World-Trade Growth Accounting

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Abstract

We propose a method of trade-growth accounting that permits decomposing data on changes in bilateral international trade flows into their direct (productivity growth, endowment accumulation, changes in trade costs) and indirect drivers (general equilibrium effects). We use this method to assess the quantitative impact of those drivers for the growth of bilateral and multilateral trade of 67 important economies over 20 consecutive years since 1988. For the considered years, endowment accumulation followed by reductions in trade costs appear to have been the main drivers of the growth of world trade. An analysis of variance of changes in pair-specific trade flows suggests that changes in trade costs can explain the largest part of the variance in the growth of bilateral trade. However, the relative importance of productivity has increased drastically over the considered time span, and so has the covariance among the drivers of world trade. The latter is an indication of the rising dependence of productivity growth on trade liberalization or, at least, the increasing openness of countries. Treating changes in endowments, trade costs, and technology as exogenous factors, the analysis suggests that endowment growth was most important for the growth of world trade, followed by reductions in trade costs and productivity in that order. Treating endowment accumulation and productivity growth as endogenous, the analysis of a model with non-homothetic preferences and R&D as well as investment incentives suggests that the reduction in trade costs raised factor accumulation and technological change by making R&D and tangible investment incentives more attractive, in particular, in middle-income countries over the considered time span, which explains their catching-up to high-income countries during the period of investigation.

Keywords: International trade; Trade-growth accounting; Trade costs .

JEL-codes: F10; F11; F14; O1.

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1 Introduction

Factor endowments, technology, and trade costs are the uncontested main drivers of goods-trade flows in both economic theory and empirical work (see Deardorff, 1998). Yet, in spite of this *old* wisdom, little is known about the relative quantitative importance of these three fundamentals for trade and real consumption.[1]

The present paper aims at filling this gap in the following way. First, it proposes a method of trade-growth accounting consistent with recent general equilibrium models of trade (Eaton and Kortum, 2002; Melitz, 2003; Anderson and van Wincoop, 2003) applied to real-world data on trade flows, prices, and endowments. This method allows determining the relative importance of different drivers of trade not only for trade but also aggregate real consumption. We find that changes in bilateral trade costs are the most important factor in explaining the variance in changes of *bilateral* trade flows and the second-most important factor (after factor accumulation) in explaining the variance in changes of *unilateral* nominal trade flows. The results suggest that middle-income countries experienced the highest increase in their exports due to falling trade costs. Relative to middle-income countries, low-income countries faced a much lesser reduction in trade impediments which led to a relatively smaller growth of their exports.

Our work is particularly related to two strands of research. One is the (surprisingly scarce) work on the accounting of the growth of world trade. The first and closest-related contribution to our work from this literature is Baier and Bergstrand's (2001), who were motivated by Krugman's (1971) work on trade and, therefore, were looking for the relative role of changes in tariffs, in (non-policy) trade costs, and in income similarity for the *growth* of world trade. Theirs was a reduced-form approach to estimation and counterfactual analysis, involving changes of the levels or the importance of observable bilateral trade costs (tariffs and non-policy trade costs) and changes of a function of real exporter and importer incomes as determinants of the growth of bilateral trade.[2]

Moreover, our work is related to Eaton and Kortum's (2002) and Dekle, Eaton, and Kortum's (2007) approach – motivated by Dornbusch, Fischer, and Samuelson's (1977) *old view* on trade through David Ricardo's lense – to address the importance of technology versus trade costs for the *level* of bilateral trade. Theirs was a reduced-form approach to estimation but a structural approach for counterfactual analysis.[3] The body of work based on this framework is growing steadily and includes, among others, the contributions of Alvarez and Lucas (2007), Caliendo and Parro (2010, 2011), Arkolakis, Costinot, and Rodríguez-Clare (2012), Costinot and Donaldson (2012), Costinot, Donaldson, and Komunjer (2012), Levchenko and Zhang (2012), Costinot and Rodríguez-Clare (2014), Egger and Nigai (2014), Levchenko, di Giovanni, and Zhang (2014). However, none of this work made an attempt to decompose the growth of world trade into its individual components, but it focused very much on the question of the consequences of openness as observed in the data relative to a counterfactual complete autarky or of the ones of gradual trade liberalization, mostly through preferential policy.

[1] Clearly, there are strands of research which vividly debate whether the pattern of trade is consistent with Ricardian and/or Heckscher-Ohlin theory (e.g., see Trefler, 1995, Davies and Weinstein, 2001). However, when it comes to the question of how important quantitatively endowments versus technology versus trade costs are for trade, a clear answer is missing.

[2] An important contribution to the explanation of the growth of world trade is certainly Yi's (2003) study on the role of vertical specialization for the gap in the growth of trade (a gross concept) relative to gross domestic product (a value-added or net concept). Yi's analysis is dynamic and structural, but, unlike Baier and Bergstrand's our ours, it is not catered towards an analysis of multiple countries.

[3] What we mean by that is that they did not impose the general equilibrium constraints in estimating the model parameters so that, unlike as in Anderson and van Wincoop (2003) or in Bergstrand, Egger, and Larch (2013), the conditional expectations of the estimated model could differ from the conditional expectations of the simulated model.

This paper's approach is different from these strands of work. First of all, unlike Baier and Bergstrand (2001), who explained trade by fundamental changes in trade costs and intermediated (or endogenous) levels of real income in a reduced-form model, the here goal is to allude to the quantitative importance of fundamental drivers of the growth of world trade – endowments, trade costs, and productivity – in a structural model. Second, unlike in the aforementioned quantitative Ricardian models, the focus of this paper is not entirely on trade costs or on trade costs and productivity alone, but we are interested in a full decomposition of trade flows in all of its components, including factor endowments. Our analysis sheds light on how fundamental drivers of trade have changed in relative importance over time, and how their covariance has changed over 20 years of recent history. One finding of this is that most of the variation in bilateral exports among 67 important economies between 1988 and 2007 can be explained by trade costs. A second finding is that technology has gained relatively more in importance than trade costs in the considered sample of data which accounts for XX percent of world trade. A third finding is that the covariance in three fundamentals – endowment-, trade- cost, and productivity growth – has increased dramatically over the sample period. The latter suggests that some nexus emerged between rising openness, factor accumulation, and productivity growth which had not been there before – at least not at the present scale. However, when asking which one of the fundamentals was most important for the growth of world trade since 1988, the answer would be: factor accumulation followed by trade-cost reductions followed by productivity growth. Clearly, the latter is a question about counterfactual change rather than variance decomposition. Interestingly, in view of the emphasis on productivity and technology as a driver of trade since Eaton and Kortum's (2002) seminal contribution, it reveals that factor accumulation and changing trade costs were more important for the growth of world trade – and even for trade among most of the pairings of high-, middle-, and low-income countries. Finally, we propose a counterfactual analysis based on a model which is capable of featuring the rising covariance among the fundamental drivers as an outcome rather than a stylized input in the analysis. That model considers changes in trade costs as deep model parameters to influence trade flows not only immediately but also through factor accumulation and technological change as mediator variables.

The remainder of the paper is organized as follows. The next section sets out the model in the vein of Eaton and Kortum (2002). We conduct analysis of the variance of changes in pair-specific trade flows in Section 3. In Section 4, we analyze the importance of different drivers of trade for different groups of countries under two alternative modelling frameworks. The last section provides a brief conclusion.

2 Trade and income in a generic cross section of country-pairs

In this section, we outline a model of aggregate trade for a generic cross section of N countries and N^2 country pairs. Each country i is populated by a measure $\ell_{i,t}$ of equipped labor in period t.[4] Workers supply their equipped labor to two sectors that produce services and manufactures, respectively. Each sector has a unit measure of heterogeneous firms that draw their total-factor-productivity parameters from country-specific distributions. The moments of the productivity distributions differ across sectors and countries. Manufactures are tradable subject to an iceberg trade cost, $\tau_{ij,t} \geq 1$ for $j \neq i$ and $\tau_{ii,t} = 1$. We model input-output linkages

[4] It is customary in the literature to refer to workers plus capital as *equipped labor* (see, e.g., Alvarez and Lucas, 2007). For our purpose, it is not necessary to model labor and capital separately. Eaton, Kortum, Neiman, and Romalis (2013) develop a Ricardian framework, where capital accumulation is explicitly modelled. We present a version of the model with endogenous endowment accumulation in Section 4.2.

in the economy broadly through the use of output of both services and manufactures in the production of each of them.

We describe the model for two generic time periods, benchmark period s and an arbitrary period $t \geq s$. First, we characterize the open-economy equilibrium in period s. In country i, there is a single representative consumer, who consumes services, owns (is endowed with) total equipped labor $\ell_{i,s}$, and earns total income $\ell_{i,s} w_{i,s}$. The representative consumer's indirect utility function reads:

$$V(\ell_{i,s} w_{i,s}) = \frac{\ell_{i,s} w_{i,s}}{p_{ni,s}}, \quad p_{ni,s} \equiv \phi_{i,s} \left(w_{i,s}^{\alpha} p_{mi,s}^{\beta} p_{ni,s}^{\gamma} \right) \text{ with } \alpha + \beta + \gamma = 1, \tag{2.1}$$

where $\phi_{i,s}$ measures the average total factor productivity of firms in services, and $p_{ni,s}$ and $p_{mi,s}$ are CES-aggregate price indices of services and manufactures, respectively.

