1/(1-\sigma)}$ is a constant.[8] This price index can also be written as

$$p_{nj} = \gamma \left[\sum_{i=1}^{N} T_{ij} \left(d_{nij} c_{ij}\right)^{-\theta} \right]^{-1/\theta} \tag{3}$$

Parameter T_{ij} represents industry-level productivity and, therefore, determines the comparative advantage across industries. For example, country n has a comparative advantage in industry j if $T_{nj}/T_{nm} > T_{ij}/T_{im}$.[9] Parameter θ determines the comparative advantage across goods within an industry. Lower value of θ means more dispersion of productivities among producers, leading to stronger forces of within-industry comparative advantage.

The EK framework makes it possible to derive expressions for the industry-level bilateral trade volumes. The probability that a producer from country i has the lowest price in country n for good l is $\pi_{nij} \equiv \Pr\left[p_{nij}(l) \leq \min\left\{p_{nsj}(l); s \neq i\right\}\right] = \int_0^\infty \prod_{s\neq i}\left[1 - G_{nsj}(p)\right] dG_{nij}(p) = T_{ij} \left(\gamma c_{ij} d_{nij}/p_{nj}\right)^{-\theta}$. Since there is a continuum of goods on the interval [0,1], this probability is also the fraction of industry j goods that country n buys from i. It is also the fraction of n 's expenditure spent on industry j goods from i : X_{nij}/X_{nj}, where X_{nij} is the spending of country n on industry j goods produced in country i and X_{nj} is the total spending in country n on industry j goods.[10] Therefore,

$$\pi_{nij} \equiv \frac{X_{nij}}{X_{nj}} = T_{ij}\left(\frac{\gamma d_{nij} c_{ij}}{p_{nj}}\right)^{-\theta} \tag{4}$$

The market clearing equation is obtained as follows. We have $w_i L_{ij} = \beta_j Q_{ij} = \beta_j \sum_{n=1}^{N} X_{nij} = \beta_j \sum_{n=1}^{N} \pi_{nij} X_{nj} = \beta_j \sum_{n=1}^{N} \pi_{nij}\left(Z_{nj} + Y_{nj}\right)$, where Z_{nj} is the spending on intermediate goods and Y_{nj} is the spending on final goods made by industry j. Following EK, it is assumed that each country spends a constant proportion of its income on goods from each industry, $\alpha_j = Y_{nj}/Y_n$. We also have

$$Z_{nj} = \sum_m Z_{nmj} = \sum_m \eta_{mj} M_{nm} = \sum_m \frac{\eta_{mj}(1-\beta_m)}{\beta_m} w_n L_{nm}$$

where Z_{nmj} is the spending by industry m on intermediate goods made by industry j and M_{nm} is the amount that industry m spends on all intermediate inputs. Therefore, the market clearing equation is

$$w_i L_{ij} = \beta_j \sum_{n=1}^{N} \pi_{nij}\left(\left(\sum_{m=1}^{J-1} \frac{\eta_{mj}(1-\beta_m)}{\beta_m} w_n L_{nm}\right) + \alpha_j Y_n\right) \tag{5}$$

where the consumption of manufactures by the nonmanufacturing industry is treated as final rather than intermediate consumption.

The model is given by equations (1)–(5). In the model, β_j, η_{mj}, γ, θ, α_{nj}, w_i, d_{nij}, T_{ij}, and Y_n are the parameters, and p_{nj}, c_{nj}, π_{nij}, and L_{nj} are the endogenous variables.

The first step to solving the model is solving for the production costs using equations (1)–(3). Solving for costs requires solving a system of

$N \times (J-1)$ equations. For example, in our case, there are 19 countries and 8 manufacturing industries, so there will be $19 \times 8 = 152$ equations with 152 unknowns.[11] Once costs are solved for, π_{nij} can be calculated from equation (4) and industry employments L_{ij} can be solved from equation (5).

Combining equations (1)–(3), we obtain the equation for costs:

$$c_{ij} = w_i^{\beta_j} \prod_{m=1}^{J-1} \left[\gamma^{-\theta} \sum_{n=1}^{N} T_{nm} (d_{inm} c_{nm})^{-\theta} \right]^{-\frac{\eta_{jm}(1-\beta_j)}{\theta}} \tag{6}$$

Taking logs of this equation we obtain

$$\log c_{ij} = \beta_j \log w_i + (1-\beta_j) \log \gamma - \frac{1-\beta_j}{\theta} \sum_{m=1}^{J-1} \left(\eta_{jm} \log \sum_{n=1}^{N} T_{nm} d_{inm}^{-\theta} c_{nm}^{-\theta} \right) \tag{7}$$

Either equation (6) or (7) can be solved numerically, but equation (7) is easier to solve.

3. Obtaining model parameters

The parameters are obtained as follows. Labor shares β_j are obtained from output and value added data. Industry shares η_{im} are obtained from input–output tables. Demand parameters α_j are calculated from production and trade data, as explained in Section 3.2. Wages w_i and country incomes (GDPs – gross domestic production) Y_n are taken directly from data. The data sources are described in Section 4.

Parameter θ is taken from EK, where it is estimated to be 8.28.[12] Trade costs d_{nij} and technology parameters T_{ij} are estimated using the methodology described in Section 3.1. The estimated values are discussed in Section 5.

3.1. Technology and trade costs

The methodology for estimating T_{ij} and d_{nij} is similar to EK, but modified to account for multiple industries. Specifically, the price of inputs ρ_{ij} is now an index of industry prices p_{ij} and cannot be substituted out in the manner used by EK.

From equation (4):

$$\frac{\pi_{nij}}{\pi_{nnj}} = \frac{X_{nij}}{X_{nnj}} = \frac{T_{ij}}{T_{nj}} d_{nij}^{-\theta} \left(\frac{c_{ij}}{c_{nj}} \right)^{-\theta} \tag{8}$$

Let's define $S_{ij} \equiv T_{ij} c_{ij}^{-\theta}$ as a measure of international competitiveness of industry j of country i. Taking logs of equations (8) and using the definition of S_{ij} we get

$$\log \frac{X_{nij}}{X_{nnj}} = -\theta \log d_{nij} + \log S_{ij} - \log S_{nj} \tag{9}$$

As in EK, trade costs are proxied by

$$\log d_{nij} = d_{kj} + b_j + l_j + f_j + m_{nj} + \delta_{nij} \tag{10}$$

where d_{kj} ($k = 1, \ldots ,6$) is the effect of distance lying in the k th interval, b_j is the effect of common border, l_j is the effect of common language, f_j is the effect of belonging to the same free trade area, m_{nj} is the overall destination effect, and δ_{nij} is the sum of geographic barriers that are due to all other factors. Note that all trade costs are industry-specific. Also note that by definition $log\ d_{iij} \equiv 0$.

As in EK, equations (9) and (10) are combined to obtain the estimating equation for S_{ij} and trade costs:

$$\log \frac{X_{nij}}{X_{nnj}} = -\theta d_{kj} - \theta b_j - \theta l_j - \theta f_j + D_{ij}^{\exp} + D_{nj}^{imp} - \theta \delta_{nij} \tag{11}$$

where $D_{ij}^{\exp} = \log S_{ij}$ is the exporter dummy and $D_{nj}^{imp} = -\theta m_{nj} - \log S_{nj}$ is the importer dummy. The overall destination effect is calculated as $m_{nj} = -(1/\theta)(D_{nj}^{\exp} + D_{nj}^{\mathrm{imp}})$. When estimating (11) the following normalization is used: $D_{us,j}^{\exp} = D_{us,j}^{\mathrm{imp}} = 0$. Consequently, the estimation produces the relative competitiveness measures $S_{ij}/S_{us,j}$.