Manufacturers draw their total productivity parameter from a Fréchet distribution (see Eaton and Kortum, 2002) with scale and shape parameters $\varphi_{i,s}$ and θ, respectively. They use equipped labor, manufactures, and services bundles (aggregates) at Cobb-Douglas expenditure shares η, μ, and ν, respectively, with $\eta + \mu + \nu = 1$. Firms in different countries that produce the same varieties compete with each other such that only the lowest-cost producer gross of trade costs supplies to a particular market. By the law of large numbers and CES aggregation of varieties, the price index of the bundle of manufactures is as follows:

$$p_{mi,s} = \Omega_m \left(\sum_k \varphi_{k,s} \left(w_{k,s}^{\eta} p_{mk,s}^{\mu} p_{nk,s}^{\nu} \tau_{ik,s} \right)^{-\theta} \right)^{-\frac{1}{\theta}}, \tag{2.2}$$

where Ω_m is a normalizing constant. The share of country i's income spent on manufactures from exporter j is:

$$\lambda_{ij,s} = \frac{\varphi_{j,s} (w_{j,s}^{\eta} p_{mj,s}^{\mu} p_{nj,s}^{\nu} \tau_{ij,s})^{-\theta}}{\sum_k \varphi_k \left(w_{k,s}^{\eta} p_{mk,s}^{\mu} p_{nk,s}^{\nu} \tau_{ik,s} \right)^{-\theta}}. \tag{2.3}$$

Closing the model involves specifying the usual product-market-clearing condition such that total income equals total expenditures in each economy i up to a deficit-level parameter $D_{i,s}$:

$$Y_{i,s} = \sum_{j=1}^{J} \lambda_{ji,s} Y_{j,s} d_{j,s}, \tag{2.4}$$

where $Y_{i,s} \equiv \ell_{i,s} w_{i,s}$ is total income and $d_{j,s} = 1 + D_{j,s}/Y_{j,s}$ is an exogenous deficit-share constant which relates the level of trade deficit, $D_{j,s}$, to $Y_{j,s}$ at a constant rate. Equation (2.4) can be solved for $(N-1)$ endogenous rates of return on equipped labor, $w_{i,s}$, with one country's return serving as the numéraire. The properties of this class of models are well-known (see Arkolakis, Costinot, and Rodrígues-Clare, 2010, for a discussion), and under certain assumptions the specification here is isomorphic to the models of Anderson and van Wincoop (2003), Melitz (2003), and many others. The focus of this paper within such a framework is novel, gauging the relative importance of *changes* in country-(time) and country-pair-(time-)specific fundamentals of the *growth* of trade: technology $(\phi_{i,t}, \varphi_{i,t})$, trade costs as well as bilateral preferences $(\tau_{ij,t})$,[5] and endowments $(\ell_{i,t})$.

[5]In this class of models, trade costs and pair-specific preference parameters cannot be disentangled. Though we refer to τ_{ij} as trade costs, it should be borne in mind that they also capture a taste-specific component which is specific to country-pairs or country-pair-time.

Suppose now that one (or more) fundamental changes between the benchmark period s and period t. Then, changes in trade flows across two, eventually but not necessarily subsequent, time periods (years) t and $s < t$ can be cast in relative changes by invoking the so-called *hat algebra* in the spirit of Jones (1965) and Dekle, Eaton, and Kortum (2007).[6] For any generic variable a, we use $\widehat{a}_t = \frac{a_t}{a_s}$ to denote the change in a in year t relative to the benchmark year s. We for now treat changes in fundamentals $\left\{\widehat{\tau}_{ij,t}, \widehat{\phi}_{i,t}, \widehat{\varphi}_{i,t}, \widehat{\ell}_{i,t}\right\}$ as given (exogenous).

Using expressions for the price indices of services and manufactures in (2.1) and (2.2), respectively, we can express the corresponding relative changes as:

$$\widehat{p}_{ni,t} = \widehat{\phi}_{i,t} \widehat{w}_{i,t}^{\alpha} \widehat{p}_{mi,t}^{\beta} \widehat{p}_{ni,t}^{\gamma}, \quad \widehat{p}_{mi,t} = \left(\sum_k \lambda_{ik,s} \widehat{\varphi}_{k,t} (\widehat{w}_{k,t}^{\eta} \widehat{p}_{mk,t}^{\mu} \widehat{p}_{nk,t}^{\nu} \widehat{\tau}_{ik,t})^{-\theta} \right)^{-\frac{1}{\theta}}, \tag{2.5}$$

and the change in bilateral trade shares based on (2.3) as:

$$\widehat{\lambda}_{ij,t} = \widehat{\varphi}_{j,t} \left(\frac{\widehat{w}_{j,t}^{\eta} \widehat{p}_{mj,t}^{\mu} \widehat{p}_{nj,t}^{\nu} \widehat{\tau}_{ij,t}}{\widehat{p}_{mi,t}} \right)^{-\theta}. \tag{2.6}$$

Finally, to close the model in period t, we specify the goods-market-clearing condition as:

$$Y_{i,t} = \sum_{j=1}^{J} \lambda_{ji} Y_{j,t} d_{j,t}, \tag{2.7}$$

which can be recast in terms of relative changes to solve for endogenous wage rates at time t as:

$$\widehat{w}_{i,t} = \sum_{j=1}^{J} \lambda_{ji,s} \widehat{\lambda}_{ji,t} \widehat{w}_{j,t} d_{j,t} \frac{\widehat{\ell}_{j,t} Y_{j,s}}{\widehat{\ell}_{i,t} Y_{i,s}}. \tag{2.8}$$

This completely characterizes the competitive open-economy equilibrium in period t, and it provides an expression for total changes in *nominal levels* of bilateral trade flows between the benchmark period s and t:

$$\widehat{X}_{ij,t} = \widehat{\lambda}_{ij,t} \widehat{\ell}_{i,t} \widehat{w}_{i,t} Y_{i,s} \widehat{d}_{i,t}. \tag{2.9}$$

Using the identities in this section, we may write changes in log bilateral exports based on the log-transformed counterpart to equation (2.9) as a function of exogenous shocks and general equilibrium effects as:

$$\ln\left(\widehat{X}_{ij,t}\right) = \underbrace{\ln\left(\widehat{\varphi}_{j,t} \widehat{\phi}_{j,t}^{\frac{-\theta\nu}{1-\gamma}} \widehat{\tau}_{ij,t}^{-\theta} \widehat{\ell}_{i,t} \right)}_{\text{Exogenous shocks}} + \underbrace{\ln\left(\widehat{w}_{j,t}^{\frac{\alpha\nu\theta}{\gamma-1} - \theta\eta} \widehat{p}_{mj,t}^{\frac{\beta\nu\theta}{\gamma-1} - \theta\mu} \widehat{p}_{mi,t}^{\theta} \widehat{w}_{i,t} \right)}_{\text{Endogenous variables}} + \underbrace{\ln\left(\widehat{d}_{i,t}\right)}_{\text{Trade deficit shock}}. \tag{2.10}$$

Within this framework we can directly assess the role of each factor for changes in trade flows *across* country pairs. In our analysis, we use a large sample of 67 biggest economies in the world for the period between 1988 and 2007. In the Appendix, we allude to the calibration procedure and the identification of parameters for calculating these changes in fundamentals using real data, and we summarize the relevant data.

[6] This method has been utilized in a number of recent papers including but not limited to Ossa (2012) who assesses the importance of trade for welfare, and Eaton, Kortum, Neiman, and Romalis (2013) who identify drivers of the Great Trade Collapse.

3 Decomposing the variance of changes in exports across country-pairs over time into exogenous and endogenous components

The goal of this section is to decompose the variance of changes in log bilateral exports into its exogenous and endogenous components in a growth-accounting-type fashion but consistent with the insights from the previous section. The first group of factors labeled *Exogenous shocks* in equation (2.10) relates to the fundamentals of particular interest in this study. The second group of factors labeled *Endogenous shocks* in equation (2.10) relates to changes in country-specific aggregates which are induced by changes in the fundamentals. The last term in equation (2.10) labeled *Trade deficit shock* captures the (numerically negligible) shock which is assumed proportional to $Y_{i,t}$.

For further convenience, let us use tilde to refer to variables in logs, suppressing the parameters on them, such that the following identities hold:

$$\widetilde{\varphi}_{j,t} \equiv \ln(\widehat{\varphi}_{j,t}),\ \widetilde{\phi}_{j,t} \equiv \ln\left(\widehat{\phi}_{j,t}^{\frac{-\theta\nu}{1-\gamma}}\right),\ \widetilde{\tau}_{ij,t} \equiv \ln\left(\widehat{\tau}_{ij,t}^{-\theta}\right),\ \widetilde{g}_{ij,t} \equiv \ln\left(\widehat{w}_{j,t}^{\frac{\alpha\nu\theta}{\gamma-1}-\theta\eta}\widehat{p}_{mj,t}^{\frac{\beta\nu\theta}{\gamma-1}-\theta\mu}\widehat{p}_{mi,t}^{\theta}\widehat{w}_{i,t}\right),\ \widetilde{d}_{i,t} \equiv \ln\left(\widehat{d}_{i,t}\right).$$

Moreover, we use $\nu(a)$ and $\rho(a,h)$ to denote the variance of any generic variable a and the correlation coefficient for any pair of generic variables (a,h), respectively. Then, the overall variance of (log) changes in bilateral exports can be decomposed as:

$$\nu\left(\widetilde{X}_{ij,t}\right) = \nu\left(\widetilde{\varphi}_{j,t}\right) + \nu\left(\widetilde{\phi}_{j,t}\right) + \nu\left(\widetilde{\tau}_{ij,t}\right) + \nu\left(\widetilde{\ell}_{i,t}\right) + \nu\left(\widetilde{g}_{ij,t}\right) + \nu\left(\widetilde{d}_{i,t}\right) + \underbrace{\sum_{h\neq a}\rho(h,a)[\nu(h)\cdot\nu(a)]^{\frac{1}{2}}}_{\text{Sum of covariance components}}, \tag{3.1}$$

where $a,h \in \left\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\tau}_{ij,t}, \widetilde{\ell}_{i,t}, \widetilde{g}_{ij,t}, \widetilde{d}_{i,t}\right\}$. We summarize the respective variances and the sum of all covariances for each year between 1989 and 2007 in Table 1.

Table 1 suggests the following conclusions. First, the total variance, all individual variance components, and the sum of all covariance components increased over time. This is not surprising, since the variance is a function of the mean, and bilateral exports are not mean stationary but grow over time. However, it is interesting to compare the relative size of these components to each other and track their changes over time. Among the variance components which are attributable to exogenous drivers of bilateral trade, the one of bilateral trade costs, $\nu\left(\widetilde{\tau}_{ij,t}\right)$, clearly dominates, followed by the ones of productivity in manufacturing, $\nu\left(\widetilde{\varphi}_{j,t}\right)$, and services, $\nu\left(\widetilde{\phi}_{j,t}\right)$. The smallest component is the one capturing changes in factor endowments, $\nu\left(\widetilde{\ell}_{i,t}\right)$. Taking into account the variance terms of exogenous as well as endogenous components, the endogenous terms together, i.e., changes in factor and output prices, $\nu\left(\widetilde{g}_{ij,t}\right)$, account for the second-biggest portion after trade costs. Obviously, the variance components add up to more than the overall variance in changes of log bilateral trade flows, which is balanced by the negative sum of covariance components. It is remarkable that, in 2007, the sum of all covariances among changes in fundamentals has grown almost to the level of importance of changes in trade costs. Moreover, while changes in trade costs still dominate the variation in changes of exports by 2007, this importance has grown twofold, while the one of technology change, endowment change, and the covariances of the changes in fundamental drivers have all grown more than eightfold over the period of investigation.

Table 1: *Variances and sum of covariances of the determinants of changes in bilateral exports*

Year	$v\left(\widetilde{X}_{ij}\right)$	$v\left(\widetilde{\varphi}_{j,t}\right)$	$v\left(\widetilde{\phi}_{j,t}\right)$	$v\left(\widetilde{\tau}_{ij,t}\right)$	$v\left(\widetilde{\ell}_{i,t}\right)$	$v\left(\widetilde{g}_{ij,t}\right)$	$v\left(\widetilde{d}_{i,t}\right)$	Sum of cov.
1989	8.91	0.43	0.10	8.93	0.00	0.43	0.00	-0.99
1990	10.64	0.59	0.13	10.68	0.00	0.54	0.00	-1.30
1991	10.67	0.96	0.48	10.60	0.01	1.41	0.01	-2.80
1992	12.16	0.86	0.25	12.14	0.01	0.80	0.01	-1.90
1993	12.21	1.20	0.30	12.23	0.01	1.14	0.01	-2.70
1994	13.30	1.54	0.33	13.43	0.02	1.52	0.01	-3.54
1995	14.10	1.56	0.44	14.20	0.03	1.75	0.01	-3.89
1996	14.49	1.58	0.40	14.47	0.05	1.71	0.01	-3.73
1997	14.97	1.58	0.45	14.99	0.05	1.77	0.02	-3.89
1998	14.89	1.53	0.35	14.99	0.05	1.60	0.02	-3.65
1999	14.76	1.34	0.47	14.86	0.05	1.59	0.03	-3.58
2000	15.16	1.86	0.65	15.31	0.05	2.02	0.03	-4.76
2001	15.20	1.90	0.61	15.27	0.06	1.96	0.03	-4.63
2002	15.47	2.20	0.62	15.55	0.07	2.30	0.03	-5.30
2003	16.01	2.09	0.65	16.05	0.07	2.43	0.03	-5.31
2004	16.17	2.21	0.64	16.62	0.08	2.70	0.03	-6.11
2005	15.88	2.20	0.71	16.02	0.09	2.57	0.04	-5.75
2006	16.01	2.88	1.17	16.76	0.10	4.31	0.03	-9.23
2007	16.28	2.65	1.05	16.33	0.11	3.30	0.03	-7.18

We report correlation coefficients $\rho(a,h)$ for all $6 \times (6-1)/2 = 15$ possible combinations of components and the year 2007 in Table 2. The corresponding estimates in that table point to a sizable correlation of changes in log productivity in the two sectors (services, $\widetilde{\phi}_{j,t}$, and manufacturing, $\widetilde{\varphi}_{j,t}$). Moreover, the estimates indicate nontrivially large correlations between changes in log endowments and trade deficits (negative), changes in log productivity parameters of manufactures and log trade costs (negative), changes in log trade costs and log endowments (positive), and changes in log trade costs and endogenous variables (positive).

Table 2: *Correlation coefficients $\rho(a,h)$ for $a,h = \left\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\tau}_{ij,t}, \widetilde{\ell}_{i,t}, \widetilde{g}_{ij,t}, \widetilde{d}_{i,t}\right\}$ and $t = 2007$*

	$\widetilde{\varphi}_{j,t}$	$\widetilde{\phi}_{j,t}$	$\widetilde{\tau}_{ij,t}$	$\widetilde{\ell}_{i,t}$	$\widetilde{g}_{ij,t}$	$\widetilde{d}_{i,t}$
$\widetilde{\varphi}_{j,t}$	1	0.32	-0.04	0.00	-0.86	0.01
$\widetilde{\phi}_{j,t}$	0.32	1	-0.13	0.00	-0.68	0.01
$\widetilde{\tau}_{ij,t}$	-0.04	-0.13	1	0.15	0.05	0.02
$\widetilde{\ell}_{i,t}$	0.00	0.00	0.15	1	-0.18	-0.16
$\widetilde{g}_{ij,t}$	-0.86	-0.68	0.05	-0.18	1	0.01
$\widetilde{d}_{i,t}$	0.01	0.01	0.02	-0.16	0.01	1

Though correlation coefficients are an important ingredient in the covariance components, what ultimately matters for the decomposition in (3.1) and for the last column in Table 1 are the covariance terms themselves. We summarize the latter for each possible pair of generic components $a,h = \left\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\tau}_{ij,t}, \widetilde{\ell}_{i,t}, \widetilde{g}_{ij,t}, \widetilde{d}_{i,t}\right\}$ in Table 3.

Considering the year 2007, it is obvious that what matters the most among those terms are the negative covariances between all exogenous fundamentals with the endogenous factors captured by $\widetilde{g}_{ij,t}$. According to

Table 3, only two pairs of exogenous fundamentals exhibit a significant positive covariance, namely changes in the productivity parameters $\varphi_{j,t}$ and $\phi_{j,t}$ on the one hand, and changes in trade costs $\tau_{ij,t}$ and in endowments $\ell_{i,t}$ on the other hand.

The parameters $\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\varphi}_{j,t}, \widetilde{\ell}_{i,t}\}$ are negatively related to the general-equilibrium effects in $\widetilde{g}_{ij,t}$, as expected from a theoretical point of view (see Eaton and Kortum, 2002; Anderson and van Wincoop, 2003; Dekle, Eaton, and Kortum, 2007). Apart from covariance terms involving general equilibrium effects, there are few sizable negative covariance terms – except between changes in both productivity parameters and trade costs.[7]

Ignoring covariance terms in Table 1 for the moment, we may normalize the variance terms by their sum and assess their relative magnitude. This type of analysis suggests that about 70%, 11%, 4%, 1%, and 14% of the variance in the growth of bilateral exports among the 67 economies between 1988 and 2007 were explained by the variance in changes of log bilateral trade costs, log productivity in manufacturing, log productivity in services, log endowments, and general equilibrium effects, respectively. Changes in trade deficits contributed a negligible share (around 0.1%) to the overall variance of changes in bilateral exports.

Table 3: *Covariance between a and h for* $a, h = \left\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\tau}_{ij,t}, \widetilde{\ell}_{i,t}, \widetilde{g}_{ij,t}, \widetilde{d}_{i,t}\right\}$