Taking logs of the definition of the (relative) competitiveness measure S_{ij} we have

$$\log \frac{S_{ij}}{S_{us,j}} = \log \frac{T_{ij}}{T_{us,j}} - \theta \log \frac{c_{ij}}{c_{us,j}} \tag{12}$$

Note that to get technology parameters T_{ij} from S_{ij}, it is necessary to strip both wages and prices from S_{ij} (unlike the EK where only wages needed to be stripped). From equation (4), we have

$$\frac{X_{iij}}{X_{ij}} = T_{ij} \left(\frac{\gamma c_{ij}}{p_{ij}} \right)^{-\theta}$$

from which we get

$$\log \frac{X_{iij}/X_{ij}}{X_{us,us,j}/X_{us,j}} = \log \frac{T_{ij}}{T_{us,j}} - \theta \log \frac{c_{ij}}{c_{us,j}} + \theta \log \frac{p_{ij}}{p_{us,j}} \tag{13}$$

Subtracting equation (12) from equation (13), we obtain the expression for industry prices. We then combine that expression with equation (2) to get the expression for input prices:

$$\log \frac{\rho_{ij}}{\rho_{us,j}} = \frac{1}{\theta} \sum_{m=1}^{J-1} \eta_{jm} \left(\log \frac{X_{iim}/X_{im}}{X_{us,us,m}/X_{us,m}} - \log \frac{S_{im}}{S_{us,m}} \right)$$

Finally, combining equations (12) and (1) with the above equation and rearranging, we get the expression for the technology parameters:

$$\log \frac{T_{ij}}{T_{us,j}} = \log \frac{S_{ij}}{S_{us,j}} + \theta\beta_j \log \frac{w_i}{w_{us}} + \left(1 - \beta_j\right) \sum_{m=1}^{J-1} \eta_{jm} \left(\log \frac{X_{iim}/X_{im}}{X_{us,us,m}/X_{us,m}} - \log \frac{S_{im}}{S_{us,m}} \right) \tag{14}$$

This suggests a two-step procedure for estimating the technology parameters. First, the gravity equation (11) is estimated to obtain exporter dummies $S_{ij}/S_{us,j}$. Then these estimates are used to calculate technology parameters $T_{ij}/T_{us,j}$ according to equation (14).

3.2. Demand share parameters

The demand share parameters α_m are calculated from the production and trade data as follows. By definition, $Z_{nm} + Y_{nm} = X_{nm}$. In addition, $X_{nm} = Q_{nm} - EX_{nm} + IM_{nm}$ and $Z_{nm} = \sum_j p_{nm} M_{njm} = \sum_j \rho_{nj} M_{nj} \eta_{jm} = \sum_j \eta_{jm}\left(1 - \beta_j\right) Q_{nj}$. Therefore, α_{nm} are calculated as

$$\alpha_{nm} = \frac{1}{Y_n} \left(Q_{nm} - EX_{nm} + IM_{nm} - \sum_{j=1}^{J-1} \eta_{jm}\left(1 - \beta_j\right) Q_{nj} \right) \tag{15}$$

Then, α_m are calculated as the averages of α_{nm} across the countries in the dataset.

4. Data

To estimate the model, I use data for 8 two-digit manufacturing industries (that can be seen in Table 1) in 19 OECD countries (that can be seen in Table 4).[13] I use data from 1989 because this is the year for which most observations are available.

Bilateral trade data needed to estimate equation (11) is from Feenstra (1997, 2000). Industry output and labor compensation are from the UNIDO's INDSTAT database. Imports from home X_{iij} are calculated as

Table 1. Values of parameters α_j and β_j.

Industry	α_j	α_j
Food	0.161	0.103
Textile	0.043	0.207
Wood	0.029	0.182
Paper	0.037	0.178
Chemicals	0.114	0.114
Nonmetals	0.034	0.185
Metals	0.011	0.125
Machinery	0.249	0.187

Note: α_j is the demand share of industry j in income, β_j is the labor share in industry j.

output minus exports, and spending X_{ij} is calculated as output minus exports plus imports. Labor's share in output, β_j, is calculated as the average of the labor shares of the countries in our dataset. Parameters α_j and β_j are presented in Table 1.

Distance measures used on the right-hand side of equation (11) are obtained as follows. The distance (in miles) between the economic centers of countries is taken from Stewart (1999). This distance is the great circle distance between the population weighted average of the latitude and longitude of major cities. The distance is divided into six intervals, as in EK: [0,375), [375,750), [750,1500), [1500,3000), [3000,6000), and [6000,maximum). The free trade agreements accounted for by the f variable include EC/EU, EFTA, EEA, FTA, NFTA, CER, (European Community, European Free Trade Association, European Economic Area, Free Trade Association, Closer Economic Relations Trade Agreement) and the free-trade agreement between Turkey and EFTA.[14]

The data for industry shares η_{jm} is obtained from the OECD input–output tables. These tables exist only for some of the countries in the dataset and only for select years. I use the input–output tables for Australia, Canada, France, Germany, Japan, United Kingdom (UK), and the US for 1990.[15] The values of η_{jm} used in the model and shown in Table 2 are the averages of η_{jm}'s of these countries (they are very similar).[16]

5. Estimated trade costs and technology parameters

The trade costs d_{ni} and technology parameters T_{ij} are estimated following the methodology described in Section 3.1. The average estimated trade costs (averaged across country pairs and industries) is 2.27.[17] The average (across country pairs) trade costs in each industry are listed in Table 3. The smallest average trade costs are in the machinery and textile industries and the largest are in the wood and food industries.

The estimated technology parameters are presented in Table 4. Technology parameters are measured relative to the US. The US has the

Table 2. Industry shares in intermediate goods.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery
Food	**0.210**	0.016	0.002	0.006	0.013	0.003	0.001	0.002
Textile	0.001	**0.458**	0.037	0.007	0.007	0.005	0.002	0.008
Wood	0.003	0.002	**0.261**	0.018	0.002	0.007	0.003	0.007
Paper	0.039	0.023	0.017	**0.388**	0.021	0.041	0.004	0.013
Chemicals	0.043	0.117	0.078	0.079	**0.355**	0.091	0.046	0.067
Nonmetals	0.011	0.001	0.012	0.002	0.006	**0.168**	0.011	0.010
Metals	0.001	0.001	0.022	0.003	0.011	0.018	**0.422**	0.140
Machinery	0.068	0.056	0.098	0.101	0.082	0.099	0.091	**0.457**
Manufacturers	0.377	0.674	0.529	0.604	0.497	0.432	0.580	0.704
Nonmanufacturers	0.623	0.326	0.471	0.396	0.503	0.568	0.420	0.296
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: The number in row m column j is η_{jm}, the share of industry m goods in the intermediate inputs of industry j. The data are the average of Australia for 1989 and Canada, France, Germany, Japan, UK, and US for 1990. The shares of industry j's own goods in its intermediate inputs are in bold.

Table 3. Estimated trade costs.