$a =$			$\widetilde{\varphi}_{j,t}$					$\widetilde{\phi}_{j,t}$			$\widetilde{\tau}_{ij,t}$			$\widetilde{\ell}_{i,t}$		$\widetilde{g}_{ij,t}$
$h =$	$\widetilde{\phi}_{j,t}$	$\widetilde{\tau}_{ij,t}$	$\widetilde{\ell}_{i,t}$	$\widetilde{g}_{ij,t}$	$\widetilde{d}_{i,t}$	$\widetilde{\tau}_{ij,t}$	$\widetilde{\ell}_{i,t}$	$\widetilde{g}_{ij,t}$	$\widetilde{d}_{i,t}$	$\widetilde{\ell}_{i,t}$	$\widetilde{g}_{ij,t}$	$\widetilde{d}_{i,t}$	$\widetilde{g}_{ij,t}$	$\widetilde{d}_{i,t}$	$\widetilde{d}_{i,t}$
1989	0.14	-0.29	0.00	-0.79	0.00	-0.03	0.00	-0.27	0.00	0.00	0.23	0.02	0.00	0.00	0.00
1990	0.11	-0.45	0.00	-1.02	0.00	-0.07	0.00	-0.28	0.00	0.04	0.31	0.08	-0.01	0.00	-0.01
1991	0.74	-0.23	0.00	-2.13	0.00	-0.02	0.00	-1.35	0.00	0.03	0.17	0.02	-0.01	0.00	-0.02
1992	0.12	-0.39	0.00	-1.45	0.00	-0.11	0.00	-0.49	0.00	0.05	0.35	0.06	-0.02	0.00	-0.01
1993	0.24	-0.69	0.00	-2.10	0.00	-0.13	0.00	-0.67	0.00	0.08	0.56	0.06	-0.03	0.00	-0.02
1994	0.34	-0.86	0.00	-2.75	0.00	-0.17	0.00	-0.82	0.00	0.12	0.59	0.06	-0.05	0.00	-0.01
1995	0.51	-0.98	0.00	-2.95	0.00	-0.29	0.00	-1.13	0.00	0.16	0.80	0.07	-0.07	0.00	0.00
1996	0.35	-0.84	0.00	-2.91	0.00	-0.30	0.00	-0.96	0.00	0.22	0.72	0.09	-0.10	0.00	0.00
1997	0.41	-0.72	0.00	-2.92	0.00	-0.42	0.00	-1.11	0.00	0.22	0.68	0.07	-0.10	-0.01	0.00
1998	0.17	-0.70	0.00	-2.70	0.00	-0.43	0.00	-0.77	0.00	0.24	0.64	-0.01	-0.11	-0.01	0.02
1999	0.27	-0.50	0.00	-2.42	0.00	-0.47	0.00	-1.06	0.00	0.27	0.48	-0.06	-0.11	-0.02	0.03
2000	0.27	-0.56	0.00	-3.19	0.00	-0.58	0.00	-1.36	0.00	0.29	0.51	-0.03	-0.12	-0.02	0.02
2001	0.18	-0.45	0.00	-3.17	0.00	-0.54	0.00	-1.23	0.00	0.28	0.46	-0.03	-0.13	-0.02	0.02
2002	0.31	-0.47	0.00	-3.81	0.00	-0.72	0.00	-1.36	0.00	0.30	0.64	-0.05	-0.14	-0.02	0.02
2003	0.55	-0.39	0.00	-3.85	0.00	-0.68	0.00	-1.57	0.00	0.35	0.38	0.05	-0.15	-0.03	0.01
2004	0.55	-0.25	0.00	-4.10	0.00	-0.63	0.00	-1.53	0.00	0.38	-0.32	-0.01	-0.21	-0.02	0.03
2005	0.44	-0.28	0.00	-4.01	0.00	-0.74	0.00	-1.56	0.00	0.36	0.22	0.02	-0.21	-0.02	0.03
2006	1.61	-0.87	0.00	-6.00	0.00	-1.25	0.00	-3.25	0.00	0.45	0.32	-0.02	-0.26	-0.02	0.03
2007	1.06	-0.50	0.00	-5.08	0.00	-1.04	0.00	-2.53	0.00	0.41	0.69	0.03	-0.21	-0.02	0.01

Summing up, this accounting exercise and the results in Tables 1-3 shed light on the changing components behind the *variability* across different country pairs of the growth of exports. However, this analysis does not necessarily permit firm conclusions about the relative importance of the parameters $\{\widetilde{\varphi}_{j,t}, \widetilde{\phi}_{j,t}, \widetilde{\tau}_{ij,t}, \widetilde{\ell}_{i,t}\}$ for tremendous growth in nominal exports, since these factors affect the endogenous components in $\widetilde{g}_{ij,t}$ to a so far unknown extent. In pursuit of an analysis of the average effects of the changes in fundamentals on changes in changes in exports, we need to resort to counterfactual analysis, taking direct as well as indirect (through general equilibrium) effects of fundamentals into account. This is the goal of Subsection 4.1. In

[7] The latter means that the variability of trade costs is negatively related to that of productivity at large.

Subsection 4.2, we will go one step further and consider a structural relationship between the fundamentals as suggested by the correlation coefficients in Table 2. The latter will require abandoning the notion of a strict exogeneity of all fundamentals.

4 Changes in fundamentals as drivers of world-trade growth

In this section, we shed light on the importance of exogenous fundamental drivers of trade under two alternative scenarios: one where trade costs, endowments, and technology are assumed to change fully independently from each other, whereby the accumulation of factors and the change in productivity parameters are treated as exogenous as is commonly assumed (Model 1, analyzed in Subsection 4.1); and an alternative one, where changes in fundamentals have direct effects and three types of intermediated effects largely affecting endogenous expenditure shares on services and manufactures through non-homothetic preferences of consumers, through endogenous factor accumulation, and through endogenous technological change (Model 2, analyzed in Subsection 4.2). It should be stressed that the analysis in this section is *not* based on cross-country-pair variation in changes of bilateral exports as in Section 3 but rather on calculating the difference between realized growth in trade across different country groups and various counterfactual scenarios where we keep one (or more) fundamentals constant relative to the benchmark year.

4.1 Exogenous changes in fundamentals

In this subsection, we assess the effects of exogenous contributions of three fundamentals – trade costs, productivity in services and goods, and endowments – to the observed growth of world trade among 67 economies between 1988 and 2007. As acknowledged before, the previous section permitted an assessment of the relative importance of these factors for explaining variation in changes in trade flows across different country pairs. Here, we are interested in accounting for non-(log-)linear effects of fundamentals on trade flows, taking their effects on endogenous (primary and secondary) factor prices into account and evaluating quantitatively how much higher (or lower) different types of trade flows would be without the realized changes in certain fundamental drivers. For this analysis, we use the structure of the model in Section 4 along with the results from the previous section to conduct counterfactual experiments, where we keep trade costs, productivity in services and goods, and endowments constant one at a time at their values of 1988, letting the remaining fundamentals vary as observed. We then compare the counterfactual growth in nominal exports with the data and draw conclusions about quantitative importance of each factor for the remarkable growth in international trade flows observed in the data. We summarize the associated results for the world as a whole as well as for blocs of three large (per-capita) income groups according to the year 2007: low-income (16 countries, L), middle-income (24 countries, M), and high-income (27 countries, H).[8] While high-income

[8]The suggested classification is based on similar principles as the one utilized by the World Bank. However, the associated income thresholds are slightly different from those used by the World Bank. There are two reasons for this. First, we distinguish between fewer groups of countries than the World Bank. For instance, we do not discern between upper-middle and middle-income countries. Second, we define thresholds to avoid excessively large differences in sample sizes across different groups. For instance, if we used the World Bank's classification, we would end up with only six low-income countries such that the sample would be heavily biased towards the middle-income group. In our sample of countries, the threshold country between low- and middle-incomes is Guatemala with 2,440 US dollars per capita in 2007. For comparison, the World Bank's interval for lower middle-income countries was 936-3,705 US dollars. The threshold country between middle- and high-income countries is Malta with a per-capita income of 16,640 US dollars in 2007, whereas the World Bank's threshold in 2007 for high-income countries was 11,455 US dollars per capita. We list all countries and their corresponding association with the proposed groups in Table 7 in the Appendix.

countries realized steady but low growth rates of their exports, middle-income countries enjoyed a drastic growth of their exports, and low-income countries experienced a modest increase in their exports over the period of investigation.

With three different country groups, L, M, and H, there are nine group-by-group combinations of export growth. Let us use $X'_{ij,t}(a)$ to denote counterfactual outcomes with respect to some fundamental $a \in \left\{\widetilde{\varphi}, \widetilde{\phi}, \widetilde{\tau}, \widetilde{\ell}\right\}$ of country pair ij at time t and define

$$\widehat{X}_{IJ,t}(a) = \frac{\sum_{(i \in I) \neq j} \sum_{(j \in J) \neq i} X'_{ij,t}(a)}{\sum_{(i \in I) \neq j} \sum_{(j \in J) \neq i} X_{ij,t}} \quad \text{for} \quad I, J \in \{L, M, H\}. \tag{4.1}$$

Then, $\widehat{X}_{IJ,t}(a)$ measures the importance of changes in fundamental a for all countries and country pairs in that group between 1988 and year t, given everything else. A lower absolute value of $\widehat{X}_{IJ,t}(a)$ suggests that period-t exports between group I and J would have been lower to a larger extent, if fundamental a had stayed at its initial level. Since all fundamentals in $a \in \left\{\widetilde{\varphi}, \widetilde{\phi}, \widetilde{\tau}, \widetilde{\ell}\right\}$ have changed in a favorable way towards exports since 1988 (productivity increased, trade costs declined, and endowments increased), $\widehat{X}_{IJ,t}(a)$ will be lower than unity on average and it will be unity by design in 1988. We plot the values of $\widehat{X}_{IJ,t}(a)$ for all nine pairs of group-by-group exports in Figures 1-3, where each panel in a figure corresponds to a group of origin (L on the left, M in the centre, and H on the right), and each locus in a panel refers to imports by L ($-\triangledown-$), M ($--$), or H ($-\circ-$). In addition to the group-by-group loci, we report total world exports denoted by $\widehat{X}_{WW}(a)$ (black solid lines) as an identical reference across all panels in a figure, which also captures results for the average country pair.

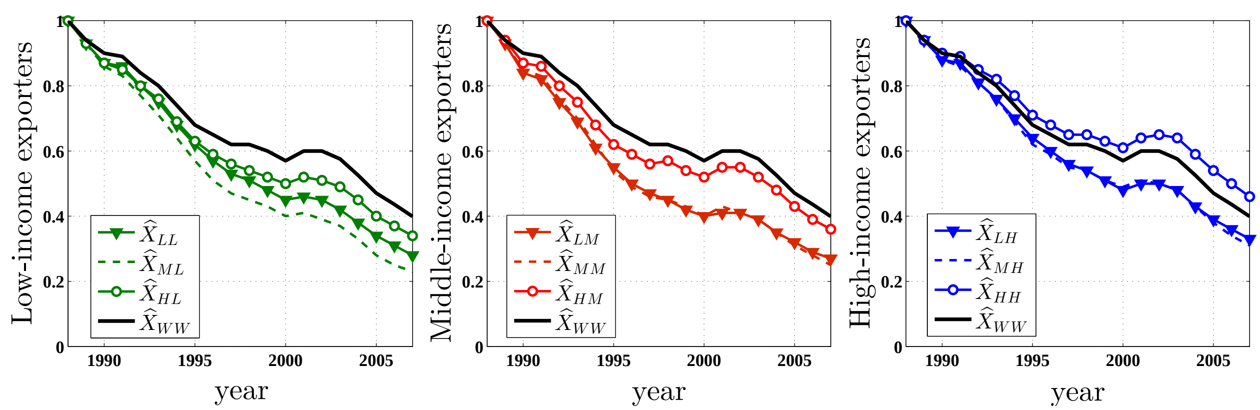

Figure 1: COUNTERFACTUAL EXPERIMENT WITH CONSTANT ENDOWMENTS

First of all, when considering $\left\{\widetilde{\varphi}, \widetilde{\phi}, \widetilde{\tau}, \widetilde{\ell}\right\}$ as exogenous fundamentals and taking their indirect effects through general equilibrium into account, the growth of world trade was stimulated to the largest extent by the change in factor endowments during the period of investigation. Without the realized change in endowments since 1988, world trade would have been around 60% lower than realized in 2007, according to the model and Figure 1. Relative to the world altogether and, in particular, relative to exports of high-income countries, exports by low-income and middle-income countries grew even faster due to the realized change in endowments. Consequently, endowment changes in middle- and low-income countries had a more important effect on the growth of their exports than on average. For example, without changes in endowments since 1988, exports from low- to middle-income and from middle- to low-income countries would have amounted to only 27% and

23% of what they were in 2007, respectively. On the contrary, endowment changes in high-income countries appear to have had a relatively less important effect for changes in exports among these countries since they were relatively large, relatively productive, and relatively open beforehand. In particular, in terms of the changes in trade flows within the high-income group, changes in endowments mattered less than on average in the world.

Second, consider the role of trade-cost changes since 1988 as portrayed in Figure 2. According to that figure, without the realized change in trade costs since 1988, world trade would have been about one-quarter lower than realized in 2007. In contrast to the changes in endowments, there is a large degree of heterogeneity in the relative importance of realized changes in trade costs on changes in exports. Relative to the world altogether, trade costs have on average declined the most for exports to and from middle-income countries. For example, exports to group M from low-, middle-, and high-income countries would have been lower by 81%, 76% and 68%, respectively, in 2007 if trade costs had stayed constant relative to 1988. Hence, for imports by middle-income countries, changes in trade costs were more important than changes in endowments. This is not the case for trade flows among other groups of countries. Since high-income countries were relatively more open (especially to exporters within the same group) in 1988, trade costs played a relatively less important role for trade flows within this group, i.e., only 9% of growth in export flows can be attributed to changes in trade impediments.

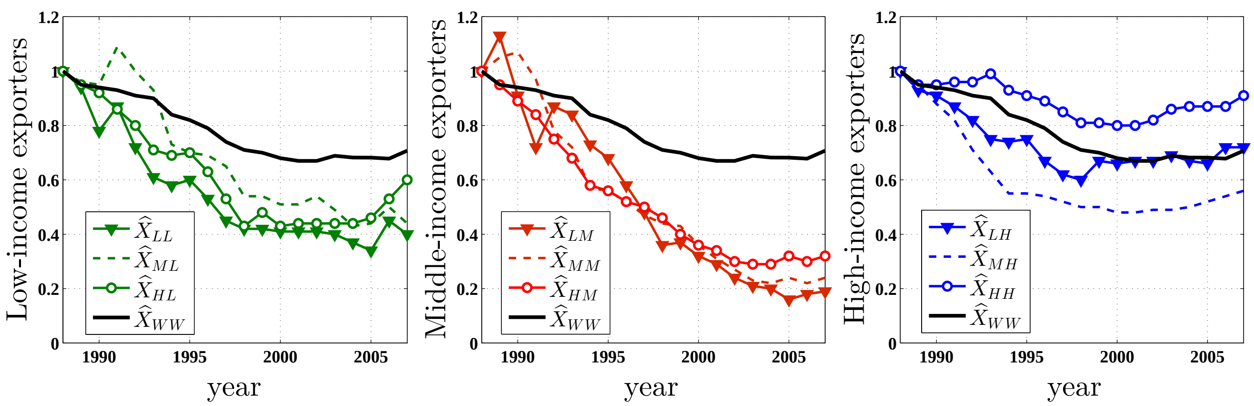

Figure 2: COUNTERFACTUAL EXPERIMENT WITH CONSTANT TRADE COSTS

Though changes in trade costs were relatively important for exports to low-income economies (but not as important as changes in endowments), they were less important for exports to high-income countries. Note that the right panel suggests that changes in trade costs within the high-income group were relatively unimportant, i.e., trade flows within this group would have been only 9% lower than in the data in 2007 in absence of the realized trade-cost change since 1988.

Lastly, in Figure 3 we consider changes in technology in tradable manufactures and non-tradable services sectors and their average marginal impact on export growth. In this counterfactual experiment, we keep both of these productivity parameters constant at their levels of 1988. Among the three considered fundamentals, changes in technology apparently induced the smallest effects on the growth of world trade since the late 1980s. According to the results in the figure, world trade among the 67 considered economies would have been lower by about 20% if productivity in manufacturing and services together had not changed since 1988. Realized changes in productivity appear to have benefited the most trade (exports and imports) of all country groups with the middle-income economies. Changes in technology were almost as important for low-income exporters and relatively less important for high-income exporters. This is again due to the fact that high-income exporters were already relatively more productive.

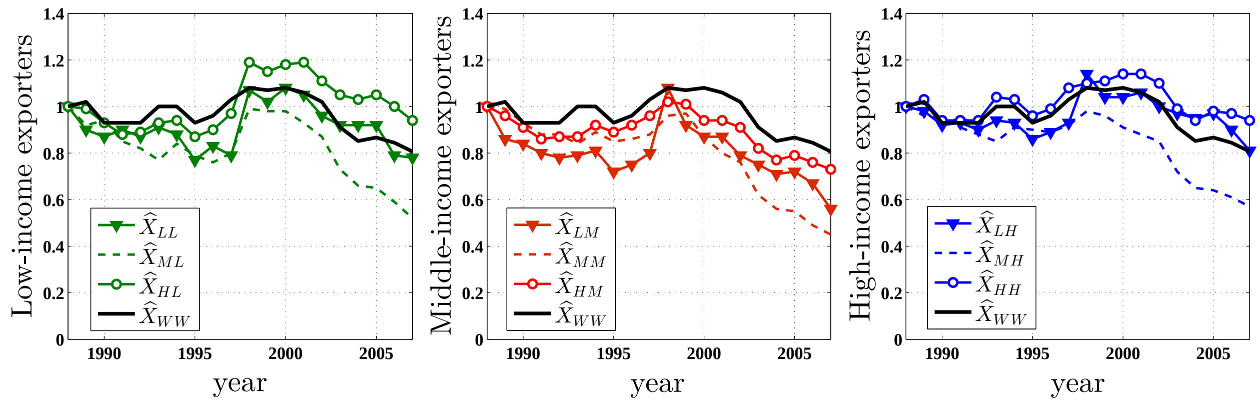

Figure 3: COUNTERFACTUAL EXPERIMENT WITH CONSTANT TECHNOLOGY

One of the peculiar results of Figure 3 is that, in some years, the realized changes in exports had been smaller than the counterfactual ones, at least for some country groups. In particular, there are two peaks (in 1998 and in 2000) which indicate that without changes in technology even overall world trade flows would have been higher than realized. These results accrue to two specific economic events in 1998 and 2000. First, the results for 1998 are driven by the financial crisis in South-East Asia which takes the form of and is not distinguishable from a negative productivity shock in the model. Many Asian economies and, to a lesser extent, some non-Asian economies were severely affected by this crisis. In our sample, the economies which responded the most most to the crisis are China, Indonesia, Japan, the Philippines, South Korea, and Thailand. Second, the result for the early 2000s are related to the economic slowdown in Europe, in particular, in Austria, Belgium, Denmark, Germany, Spain, and Switzerland.[9]The just-mentioned pattern becomes obvious when grouping the data appropriately into groups $R \in \{A, E\}$ with associated changes in exports $\widehat{X}_{RW,t}$, where A and E stand for *Asia* and *Europe*, respectively, and W stands for world. The corresponding results are illustrated in the upper panel of Figure 4. In the lower panel, we plot growth rates in nominal GDPs using regional data

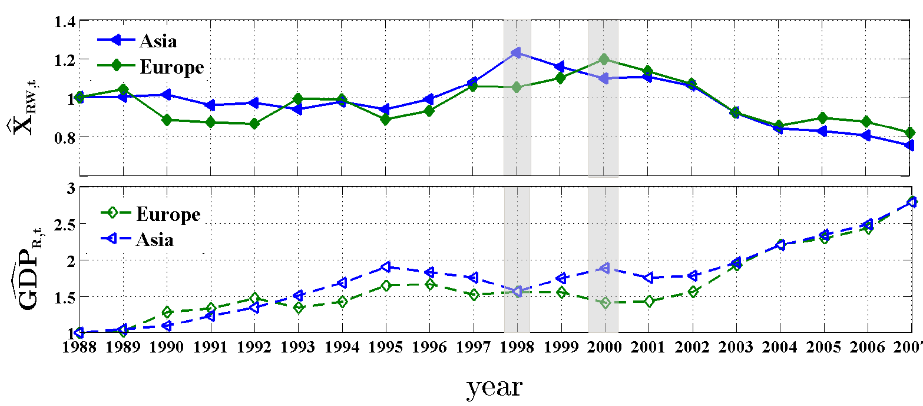

Figure 4: RECESSIONS AND TRADE FLOWS

[9]The results are robust to including more (less) countries in the two groups.

from the World Bank for *East Asian and Pacific regions* and the *Euro area*. The two years of interest are shaded in gray. It is apparent from this figure that the results for world trade flows are indeed driven by these two regional groups: in relative terms and without the technology shocks, Asia and Europe would have exported more in 1998 and 2000, respectively. Moreover, the crisis- and slowdown-related slumps in exports are visible in external data series on nominal GDP which had not been used for the analysis.