	Trade cost
Food[1]	2.45
Textile[1]	2.02
Wood[1]	2.57
Paper[1]	2.44
Chemicals[1]	2.21
Nonmetals[1]	2.38
Metals[1]	2.04
Machinery[1]	2.01
Average[2]	2.27
Maximum[2]	6.62
Minimum[2]	1.00
Standard deviation[2]	0.77

Note: [1] Average for all country pairs. [2] Of all country pairs and industries.

highest technology parameter in food, wood, paper, and chemicals industries. Italy has the highest technology parameter in the textile industry while Japan has the highest technology parameter in nonmetals, metals, and machinery. Developing countries (Mexico, Turkey) typically have the lowest technology parameters.

The quality of the model can be checked by simulating the model as described in Section 2 using the estimated parameter values, and then comparing the predicted industry employments with the actual ones. They turn out to be very close with the correlation equal to 0.98.

6. Counterfactual simulations

The model will now be used to perform several counterfactual experiments that are interesting because of their policy relevance. The first set of experiments will simulate trade wars between the US and EU. The second set will simulate the reduction of the trade barriers between the high-income and middle-income countries. The third set of experiments will simulate the spillover of the technological growth in the US Machinery industry to other industries and countries.

In all of these experiments the focus will be on the effects on employments (industry and total manufacturing), specialization, welfare, as well as goods prices and costs of production. Specialization will be measured by the proportion of industry employment in total manufacturing employment. Since the model assumes full employment and fixed labor forces in each country, the workers who lose their jobs in manufacturing move to the nonmanufacturing sector. While there is no unemployment in the model, the number of manufacturing jobs is an interesting variable to track given the importance that policy-makers often place on it. The welfare

Table 4. Estimated technology parameters, relative to the US.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery
Australia	0.272	0.154	0.022	0.045	0.047	0.054	0.444	0.042
Austria	0.029	0.173	0.025	0.108	0.060	0.232	0.124	0.057
Canada	0.288	0.359	0.683	0.950	0.149	0.156	1.002	0.117
Finland	0.014	0.096	0.110	0.566	0.049	0.046	0.214	0.055
France	0.391	0.969	0.144	0.269	0.361	1.042	0.378	0.271
Germany	0.206	0.754	0.259	0.308	0.513	0.856	0.518	0.427
Greece	0.044	0.068	0.001	0.003	0.009	0.037	0.055	0.002
Italy	0.203	2.110	0.391	0.275	0.240	1.448	0.325	0.299
Japan	0.072	0.906	0.138	0.391	0.595	1.602	1.181	1.185
Korea	0.034	0.493	0.011	0.023	0.063	0.052	0.185	0.056
Mexico	0.009	0.011	0.000	0.002	0.019	0.012	0.024	0.002
New Zealand	0.373	0.086	0.030	0.058	0.029	0.009	0.072	0.013
Norway	0.102	0.037	0.037	0.120	0.073	0.035	0.275	0.042
Portugal	0.019	0.033	0.003	0.018	0.007	0.025	0.013	0.004
Spain	0.115	0.189	0.022	0.071	0.087	0.194	0.205	0.046
Sweden	0.034	0.090	0.100	0.306	0.080	0.092	0.216	0.097
Turkey	0.013	0.026	0.000	0.000	0.009	0.015	0.034	0.001
UK	0.228	0.333	0.074	0.210	0.252	0.368	0.310	0.160
US	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

will be measured by the real income $W_n = Y_n / \prod_j p_{nj}^{\alpha j}$. Changes in variables will be measured with respect to their baseline 1989 values.

6.1. US–EU trade wars

The volume of trade between the US and EU is very high. However, these two entities often threaten to go to a trade war with each other when they perceive an unfairness in trade arrangements or competition. In 1999, the US imposed punitive tariffs on a range of European food products because of a dispute over banana exports by American companies to Europe. This dispute was resolved in 2001. In another incident, the imposition by the US of high tariffs on steel imports (to protect its steel industry in a time of recession) in 2002 resulted in reciprocal tariffs by the EU. That dispute was resolved in 2003.

There are several ongoing disputes between the US and EU that threaten to deteriorate into trade wars. For example, there are challenges by the EU against the US in the World Trade Organization (WTO) about the US dumping calculations and tax breaks for large corporations.

These disputes and threats of trade wars almost always focus on one particular industry. No one is really talking about an all-out trade war between the US and the EU. However, since all industries are linked with each other, a trade war in one industry will affect all industries. The model described in this article makes it possible to simulate a trade war between the EU and the US that is limited to one industry. The results will tell us about the effects of such a trade war on industry employments, prices, costs of production, and welfare in the US, EU, and the rest of the world.

In 1989, the EU included Austria, France, Germany, Greece, Italy, Portugal, Spain, and the UK. A trade war will be simulated by increasing the trade costs between the US and EU in an industry to the point where trade becomes prohibitively expensive, while keeping all other trade costs constant.

Table 5 summarizes the effects of trade wars in different industries on total manufacturing employment. The name of the industry in which there is a trade war is at the top of the column. The last column refers to the all-out trade war in all industries.

Countries with higher initial net export positions in industry *j* vis-à -vis their trade war 'enemy' experience greater declines in industry *j* and total manufacturing employment as a result of a trade war in industry *j*. For example, an EU country that was initially a net exporter of industry *j* to the US would experience a decline in its industry *j* and total manufacturing employments as a result of a trade war in industry *j*. The correlation between the initial net export position and change in industry employments is around -0.9 for a typical industry.

Table 5. Changes in manufacturing employment.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery	All manufacturers
Australia	194	276	49	124	713	95	1,288	5,012	7,743
Austria	**−456**	**−1,345**	**371**	**944**	**244**	**−1,918**	**−1,316**	**2,650**	**−911**
Canada	710	3,094	1,806	1,130	3,945	1,463	7,484	28,359	48,213
Finland	−36	103	379	1,641	760	−35	760	5,196	8,786
France	**−6,816**	**−12,475**	**33**	**3,439**	**−2,055**	**−5,312**	**−13,207**	**17,889**	**−18,886**
Germany	**−633**	**−12,098**	**193**	**6,433**	**−8,693**	**−7,614**	**−13,647**	**−35,818**	**−73,581**
Greece	**−1,148**	**−8,522**	**574**	**511**	**556**	**−3,625**	**−384**	**2,461**	**−9,559**
Italy	**−3,145**	**−59,925**	**−5,199**	**3,648**	**8**	**−14,133**	**−1,764**	**16,041**	**−64,905**
Japan	557	5,261	706	851	9,276	2,365	16,654	141,099	177,570
Korea	483	44,462	358	486	5,976	1,209	6,676	47,383	107,478
Mexico	1,142	5,533	271	245	3,353	2,747	8,251	15,621	37,206
New Zealand	199	73	14	42	222	33	158	960	1,701
Norway	49	17	68	397	555	−11	782	3,069	4,926
Portugal	**−272**	**−17,378**	**337**	**698**	**−245**	**−3,617**	**−293**	**−112**	**−20,855**
Spain	**−5,682**	**−22,094**	**1,586**	**1,950**	**1,571**	**−9,352**	**−6,057**	**39,203**	**1,012**
Sweden	−52	2	575	2,444	1,723	−55	1,888	17,999	24,542
Turkey	171	7,316	135	664	3,058	46	1,392	9,019	21,844
United Kingdom	**−8,780**	**−16,783**	**468**	**1,949**	**−6,880**	**−7,878**	**−15,018**	**−44,084**	**−97,079**
United States	21,279	116,429	−76	−25,842	−5,646	40,727	6,932	−208,561	−53,543
Total EU	−26,932	−150,620	−1,638	19,571	−15,495	−53,449	−51,684	−1,771	−284,763
Total US	21,279	116,429	−76	−25,842	−5,646	40,727	6,932	−208,561	−53,543
Total other	3,418	66,136	4,361	8,023	29,581	7,859	45,333	273,716	440,010
World	−2,236	31,945	2,648	1,753	8,439	−4,864	581	63,385	101,703

Notes: Column headings specify the industry in which the trade war occurs. A trade war means trade barriers being raised to prohibitively high levels. EU countries are in bold.

Let's consider a trade war in the textile industry. We can see from Table 5 that this trade war would result in a loss of more than 150,000 manufacturing jobs in the EU, mostly in Italy and Spain. The US, on the other hand, would stand to gain over 116,000 manufacturing jobs from this trade war. This makes sense since initially, the EU was a net exporter of textiles to the US. The rest of the world also gains manufacturing jobs. Korea, with its high technology of producing Textile products, would be able to gain 44,000 manufacturing jobs.

However, this trade war, as all other trade wars, would cause lower welfare in all countries because of higher goods prices. Even so, welfare losses from the trade war in textiles would be relatively small ($<0.04\%$) because production would be able to move easily between countries. The industry in which a trade war between the EU and US would cause the highest decline in welfare is the machinery industry (0.2–0.5%, depending on a country) because only few countries in the world have the technology to produce machinery cheaply.

The welfare losses from any of the trade wars considered here would also be significantly smaller than the welfare losses from complete autarky. The model predicts the losses from complete autarky (when trade is shut down in all industries) to vary between 0.66% and 14%, depending on a country (these magnitudes are similar to the welfare losses of 0.2%–10.3% estimated in Eaton and Kortum (2002)).

Returning to Table 5, we can see that a trade war in the food industry would also hurt the EU manufacturing employment while benefiting the US manufacturing employment. Again, this makes sense since most EU countries were initially net exporters of food to the US The rest of the world would gain little from this trade war. Interestingly, in the recent 'banana' dispute, the EU quickly agreed to the US demands once the US sanctions against the EU's (mainly food) products were in place. The final deal was hailed as a victory for the US Clearly, the EU felt that a trade war in the food industry was not in its interest.

If there ever were a trade war in the machinery industry, the US would lose many more manufacturing jobs than the EU. However, the total change of manufacturing employment in the EU due to this trade war is not the complete story. We can see that the UK and Germany would lose many manufacturing jobs while Spain and France would gain nearly as many manufacturing jobs. Spain and France would at least partially substitute disappeared US imports with increased domestic production. The country which stands to gain the most from this trade war is Japan, which would be able to export machinery with less competition to both the US and EU.

So far, we have focused on changes in total manufacturing employments. However, changes in total manufacturing employments mask the underlying changes in industry employments. Lets focus on a trade war in the metals industry. It is a good approximation to the recent trade war in the steel industry since the steel industry is a major component of the metals industry.

Metals industry has strong forward linkages to the machinery industry. Therefore, one of the results of a trade war in the metals industry is the higher cost of production in the machinery industry. Because the US depends so much on the imported steel, it suffers one of the highest increases of the costs of production in the machinery industry (second only to the UK).

In the US metals industry, higher costs of production are offset by the increased domestic demand for domestic metal products. So, the US metals industry actually gains almost 18,000 jobs as a result of a trade war in that industry. In the machinery industry, on the other hand, higher costs of production are not offset by higher demand and, therefore, the industry loses about 11,000 jobs (see Table 6). Thus, the main employment result for the US of a trade war in the metals industry is the redistribution of employment from the machinery industry to the metals industry. The net effect on total manufacturing employment is relatively small. These simulation results explain why the US firms that produce machinery were such vocal opponents of the higher US tariffs on steel.

Table 7 shows the changes in specialization, measured by the percent changes in the employment shares of each industry in total manufacturing employment, that occur as a result of this trade war. The US increases its specialization in metals (share increases by 1.5%) at the expense of the machinery industry (share falls by 0.16%). Canada and Mexico increase their sales of metals to the US to pick up the slack from the EU, so their specialization in metals also increases. The EU countries decrease their specialization in metals. For example, the share of the metals industry in Spain declines by 4.3%.[18]

6.2. Reducing trade barriers between the high-income and middle-income countries

There has been much political debate about the trade barriers between richer and poorer countries. Poorer countries often accuse richer countries of having high trade barriers for products in which poorer countries specialize, for example textiles. Richer countries, on the other hand, often accuse poorer countries of having high trade barriers on products in which poorer countries face tough competition from richer countries, for example machinery.

The model of this article makes it possible to simulate industry-specific reductions of the trade barriers between richer and poorer countries. To perform this simulation, the countries in the dataset will be divided into two groups. One group will include Greece, Korea, Mexico, Portugal, and Turkey. In 1989, the per capita GDP of these countries was less than 1/3 of

Table 6. Changes in industry employments due to a trade war in the metals industry.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery
Australia	9	16	12	21	68	18	514	630
Austria	**−2**	**−4**	**−2**	**−8**	**−42**	**−19**	**−1,354**	**115**
Canada	21	74	123	104	375	113	3,730	2,944
Finland	2	9	13	12	35	12	358	320
France	**−24**	**−82**	**−75**	**−114**	**−468**	**−139**	**−10,527**	**−1,776**
Germany	**−22**	**−55**	**−60**	**−112**	**−575**	**−214**	**−11,889**	**−719**
Greece	**1**	**−6**	**−2**	**−3**	**−18**	**−5**	**−340**	**−10**
Italy	**2**	**−18**	**4**	**−10**	**−75**	**−35**	**−2,082**	**450**
Japan	79	323	202	258	880	244	3,180	11,488
Korea	26	407	67	98	369	95	1,720	3,893
Mexico	31	49	33	72	286	148	5,603	2,029
New Zealand	8	3	3	4	12	3	37	89
Norway	3	2	6	8	26	11	517	209
Portugal	**1**	**−11**	**2**	**−7**	**−11**	**−7**	**−349**	**89**
Spain	**−6**	**−26**	**−31**	**−47**	**−237**	**−117**	**−5,781**	**188**
Sweden	5	5	21	16	71	24	861	886
Turkey	9	68	18	19	60	24	621	574
United Kingdom	**−57**	**−209**	**−125**	**−186**	**−746**	**−219**	**−7,113**	**−6,362**
United States	−39	−281	−184	−88	278	175	17,973	−10,902

Notes: Column headings specify the industry in which the trade war occurs. A trade war means trade barriers being raised to prohibitively high levels. EU countries are in bold.

Table 7. Changes in specialization due to a trade war in the metals industry.