To sum up the quantitative results in this section, we rank the three drivers of changes in trade flows according to their relative importance in Table 4. In terms of changes in global trade flows, the most important driver was endowment accumulation followed by changes in trade costs and technological change. This holds for trade flows across all country groups except for exports from middle-income countries. For the latter, falling trade costs constituted the most important factor of growth in exports. Hence, the model suggests that lower preferential market access costs for exporters from these countries played a particularly important role.

Table 4: *Relative ranking of trade drivers between 1988 and 2007*

Driver	$\widehat{X}_{LL}$	$\widehat{X}_{ML}$	$\widehat{X}_{HL}$	$\widehat{X}_{LM}$	$\widehat{X}_{MM}$	$\widehat{X}_{HM}$	$\widehat{X}_{LH}$	$\widehat{X}_{MH}$	$\widehat{X}_{HH}$	$\widehat{X}_{WW}$
Endowment accumulation	1	1	1	2	2	2	1	1	1	1
Changes in trade costs	2	2	2	1	1	1	2	2	2	2
Technological change	3	3	3	3	3	3	3	3	3	3

4.2 Going beyond exogenous shocks

The parsimonious model in Section 4.1 which underlies in its generic form most new-trade-theory (gravity) models of bilateral demand was fit to analyze consequences of exogenous shocks to the fundamentals – $\left\{\widetilde{\varphi}, \widetilde{\phi}, \widetilde{\tau}, \widetilde{\ell}\right\}$ – under the assumption that shocks on the fundamentals were independent of each other and that changes in the fundamentals were exogenous.[10]In Ricardian endowment-economy models or increasing-returns-to-scale monopolistic-competition models, this assumption implies that country-size, the level of technology and, in general, a country-'s supply potential of goods are independent of each other and of the country's integration into the global market for goods. However, at this point it is useful to recall the insights from Table 2, which suggested that changes in the fundamental drivers of trade are not always independent of each other. The latter is an indication of some behavioral response of, say technology, as in Bustos (2011), and of factor supply through factor accumulation consistent with the hypotheses of human capital upgrading in response to trade liberalization as in Falvey, Greenaway, Silva (2010).[11]

In order to permit some adjustment of technology and factor supply to economic integration, we offer a richer set-up for quantitative analysis in this subsection relative to the previous one. This set-up is capable of featuring the following stylized facts which were supported by earlier work mostly on macroeconomics growth as well as international trade:

[10]This is the leading assumption made in most of the quantitative work on, e.g., the importance of trade costs for trade (see, e.g., Eaton and Kortum, 2002; Anderson and van Wincoop, 2003, 2004; Caliendo and Parro, 2010, 2011; Arkolakis, Costinot, and Rodrígues-Clare, 2012; Costinot, Donaldson, and Komunjer, 2012; Levchenko and Zhang, 2012; Bergstrand, Egger, and Larch, 2013; Levchenko, di Giovanni, and Zhang, 2014).

[11]Bustos (2011) uses micro-data for Argentinean exporters to show that trade liberalization may induce exporters to upgrade their technology in response to falling trade costs. Edmonds, Pavcnik and Topalova (2010) use micro-data for India and show that there are considerable, though heterogenous, adjustments in terms of the investment in education in response to a trade liberalization.

(i) *Endowment accumulation.* The model considered below incorporates endogenous endowment accumulation in the spirit of Lucas (1988). In the underlying model, we will place particular focus on an accumulation of *equipment* (or capital) in response to (endogenous) changes in technology and (exogenous) changes in trade frictions. In comparison, equipped labor was allowed to be time-specific, but it was randomly (exogenously) assigned to countries in each period, being invariant to levels and changes of income, factor prices, output prices, etc.

(ii) *Technological change.* Beyond endowment accumulation, we will consider an endogenous adjustment of technology in either sector and across countries in the spirit of Aghion and Howitt (1992, 1997), whereby average levels of productivity may adjust in response to (endogenous) changes in endowments and (exogenous) changes in trade frictions.[12]In the benchmark model of the previous subsection, technology parameters were allowed to be time-specific, but they were random (exogenous) in each period and invariant to levels and changes of income, factor prices, output prices, etc.

(iii) *Non-homothetic preferences, income heterogeneity, and demand-driven structural change.* Non-homotheticity and income distribution have been identified as important determinants of bilateral trade. There is a number of papers that incorporate non-homotheticity (see Fieler, 2011; Simonovska, 2014) and consumer heterogeneity (Nigai, 2014) in new-trade-theory models. We consider a preference structure in this subsection which results in variable expenditure shares on manufactures versus services and a role of income heterogeneity within countries for trade, demand-driven structural change which shows in a rising relative consumption of services as consumers get richer (see Boppart, 2014) and a declining share of manufacturing as countries become richer on average (see Pierce and Schott, 2013, for evidence in the United States).

Clearly, incorporating these features into the model calls for an inter-temporal model of optimization by both consumers and firms. For its ease of tractability relative to an infinite-horizon model with a multi-country structure, we keep a relatively tractable two-period framework for the analysis. In this set-up consumers and firms can allocate consumption, investment, and production across two periods. Consumers and firms have perfect foresight such that under each scenario they can observe prices in both the benchmark period s and a subsequent period t.

As before, we use s to denote the benchmark year (here, the first period) and t to denote any subsequent year (here, the second period). The consumers in country i now allocate their total life-endowment across periods, $\ell_i = \ell_{i,s} + \ell_{i,t}$, where $\ell_{i,s}$ means working and earning income in the first period, $\ell_{i,s} = z_{i,t}\ell_i$ with $z_{i,t} \in (0,1)$. The consumer saves a share of $(1-z_{i,t})$ of her total endowment which accumulates according to the following law of motion:

$$\ell_{i,t} = \delta_{i,t}(1-z_i)\ell_i, \tag{4.2}$$

where $\delta_{i,t}$ reflects a compound investment shock which can be related to investment efficiency and investment incentives (see Acemoglu and Ventura, 2002). Given this law of motion, we can recast the relative change in endowment in terms of the consumer decision as follows:

$$\widehat{\ell}_{i,t} = \frac{\ell_{i,t}}{\ell_{i,s}} = \delta_{i,t}\frac{(1-z_{i,t})}{z_{i,t}}. \tag{4.3}$$

Now relative changes in endowments are not fully exogenous but rather depend on the exogenous investment

[12]For trade models with endogenous growth see Grossman and Helpman (1990, 1991) and Baldwin and Forslid (2000).

shock, $\delta_{i,t}$ and endogenous variable $z_{i,t}$ which is an outcome of consumer optimization given wages and prices. Notice that endogenous endowment accumulation can be a source of growth even under constant technology which is in the spirit of Uzawa (1965) and Lucas (1988). We will see below, after adding more structure to the model, how $z_{i,t}$ is chosen optimally by consumers.

We introduce non-homothetic, price-independent generalized-linearity (PIGL) preferences in the spirit of Muellbauer (1975, 1976) by following Boppart (2014).[13] This allows using the framework of non-homotheticity of demand with a representative consumer, where aggregate expenditure shares may be characterized by those of a representative consumer (in Muellbauer's sense), involving some scale-invariant measure of the income distribution in the economy. Consumers allocate their total income in each period $b \in \{s, t\}$ across manufactures and services according to the following indirect utility function:

$$V_{i,b} = \frac{1}{\epsilon}\left[\frac{\ell_{i,b} w_{i,b}}{p_{ni,b}}\right]^{\epsilon} - \frac{\upsilon_{i,b}}{\xi}\left[\frac{p_{mi,b}}{p_{ni,b}}\right]^{\xi}, \tag{4.4}$$

where the parameters ϵ and ξ govern relative income elasticity of demand and elasticity of substitution between manufacturing goods and services, respectively, and $\upsilon_{i,t}$ is a period-specific preference shock which also subsumes changes in a scale invariant measure of the income distribution in country i.[14]Given this intra-period optimization problem, consumers maximize the sum of $V_{i,s}$ and $V_{i,t}$ by allocating their total labor endowment across two periods while taking into account the law of motion for endowments:

$$\max_{z_{i,t}}\left\{\frac{1}{\epsilon}\left[\frac{z_{i,t}\ell_i w_{i,s}}{p_{ni,s}}\right]^{\epsilon} - \frac{\upsilon_{i,s}}{\xi}\left[\frac{p_{mi,s}}{p_{ni,s}}\right]^{\xi} + \frac{1}{\epsilon}\left[\frac{\delta_{i,t}(1-z_{i,t})\ell_i w_{i,t}}{p_{ni,t}}\right]^{\epsilon} - \frac{\upsilon_{i,t}}{\xi}\left[\frac{p_{mi,t}}{p_{ni,t}}\right]^{\xi}\right\} \tag{4.5}$$

First, the intra-temporal optimization problem (allocating income in each period between services and manufactures) yields the following expenditure share on manufacturing goods in two periods:

$$\varsigma_{mi,s} = \upsilon_{i,s}\left(z_{i,t}\ell_i w_{i,s}\right)^{-\epsilon} p_{ni,s}^{\epsilon-\xi} p_{mi,s}^{\xi}, \quad \varsigma_{mi,t} = \upsilon_{i,t}\left((1-z_{i,t})\delta_{i,t}\ell_{i,t} w_{i,t}\right)^{-\epsilon} p_{ni,t}^{\epsilon-\xi} p_{mi,t}^{\xi}, \tag{4.6}$$

, whereby

$$\widehat{\varsigma}_{mi,t} = \frac{\varsigma_{mi,t}}{\varsigma_{mi,s}} = \widehat{\upsilon}_{i,t}\left(\frac{\delta_{i,t}(1-z_{i,t})}{z_{i,t}}\widehat{w}_{i,t}\right)^{-\epsilon} \widehat{p}_{ni,t}^{\epsilon-\xi} \widehat{p}_{mi,t}^{\xi}. \tag{4.7}$$

Here, the term $\widehat{\upsilon}_{i,t}$ reflects changes to preferences of the representative consumer in country i as well as changes in the scale invariant measure of the income distribution in i, both measured in period t relative to s.