	Food%	Textile%	Wood%	Paper%	Chemicals%	Nonmetals%	Metals%	Machinery%
Australia	−0.11	−0.11	−0.10	−0.09	−0.07	−0.08	0.53	0.05
Austria	**0.23**	**0.23**	**0.23**	**0.21**	**0.17**	**0.17**	**−2.84**	**0.29**
Canada	−0.32	−0.30	−0.27	−0.29	−0.20	−0.21	2.25	0.02
Finland	−0.16	−0.14	−0.13	−0.14	−0.09	−0.11	0.89	0.06
France	**0.39**	**0.37**	**0.35**	**0.34**	**0.29**	**0.29**	**−3.25**	**0.26**
Germany	**0.22**	**0.21**	**0.20**	**0.19**	**0.15**	**0.14**	**−2.78**	**0.20**
Greece	**0.12**	**0.12**	**0.11**	**0.10**	**0.07**	**0.09**	**−2.51**	**0.10**
Italy	**0.06**	**0.06**	**0.06**	**0.05**	**0.04**	**0.04**	**−1.18**	**0.10**
Japan	−0.12	−0.10	−0.09	−0.09	−0.07	−0.08	0.32	0.05
Korea	−0.17	−0.14	−0.11	−0.11	−0.08	−0.10	0.77	0.12
Mexico	−0.44	−0.42	−0.35	−0.39	−0.32	−0.33	2.66	−0.09
New Zealand	−0.06	−0.06	−0.06	−0.05	−0.03	−0.05	0.51	0.08
Norway	−0.26	−0.25	−0.24	−0.25	−0.20	−0.19	1.14	−0.05
Portugal	**0.05**	**0.04**	**0.05**	**0.03**	**0.03**	**0.03**	**−2.71**	**0.14**
Spain	**0.27**	**0.26**	**0.25**	**0.24**	**0.18**	**0.18**	**−4.32**	**0.30**
Sweden	−0.19	−0.18	−0.17	−0.19	−0.13	−0.14	0.92	0.03
Turkey	−0.08	−0.08	−0.06	−0.06	−0.04	−0.05	0.90	0.09
United Kingdom	**0.33**	**0.30**	**0.27**	**0.27**	**0.22**	**0.24**	**−2.41**	**−0.02**
United States	−0.03	−0.04	−0.05	−0.04	−0.02	−0.01	1.55	−0.16

Notes: Numbers represent percent changes in the employment shares of each industry out of total manufacturing employment. EU countries are in bold.

the US's. They also specialized in labor-intensive industries, such as Textiles. We will call these countries the middle-income countries. The other countries will be called the high-income countries.

The simulation will study the effects of lowering the trade barriers between the high-income and middle-income countries, while keeping the trade barriers within each group of countries constant. The simulation will reduce the trade barriers by 10% since Anderson and van Wincoop (2004) estimate that policy-related trade barriers constitute about 10–15% of all international trade costs.[19] It will be assumed that all trade barriers removed during the simulation are tariffs. Since NTBs (non-tarrif barriers) generally result in greater welfare losses than tariffs, this assumption means that the welfare increases reported in Table 9 are likely the lower bounds of the welfare gains that are possible with this trade liberalization. The revenue loss resulting from the removal of tariffs previously rebated to consumers is taken into account when calculating welfare changes reported in Table 9.

Tables 8 and 9 summarize the changes in the total manufacturing employment and welfare in each country that occur when the trade costs between the high-income and middle-income countries are reduced by 10% in a particular industry. The name of the industry in which the costs are reduced is at the top of each column in these tables. The last columns refer to the simultaneous 10% reduction of the trade barriers in all industries. Middle-income countries are highlighted in bold.

We can see that employment effects vary depending on which industry has the trade barrier reduction. The most dramatic employment implications occur when trade barriers are reduced in the textile industry. This happens for two reasons. First, the textile industry is a large industry (second-largest for the average country, after machinery). It is also the most labor-intensive industry. Second, the textile industry has the smallest technology gap between high-income and middle-income countries. Therefore, middle-income countries have the technological comparative advantage in the textile industry. For these reasons, when trade barriers between high-income and middle-income countries are lowered, textile production moves from high-income to middle-income countries, resulting in large employment changes.

Almost half a million manufacturing jobs are added in the middle-income countries while about 175,000 manufacturing jobs are lost in the high-income countries. Korea, with its high productivity in textiles (relative to other middle-income countries), gains most of the manufacturing jobs. As a percentage of labor force, Portugal gains almost as much as Korea, 8.5%. All high-income countries lose manufacturing jobs. The US loses the most manufacturing jobs in absolute terms, about 75,000.

Interestingly, Mexico loses manufacturing jobs when trade costs are reduced in the textile industry. This is because Mexico already had easy access to a big market (US) before the reduction of the trade barriers.

Table 8. Changes in manufacturing employment.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery	All manufacturers
Australia	342	−4,384	−39	−247	−928	−199	−67	−3,157	−8,849
Austria	−145	−1,600	30	81	−150	41	−291	−769	−2,869
Canada	144	−8,388	114	988	−664	−362	−762	−4,433	−13,650
Finland	−58	−2,124	147	568	−232	−103	−135	−779	−2,782
France	−456	−7,060	−26	−318	−388	−118	−1,495	−5,435	−15,762
Germany	−583	−8,357	96	−272	233	−203	−2,283	−7,290	−19,206
Greece	**4,848**	**8,890**	**−2,263**	**−1,873**	**−179**	**875**	**3,630**	**−4,798**	**10,032**
Italy	−1,172	−12,279	371	−529	−967	169	−799	−4,304	−19,985
Japan	−6,875	−32,115	−1,106	−585	−1,864	−500	−5,021	3,028	−45,957
Korea	**8,128**	**374,529**	**−3,015**	**−5,175**	**21,960**	**5,394**	**38,262**	**195,973**	**645,808**
Mexico	**−18,953**	**−4,369**	**−3,993**	**−14,581**	**3,073**	**1,624**	**20,019**	**−12,202**	**−26,029**
New Zealand	1,234	−708	142	67	−133	−46	163	−527	149
Norway	87	−490	−10	100	−55	−86	−154	−565	−1,207
Portugal	**2,094**	**51,411**	**2,912**	**5,789**	**3,868**	**4,767**	**6,064**	**23,723**	**103,874**
Spain	463	−6,720	−198	−113	−276	156	−569	−6,319	−14,008
Sweden	−131	−1,214	109	648	−307	−237	−435	−1,006	−2,663
Turkey	**2,316**	**40,624**	**−4,441**	**−6,744**	**1,340**	**3,035**	**9,379**	**−48,189**	**864**
United Kingdom	99	−14,249	−393	−415	−925	−407	−1,518	−7,485	−25,962
United States	4,999	−75,396	3,173	4,554	−3,049	−2,648	−8,553	−27,961	−107,268
All middle-income	−1,566	471,084	−10,800	−22,584	30,062	15,696	77,355	154,506	734,549
All high-income	−2,051	−175,084	2,409	4,527	−9,706	−4,543	−21,917	−67,001	−280,019
Total	−3,618	296,000	−8,391	−18,057	20,356	11,152	55,438	87,505	454,530
Middle-income gain/ High-income loss	2.69			3.10	3.45	3.53	2.31	2.62	

Notes: Column headings specify the industry in which the trade barriers are reduced (by 10%). Middle-income countries are in bold.

Table 9. Percent changes in welfare.