Second, the inter-temporal optimization problem (allocating labor to maximize life-time consumption) yields an expression for optimal $z_{i,t}$:

$$z_{i,t} = \left(1 + \delta_{i,t}^{\frac{\epsilon}{1-\epsilon}}\left[\frac{\widehat{w}_{i,t}}{\widehat{p}_{ni,t}}\right]^{\frac{\epsilon}{1-\epsilon}}\right)^{-1}. \tag{4.8}$$

Combining this equation with (4.3) allows solving for equilibirium value of $z_{i,t}$ and $\widehat{\ell}_{i,t}$ given changes in prices and the realized investment shock. Given the parameters values, optimal share of labor devoted to production in period s is decreasing in $\delta_{i,t}$ and in $(\widehat{w}_{i,t}/\widehat{p}_{ni,t})$. This is intuitive as higher $\delta_{i,t}$ means higher opportunity

[13]E.g., Rydzek (2013) uses this preference structure in the context of Krugman's trade model.
[14]See Boppart (2014) for additional discussion of this preference structure.

cost of producing in period s versus saving for period t and higher change in normalized income between s and t induces consumers to postpone consumption to period t.

Non-homotheticity of preferences and demand implies that, as countries get richer, their expenditure share on manufacturing goods shrinks. In other words, this model is able to account for endogenous structural change as a demand-driven phenomenon, showing in a positive relation of the growth in relative employment in manufacturing with the growth in income in a country. Let us use $\ell_{mi,t}$ and $\ell_{ni,t} = 1 - \ell_{mi,t}$ to denote the share of total endowment employed in the manufacturing sector and services, respectively. Then, the demand and supply equations for tradable goods are characterized as follows:

$$\underbrace{\frac{1}{\eta}\ell_{mi,t}\ell_{i,t}w_{i,t}}_{\text{Total supply of manufactures}} + D_{i,t} = \underbrace{\frac{\mu}{\eta}\ell_{mi,t}\ell_{i,t}w_{i,t} + \frac{\beta}{\alpha}\ell_{ni,t}\ell_{i,t}w_{i,t}}_{\text{Demand by firms}} + \underbrace{\varsigma_{mi,t}\left(\ell_{i,t}w_{i,t} + D_{i,t}\right)}_{\text{Demand by consumers}}. \tag{4.9}$$

As in the previous section, define d_i as one plus ratio of nominal deficit, $D_{i,t}$, to total production in manufacturing, $\frac{1}{\eta}\ell_{mi,t}\ell_{i,t}w_{i,t}$, and normalize equation (4.9) by the latter to obtain:

$$d_{i,t} = \mu + \frac{\beta\eta}{\mu}\left(\frac{1-\ell_{mi,t}}{\ell_{mi,t}}\right) + \varsigma_{i,t}\left(\frac{\ell_{mi,t}}{\eta} + d_{i,t} - 1\right). \tag{4.10}$$

This allows us specifying employment share in the manufacturing and service sectors in terms of the hat notation as functions of the model's parameters as well as of the benchmark levels and the changes in expenditure shares on tradables:

$$\ell_{mi,t} = \frac{\frac{\beta\eta}{\mu} + \widehat{\varsigma}_{i,t}\varsigma_{i,s}}{d_{i,t} - \mu + \frac{\beta\eta}{\alpha} - \widehat{\varsigma}_{i,t}\varsigma_{i,s}(d_{i,t}-1)}, \quad \widehat{\ell}_{mi,t} = \frac{\ell_{mi,t}}{\ell_{mi,s}}, \quad \widehat{\ell}_{ni,t} = \frac{1-\ell_{mi,t}}{1-\ell_{mi,s}}. \tag{4.11}$$

The main result in (4.11) are intuitive, i.e., the share of labor devoted to production of manufacturing goods is increasing in the respective expenditure share. The latter is decreasing in real income, hence the model predicts that as countries get richer relative employment in the manufacturing sector should decrease.

Next, let us now consider a firm's inter-temporal problem, allowing firms to devote a certain share $\kappa_{ni,t}$ of total demanded labor in period s, to research and development (R&D investments) in order to improve their productivity in period t. We start with an example of a firm in the services sector. The technology evolves according to the following law of motion:

$$\phi_{i,t}^{-1} = \phi_{i,s}^{-1}\left[e_{\phi i,t}(1-\kappa_{ni,t})\right], \tag{4.12}$$

where $e_{\phi i,t}$ is the productivity of workers in R&D. Here, we follow Jones (1995a, 1995b) in making the simplifying assumption that technological progress is increasing in the *share* of labor devoted to R&D.[15] With this specification at hand, we may formulate the profit function of firms as follows:

$$\Pi_i = \left(n_{i,s}p_{ni,s} - \ell_{ni,s}^d w_{i,s} - m_{i,s}p_{mi,s}\right) + \left(n_{i,t}p_{ni,t} - \ell_{i,t}^d w_{i,t} - m_{i,t}p_{mi,t}\right), \tag{4.13}$$

$$\text{where } n_{i,s} = \phi_{i,s}^{-\frac{1}{1-\gamma}}\left(\kappa_{ni,t}\ell_{ni,s}^d\right)^{\frac{\alpha}{1-\gamma}} m_{i,s}^{\frac{\beta}{1-\gamma}} \text{ and } n_{i,t} = \phi_{i,t}^{-\frac{1}{1-\gamma}}(1-\kappa_{ni,t})^{\frac{1}{1-\gamma}} e_{\phi i,t}^{\frac{1}{1-\gamma}}\left(\ell_{i,t}^d\right)^{\frac{\alpha}{1-\gamma}} m_{i,t}^{\frac{\beta}{1-\gamma}}, \tag{4.14}$$

[15] Jones (1965) who pointed out the problem of the scale effect in productivity growth in the endogenous growth models.

where $m_{i,b}$ denotes the amount of inputs used in period $b \in \{s,t\}$. Note that here we use $\ell^d_{ni,s}$ and $\ell^d_{ni,t}$ to denote demanded labor in periods s and t, respectively. Now in addition to the usual intra-temporal profit maximization, firms choose optimal share $\kappa_{ni,t}$ to allocate for production across periods. Using first-order conditions from the maximization problem in (4.13) and (ex post) zero profit conditions in each period we get the following expression for the optimal level of $\kappa_{ni,t}$:

$$\kappa_{ni,t} = \left(1 + \frac{\widehat{\ell}^d_{ni,t}\widehat{w}_{i,t}}{\alpha}\right)^{-1}. \tag{4.15}$$

Knowing $\kappa_{ni,t}$ and $e_{\phi i,t}$, we may characterize the change in productivity in the services sector between periods s and t as:

$$\widehat{\phi}_{i,t} = \frac{\kappa^{\alpha}_{ni,t}}{e_{\phi i,t}(1-\kappa_{ni,t})}. \tag{4.16}$$

Analogously to the services sector, we may specify the same problem for firms in manufacturing as:

$$\kappa_{mi,t} = \left(1 + \frac{\widehat{\ell}^d_{mi,t}\widehat{w}_{i,t}}{\eta}\right)^{-1}, \text{ and } \widehat{\varphi}_{i,t} = \frac{\kappa^{\eta}_{mi,t}}{e_{\varphi i,t}(1-\kappa_{mi,t})}, \tag{4.17}$$

where $\widehat{\ell}^d_{mi,t}$ is the change in the share of labor demanded by firms in manufacturing in country i between periods s and t, $\kappa_{mi,t}$ is the share of labor in that sector devoted to research, and $e_{\varphi i,t}$ is the effectiveness of this investment in terms of the increase in productivity.

International trade occurs in the same fashion as in Section 4.1 so that the change in the trade share for exporter j and importer i from period s to t is characterized also as in Section 4.1. We close the model by noting that, in equilibrium, labor markets clear such that $\widehat{\ell}^d_{ni,t} = \widehat{\ell}_{ni,t}$ and $\widehat{\ell}^d_{mi,t} = \widehat{\ell}_{mi,t}$, and goods market clear whereby endogenous changes in wages are determined by:

$$\widehat{w}_{i,t}\widehat{\ell}_{i,t}\widehat{\ell}_{im,t}Y_{i,s} = \sum_{j=1}^{J} \lambda_{ji,s}\widehat{\lambda}_{ji,t}\widehat{w}_{j,t}\widehat{\ell}_{j,t}\widehat{\ell}_{jm,t}d_{j,t}Y_{j,s}. \tag{4.18}$$

This completes the description of the competitive equilibrium for the two-period model in years s and t.

Next, we conduct counterfactual experiments as in Subsection 4.1 to assess quantitative importance of different set of factors for growth in trade across different country groups. In the first experiment, we keep investment shock fixed relative to the benchmark year such that $\delta_{i,t} = \delta_{i,s}$. We plot the results of this experiment in the upper panel of Figure 5. We have four subpanels that picture exports from (left to right) low-income, middle-income and high-income exporters. We again use $-\triangledown-$, $--$ and $-\circ-$ to denote exports to low-income, middle-income and high-income importers. The black solid line corresponds to total world trade flows. First, in terms of the world trade flows, endogenous trade model implies that under constant investment shock trade would be lower by 30% than in the data, and by 10 percentage points lower than in Model 1 in 2007. Accordingly, all group-specific types of trade flows would be lower than in Model 1. Endowment accumulation is of particular importance for exports from low-income and middle-income groups to middle-income importers. Under constant $\delta_{i,t}$, $\widehat{X}_{ML}$ and $\widehat{X}_{MM}$ would be lower by 88% and 85% than in the data in 2007, respectively. The difference between the results here and in Model 1 is due to the fact that no endowment accumulation indirectly affects technological change and the structure of the economy. Such that the outcomes are now more extreme (relative to the benchmark) as the effects of no change in endowments are now amplified due to the endogenous structure of the model.