	Food (%)	Textile (%)	Wood (%)	Paper (%)	Chemicals (%)	Nonmetals (%)	Metals (%)	Machinery (%)	All manufacturers (%)
Australia	0.001	0.007	0.000	0.001	0.005	0.001	0.002	0.013	0.031
Austria	0.001	0.007	0.000	0.001	0.002	0.000	0.002	0.010	0.023
Canada	0.001	0.008	0.000	0.000	0.002	0.001	0.002	0.010	0.024
Finland	0.001	0.014	0.000	0.000	0.003	0.001	0.002	0.008	0.030
France	0.001	0.005	0.000	0.001	0.002	0.000	0.002	0.007	0.019
Germany	0.001	0.006	0.000	0.001	0.002	0.000	0.002	0.007	0.020
Greece	**0.052**	**0.005**	**0.023**	**0.039**	**0.080**	**0.013**	**0.010**	**0.332**	**0.518**
Italy	0.003	0.003	0.000	0.001	0.002	0.000	0.002	0.007	0.019
Japan	0.002	0.005	0.000	0.000	0.002	0.000	0.002	0.003	0.016
Korea	**0.030**	**0.002**	**0.010**	**0.013**	**0.029**	**0.005**	**0.000**	**0.083**	**0.165**
Mexico	**0.059**	**0.027**	**0.034**	**0.038**	**0.068**	**0.010**	**0.003**	**0.267**	**0.500**
New Zealand	0.001	0.006	0.000	0.000	0.005	0.001	0.005	0.015	0.034
Norway	0.001	0.019	0.000	0.001	0.004	0.001	0.002	0.015	0.041
Portugal	**0.052**	**0.000**	**0.007**	**0.013**	**0.057**	**0.011**	**0.001**	**0.223**	**0.308**
Spain	0.001	0.004	0.001	0.001	0.003	0.001	0.003	0.012	0.026
Sweden	0.001	0.015	0.000	0.001	0.004	0.001	0.002	0.009	0.036
Turkey	**0.023**	**0.001**	**0.009**	**0.027**	**0.045**	**0.006**	**0.013**	**0.264**	**0.370**
United Kingdom	0.001	0.007	0.000	0.001	0.002	0.000	0.002	0.009	0.023
United States	0.001	0.006	0.000	0.000	0.002	0.001	0.002	0.008	0.020
Average middle-income	0.043	0.007	0.017	0.026	0.056	0.009	0.005	0.234	0.372
Average high-income	0.001	0.008	0.000	0.001	0.003	0.001	0.002	0.009	0.026
Average world	0.012	0.008	0.005	0.007	0.017	0.003	0.003	0.069	0.117

Notes: Column headings specify the industry in which the trade barriers are reduced (by 10%). Middle-income countries are in bold.

Therefore, the reduction mostly benefits other developing countries, which can now compete with Mexico on more equal terms. In addition, Mexican technology parameter in the textile industry is the lowest of all countries in the dataset. As a result, Mexico loses textile and total manufacturing jobs.

Significant employment changes also occur when trade barriers are reduced in the machinery industry. Korea and Portugal (which have higher technology than the other middle-income countries) gain manufacturing employment while the rest of the middle-income countries and most of the high-income countries lose manufacturing employment. Korea gains the most manufacturing jobs in absolute terms, but Portugal gains almost as much in relative terms.

Table 9 shows that a reduction of the trade barriers in the machinery industry results in the greatest increase in welfare, largely because the machinery industry has the strongest forward linkages. The increase in welfare is especially noticeable in the middle-income countries, where machinery prices fall significantly when the trade barriers in that industry are reduced.

In five out of eight industries, the middle-income countries gain jobs while the high-income countries lose jobs when the trade barriers between them are lowered. In these five industries, the world as a whole gains jobs. In two industries, wood and paper, the high-income countries gain and the middle-income countries lose jobs. In one industry, food, both high- and middle-income countries lose as a group. The world loses manufacturing jobs when trade barriers are reduced in the wood, paper, and food industries and gains manufacturing jobs when trade barriers are reduced in other industries.

Why does the world gain manufacturing jobs when trade barriers are reduced in some industries and loses manufacturing jobs when trade barriers are reduced in other industries? When trade barriers in an industry are lowered, world production in that industry concentrates in countries where the cost of production is low. The cost of production is determined by the exogenous wage and productivity. If production ends up moving from countries with low productivity to countries with high productivity, world employment in that industry falls. In this case, the high-productivity countries probably have high wages, but their advantage in productivity more than offsets their disadvantage in wages. If production ends up moving from countries with high productivity to countries with low productivity, world employment in that industry rises. In this case, the low-productivity countries have very low wages that more than offset these countries' disadvantage in productivity.

Welfare, of course, always increases when trade barriers are reduced, though the welfare gains are much smaller than the gains from completely free trade. The model predicts the gains from completely free trade (in all industries and between all countries) to be between 16% and 31%, depending on a country. These magnitudes are comparable to the welfare gains from free trade of 16.1%–24.1% reported by Eaton and Kortum (2002).

Which industry is the best target for reducing trade barriers if the goal is to increase world manufacturing employment? Table 8 shows that the textile industry is the best target in this case. If the goal is to increase manufacturing employment in the middle-income countries while maintaining manufacturing employment in the high-income countries as much as possible, then the metals industry is the best target for reducing trade barriers (and machinery is the worst). If the goal is to increase welfare, then the best target for trade barrier reduction is by far the machinery industry.

6.3. Technology spillovers

Technology spillovers have been the focus of many studies in recent years (see Keller 2001 a for summary). Capital goods and intermediate goods have been identified as the channels that can transmit the positive effects of the new technology across industries and countries. The model developed in this article makes it possible to simulate this transmission. Since capital goods are treated as intermediate goods in the model, both channels are combined into one.

This section will look at the effects of higher technology in the US machinery industry, since this industry is an important provider of intermediate and capital goods and the US is a key producer of machinery. The results will show how technology interacts with geography and inter-industry linkages to affect specialization, employment, and welfare.

The technology spillovers from the US machinery industry considered in this section operate through the trade and inter-industry linkages, and not through direct knowledge diffusion. In other words, it is not that the improvement of the technology parameter T in the US machinery industry leads to an improvement in the T parameter for other countries and industries.

The machinery industry has strong forward linkages to all other industries as shown in Table 4. The machinery industry also has a strong backward linkage to the metals industry. We are interested in the effect of the improvement in machinery technology on prices, costs of production, and employment in other industries and other countries. For example, will more efficient technology in the US machinery industry have a greater effect on the other US industries or on the machinery industry in the other countries?

During the simulation, parameter T in the US machinery industry is increased from 1 to 1.5. This increase corresponds to the increase in the average productivity draw from 1 to 1.05 (given by $T^{1/\theta}$), a 5% increase. By comparison, the average productivity draw in Germany's machinery industry (relative to the US) is 0.9.

Tables 10–12 show the effects of this change on the costs of production, goods prices, employment, specialization, and welfare. As a result of this increase in technology, the costs of production and goods prices fall in all industries and countries. The largest declines are, of course, in the US machinery industry itself. Other industries in the US benefit from access to cheaper domestic intermediate machinery goods and, therefore, face lower production costs. Other countries also benefit from access to cheaper intermediate machinery goods, but the degree to which they benefit depends on their proximity to the US. Canadian and Mexican machinery industries benefit the most, while the Japanese machinery industry, which is far away from the US and is itself quite productive, benefits the least. The technological improvement in the US machinery industry benefits the machinery industry in the nearby countries because the machinery industry uses a large amount of inputs that are classified as coming from the same industry.

Goods prices also fall around the world. Machinery prices fall the most. Prices of all goods in the US and the nearby countries fall significantly. Prices of non-machinery products in countries far from the US fall the least.

The relatively modest improvement in the US machinery technology has significant effects on employment. The employment in the US machinery industry grows dramatically: it increases by more than 1.5 million or nearly 20%. Other US industries, benefiting from cheaper intermediate goods, are able to hire more workers as well. The largest beneficiary is the metals industry, which is also helped by the higher demand for its products by the machinery industry.[20]

The employment in the Mexican metals industry also increases. Its proximity to the US and its low wages mean that the Mexican metals industry is in a good position to buy new machinery from the US and supply the US machinery industry with intermediate goods. The metals industry in Canada benefits from its proximity to the US as well, but suffers because of its high wages. As a result, Canada increases its specialization in metals, but the employment in its metals industry (in absolute terms) declines.

Manufacturing employment in all other countries falls. The machinery industries in Japan, Germany, and Korea (being the major suppliers of machinery in the world) are hurt the most in absolute terms, even though in percentage terms, Canadian and Mexican machinery industries lose the most.

These changes in employment lead to changes in specialization. The US increases its specialization in machinery and metals industries while decreasing its specialization in all other industries. Mexico and Canada decrease their specialization in machinery and increase their specialization in all other industries, including the metals industry. All other countries decrease their specialization in metals and machinery and increase their specialization in all other industries.

Table 10. Percent changes in the costs of production.

	Food (%)	Textile (%)	Wood (%)	Paper (%)	Chemicals (%)	Nonmetals (%)	Metals (%)	Machinery (%)
Australia	−0.148	−0.158	−0.206	−0.237	−0.200	−0.186	−0.225	−0.642
Austria	−0.057	−0.066	−0.080	−0.098	−0.080	−0.072	−0.093	−0.242
Canada	−0.385	−0.394	−0.535	−0.608	−0.507	−0.487	−0.611	−1.694
Finland	−0.080	−0.087	−0.112	−0.126	−0.110	−0.102	−0.130	−0.352
France	−0.071	−0.077	−0.098	−0.114	−0.096	−0.089	−0.115	−0.304
Germany	−0.071	−0.077	−0.099	−0.121	−0.095	−0.089	−0.114	−0.301
Greece	−0.073	−0.078	−0.106	−0.124	−0.096	−0.091	−0.116	−0.313
Italy	−0.058	−0.066	−0.085	−0.100	−0.079	−0.073	−0.093	−0.243
Japan	−0.034	−0.039	−0.056	−0.054	−0.045	−0.039	−0.055	−0.128
Korea	−0.127	−0.129	−0.181	−0.209	−0.163	−0.153	−0.187	−0.519
Mexico	−0.442	−0.464	−0.634	−0.703	−0.577	−0.555	−0.684	−1.932
New Zealand	−0.135	−0.149	−0.187	−0.215	−0.189	−0.171	−0.208	−0.584
Norway	−0.108	−0.109	−0.148	−0.168	−0.144	−0.135	−0.167	−0.476
Portugal	−0.076	−0.079	−0.100	−0.117	−0.096	−0.091	−0.115	−0.317
Spain	−0.068	−0.074	−0.096	−0.110	−0.091	−0.085	−0.107	−0.292
Sweden	−0.112	−0.111	−0.152	−0.173	−0.146	−0.140	−0.171	−0.492
Turkey	−0.088	−0.092	−0.120	−0.141	−0.113	−0.107	−0.132	−0.368
United Kingdom	−0.111	−0.115	−0.157	−0.177	−0.146	−0.140	−0.180	−0.489
United States	−0.581	−0.577	−0.791	−0.897	−0.748	−0.726	−0.865	−2.573

Note: The technology parameter in the US Machinery industry is increased by 50%.

Table 11. Changes in industry employments.

	Food	Textile	Wood	Paper	Chemicals	Nonmetals	Metals	Machinery
Australia	−379	−609	−460	−815	−2,116	−441	−5,299	−39,950
Austria	−91	−626	−399	−614	−1,088	−329	−2,803	−15,836
Canada	−487	−2,343	−1,439	−2,366	−7,812	−1,715	−3,421	−215,416
Finland	−61	−252	−352	−1,133	−831	−210	−2,036	−13,253
France	−829	−2,662	−1,340	−2,665	−7,470	−1,378	−16,867	−104,750
Germany	−1,035	−4,059	−2,954	−5,889	−17,357	−3,824	−27,159	−272,909
Greece	−101	−982	−71	−117	−263	−165	−652	−2,569
Italy	−542	−6,271	−1,852	−1,965	−5,116	−1,895	−9,757	−79,667
Japan	−4,498	−16,579	−9,588	−13,534	−40,055	−9,819	−58,424	−675,004
Korea	−1,250	−17,074	−2,816	−4,810	−14,286	−3,027	−17,962	−236,900
Mexico	−750	−551	−448	−1,594	−2,503	−436	5,984	−138,668
New Zealand	−377	−157	−108	−177	−408	−77	−407	−5,723
Norway	−81	−48	−115	−296	−543	−121	−1,897	−8,674
Portugal	−217	−2,313	−307	−523	−554	−368	−742	−7,393
Spain	−663	−2,329	−1,076	−1,479	−3,374	−1,237	−6,256	−51,507
Sweden	−144	−182	−563	−1,423	−1,929	−449	−4,855	−44,418
Turkey	−400	−5,822	−405	−573	−1,358	−464	−2,303	−20,618
United Kingdom	−743	−3,604	−1,872	−3,388	−10,789	−2,515	−18,068	−189,181
United States	9,843	53,036	25,311	40,830	103,526	25,603	156,571	1,631,000
World	−2,805	−13,429	−851	−2,530	−14,325	−2,865	−16,355	−491,435

Note: The technology parameter in the US machinery industry is increased by 50%.

The world manufacturing employment falls in this simulation because production moves from less productive countries to the US, which is one of the most productive countries in the sample. On the other hand, if we were to simulate a technological improvement in the Mexican machinery industry (which is one of the least productive in the sample), the world manufacturing employment would have grown.

Table 12 presents the summary of the country-wide effects on employment and welfare. The US benefits the most from the technological change in its machinery industry, ending up with higher manufacturing employment and lower prices. For other countries, this technological change is a mixed blessing. On one hand, goods prices decline, but on the other hand, manufacturing employment declines as well. While I do not want to assign relative weights to price declines and manufacturing employment losses, I can compare changes across countries. Korea, for example, seems to fare badly. It loses 8% of its manufacturing employment while benefitting from only 0.4% welfare increase. Mexico, by comparison, loses a slightly smaller percentage of its manufacturing employment while benefitting from greater price declines.

Table 12. Summary of changes.

	Total manufacturing employment		
	Absolute change	Percent change (%)	Percent change in welfare (%)
Australia	−50,069	−4.617	0.485
Austria	−21,785	−3.836	0.184
Canada	−235,000	−10.485	1.279
Finland	−18,127	−3.791	0.264
France	−137,961	−4.089	0.229
Germany	−335,187	−5.444	0.228
Greece	−4,919	−1.552	0.237
Italy	−107,063	−3.654	0.186
Japan	−827,501	−6.235	0.102
Korea	−298,126	−7.923	0.399
Mexico	−138,967	−7.528	1.469
New Zealand	−7,434	−3.493	0.443
Norway	−11,775	−4.093	0.356
Portugal	−12,416	−2.055	0.241
Spain	−67,921	−3.032	0.221
Sweden	−53,963	−5.676	0.368
Turkey	−31,942	−2.059	0.280
United Kingdom	−230,160	−5.185	0.365
United States	2,045,721	9.178	1.952

Note: The technology parameter in the US machinery industry is increased by 50%.

7. Conclusion

This article extends the EK model of trade to include multiple interlinked industries. It estimates the model using data for 8 two-digit industries of 19 OECD countries in 1989. In particular, it estimates industry-level technology parameters and trade costs. It then uses the model to perform several counterfactual experiments with policy implications.

First, the model is used to study various US–EU trade war scenarios. It is found that the employment effects of a trade war tend to be negatively correlated with the initial net export position. In addition, a trade war in an industry may have significant effects on other industries, depending on the forward and backward linkages. As a result, trade wars in some industries, such as machinery, hurt the US economy more than they do the EU economy, while trade wars in other industries, such as food, do the opposite. These results help explain the outcomes of several recent US–EU trade disputes, such as the banana and steel disputes.

Second, the model is used to investigate the effects of reducing trade barriers between high-income and middle-income countries. It is found that following trade liberalization employment tends to shift from less to more productive countries, thus following technological comparative advantages. The results show that different policy goals call for different industries to be targeted for barrier reductions. For example, if the goal is to increase employment in the middle-income countries while maintaining it in the high-income countries, then the metals industry is the best target. On the other hand, if the goal is to increase welfare everywhere then the machinery industry is the best target.

Third, the model is used to study the spillovers from the technological progress in the machinery industry of the US. The results show which countries and industries are in a good position to benefit from this progress and which ones are actually hurt by it. Nearby countries and complementary industries benefit the most, while direct competitors suffer.

All of the simulation results demonstrate how technology, trade costs, and industry linkages interact to determine the complex pattern of trade and specialization. For example, when technology in the US machinery industry expands, the Mexican metals industry grows because it is able to cheaply buy US machinery and because it is able to cheaply supply intermediate goods to the growing US machinery industry. Metals industries in other countries shrink because the declines in their domestic machinery industries outweigh their ability to supply metal products to the US.

The simulation results also show that the effects of trade costs vary across industries. For example a trade war between the US and EU in the textile industry benefits the US and hurts the EU, while causing only small welfare losses the world as a whole. A trade war in the machinery industry, on the other hand, hurts the US more than the EU and causes large welfare losses for the world as a whole.

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Notes

1. See for example Leamer (1984). Most of this literature focuses on factor endowment differences as the determinants of specialization, whereas this article focuses on the differences of technology.
2. A recent example is Midelfart-Knarvik, Overman and Venables (2000).
3. Keller (2001) provides a summary.
4. Other models that extend Eaton and Kortum (2002) to multiple industries include Chor (2010) who studies the effects of distance, factor endowments, productivity, and institutions on welfare, Costinot, Donaldson and Komunjer (2010) who quantify the importance of Ricardian comparative advantage for trade and welfare, Caliendo and Parro (2010), who evaluate the trade and welfare effects of NAFTA, and Shikher (2005) who studies the effects of technology, factor endowments, transport costs, and preferences on trade.
5. The assumption of tradability of the nonmanufacturing output means that the wages w_n in each country are given by the productivity in nonmanufacturing and the (numeraire) price of the nonmanufacturing good deflated by the price of the bundle of intermediates used in producing this good.
6. Kortum (1997) and Eaton and Kortum (1999) provide microfoundations for this approach. Parameter T_{ij} governs the mean of the distribution, while parameter θ, which is common to all countries and industries, governs the variance. The support of the Fréchet distribution is $(0,\infty)$.
7. To receive [dollar]1 of product in country n requires sending $d_{nij} \geq 1$ dollars of product from country i. By definition, domestic transport costs are set to one: $d_{nnj} \equiv 1$. Trade barriers result in $d_{nij} > 1$. Note that trade costs are not restricted to be symmetric (d_{nij} can be different from d_{inj}). Waugh (2007) studies the effects of the asymmetry of trade costs.
8. It follows from $P_{nj} = [\int_0^1 p_{nj}(l)^{1-\sigma} dl]^{1/(1-\sigma)} = [\int_0^\infty p_{nj}^{1-\sigma} dG_{nj}(p)]^{1/(1-\sigma)} = E[P_{nj}^{1-\sigma}]^{1/(1-\sigma)} = \gamma\Phi_{nj}^{-1/\theta}$. The last equality follows from a known statistical result (see Eaton and Kortum 2002).
9. Note that parameter T is not the same as total factor productivity (TFP). T is an exogenous parameter of the Fréchet distribution. TFP, on the other hand, is endogenous and represents the average productivity of the firms actually operating in an industry.
10. This is true because conditional on the fact that country i actually supplies a particular good, the distribution of the price of this good is the same regardless of the source i.
11. This system of equations is easily solved using numerical methods in Matlab.
12. They also obtain a second estimate of 3.6, but 8.28 is their preferred estimate since $\theta = 3.6$ results in unreasonably high trade costs.
13. I have decided not to include Ireland, Netherlands, and Denmark because in these countries, in several industries, exports exceed output. This problem occurs because these countries are entrepôts. See Feenstra (2000) for discussion.

Also, I have decided not to use ISIC industry 'Other' because of many irregularities in its data in many countries. The countries in the dataset accounted for about 85% of the world manufacturing trade in 1989.

14. For some pairs of countries, the volumes of bilateral trade were missing in 1989. Therefore, δ_{nij}, which are part of the distance measure, could not be estimated for some $\{n,i,j\}$. There are $19 \times 19 \times 8 = 2888$ observations of δ_{nij} possible in our data, of which 105 or 3.6% are missing. Most were proxied by estimates from neighboring years. Six observations that could not be proxied in this manner were proxied by the estimates of δni for total manufacturing.
15. The table for Australia was for 1989.
16. In the data, in addition to intermediate and final goods, there are also investment goods. Since there is no investment in the model, investment goods are treated as intermediate goods.
17. Anderson and van Wincoop (2004) roughly estimate the average international trade cost between OECD countries to be around 1.7 (excluding local distribution margins, see pp. 692–693). This is lower than the (non-weighted) average trade cost of 2.27 estimated in this article. However, Mexico, Turkey, and Korea, which are included in the dataset of this paper, are relatively new to OECD. They are not included in most of the previous studies of OECD trade costs. They also have high trade costs. If these three countries are excluded from the dataset, the (non-weighted) average trade cost for the remaining OECD countries is 1.78, which is much closer to the number reported by Anderson and van Wincoop (2004).
18. Perhaps one may have expected a trade war between the US and EU to have greater effects. However, it is necessary to remember that the vast majority of domestic output is consumed domestically. In addition, a trade war between the US and EU does not affect the trade within the EU or trade with third countries.
19. Unfortunately, there is no data on absolute policy-related trade barriers (tariffs and NTBs) for all the industries and countries in the dataset, which would have been preferable.
20. These results are obtained under the assumption that the US wage does not change. This assumption may have resulted in overly high predictions for employment changes.

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