In the second horizontal panel in Figure 5, we plot counterfactual changes in nominal trade flows under constant trade costs. Quantitatively, the results are similar to those in Model 1. There are minor differences for exports from low-income and high-income countries to middle-income exporters in 2007. In the endogenous growth model, changes in trade costs are less important for exports from low- and high- to middle-income countries such that $\widehat{X}_{ML}$ and $\widehat{X}_{MH}$ are higher by 2 and 4 percentage points than in Model 1. Overall, relative to the data, changes in trade costs prove to be extremely important for all trade flows and especially for exports from middle-income countries.

In our third experiment, we keep the R&D efficiency constant such that $e_{\phi i,t} = e_{\phi i,s}$ and $e_{\varphi i,t} = e_{\varphi i,s}$. In terms of the world trade flows, the model here predicts higher $\widehat{X}_{WW}$ than in Model 1 for all years except for 2007. The largest positive differences of 17 and 15 percentage points are observed in 2001 and 2002, respectively. In these years, without disincentives to invest in R&D due to crises, world trade would be higher than in the data and Model 1. The latter is due to a more acute response of the system since more modest investments in research also generally entail lower savings in endowments. The differences in changes in trade flows between the model here and Model 1 in terms of trade flows from low-income exporters to low-, middle- and high-income importers are 11, -31 and 13 percentage points in 2007, respectively. Hence, under the endogenous growth framework technology related shocks are relatively more important for exports to middle-income group. This holds for all types of trade flows that involve middle-income countries. The differences between the model with endogenous changes in technology and Model 1 for $\widehat{X}_{LM}$, $\widehat{X}_{MM}$, $\widehat{X}_{HM}$ and $\widehat{X}_{MH}$ are 32, 29, 24 and 29 percentage points in 2007, respectively. Hence, the current framework suggests that in 2007 technology related shocks were almost as important as shocks to endowments and as (or more for certain types of trade flows) important as shocks to trade costs for exports and imports to middle-income countries.

The results of our final experiment are reported in the lower panel of Figure 5. This experiment is new relative to Model 1, where preferences were assumed to stay constant. Here, we set $\widehat{\upsilon}_{i,t} = 1$ so that preferences stay constant relative to the benchmark year. The results are fairly homogenous across different types of trade flows. They suggest that there was a global preference shock towards consumption of services relative to manufacturing goods in 2001-2006. Without this shock, global trade would be higher than in the data by 10 and 5 percentage points in 2001 and 2006, respectively. These results are consistent with the findings of Eaton, Kortum, Neiman and Romalis (2013) who identified preference shocks to be the main driver of the trade to GDP collapse during the great recession. Our results suggest a similar insight, i.e., during recessions trade can fall down by more than GDP due to preference shocks.

In Table 5, we rank these four drivers of changes in trade flows across different country groups between 1988 and 2007 according to the quantitative importance. In terms of the changes in global trade flows, the most important factor was endowment accumulation followed by falling trade costs, technological change and changes in preferences. Hence, overall the results of the model based on endogenous adjustments are in line with those of Model 1. However, there are considerable differences between group-specific changes in trade flows between the model here and Model 1. First, the results suggest that endowment accumulation was the most important factor for changes in trade flows across all types of trade flows except for $\widehat{X}_{LM}$ which was still mainly driven by reduction in trade costs. Second, falling trade costs no longer unanimously constitute the second most important driver for changes in trade flows. They are now less important than changes in

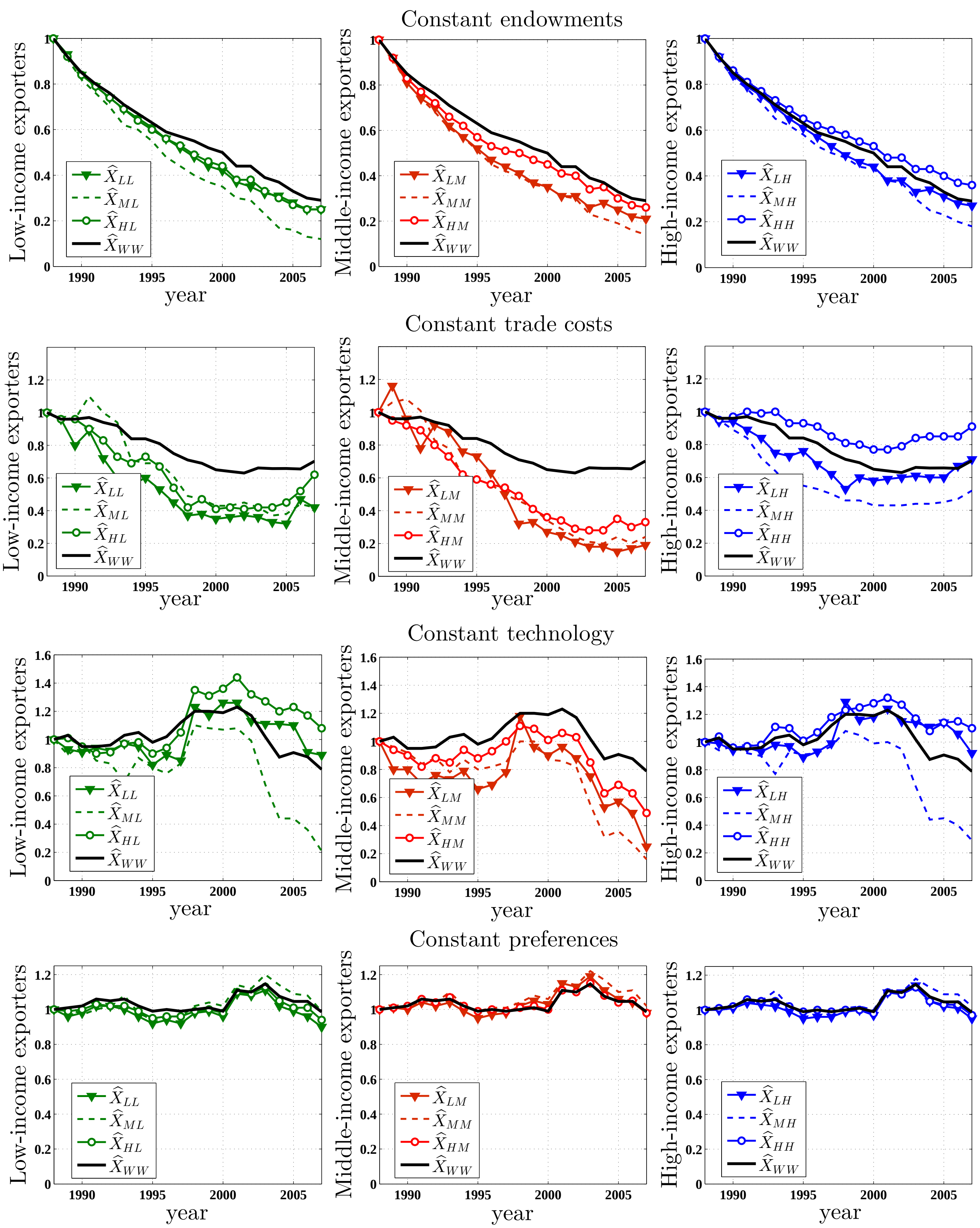

Figure 5: Counterfactual experiments (Endogenous growth model)

technology for $\widehat{X}_{ML}, \widehat{X}_{MM}, \widehat{X}_{MH}, \widehat{X}_{HH}$. Nevertheless, reductions in trade costs had a sizable effect on changes in trade flows and remain the second most important driver for $\widehat{X}_{LL}, \widehat{X}_{HL}, \widehat{X}_{HM}, \widehat{X}_{LH}$.

Table 5: *Relative ranking of trade drivers between 1988 and 2007*

Driver	$\widehat{X}_{LL}$	$\widehat{X}_{ML}$	$\widehat{X}_{HL}$	$\widehat{X}_{LM}$	$\widehat{X}_{MM}$	$\widehat{X}_{HM}$	$\widehat{X}_{LH}$	$\widehat{X}_{MH}$	$\widehat{X}_{HH}$	$\widehat{X}_{WW}$
Endowment accumulation	1	1	1	2	1	1	1	1	1	1
Changes in trade costs	2	3	2	1	3	2	2	3	3	2
Technological change	3	2	3	3	2	3	3	2	2	3
Changes in preferences	4	4	4	4	4	4	4	4	4	4

Quantitative importance of changes in preferences is relatively small and is ranked fourth for all types of trade flows.

5 External validity check

In the world-trade growth accounting exercises in Section 3 and Subsections 4.1 and 4.2, we exactly fit the data in many dimensions by design. However, it is important to show that the model used in the analysis also fits moments of the data that had not been used for estimation or calibration. In this section, we provide some evidence of the validity of the models in Subsections 4.1 and 4.2 along those lines. By design, the model based on endogenous growth in Subsection 4.2 is more suitable for such analysis, as it provides a richer set of hypotheses and predictions than the parsimonious model in Subsection 4.1 – in particular, regarding the levels and changes of the allocation of labor across sectors and the consumption expenditure shares on manufactures and services.

The model provides predictions regarding the allocation of labor in manufacturing and services across countries and time through equation (4.11). Hence, its predictions broadly capture labor adjustment to trade liberalization in Artuc, Chaudhuri and McLaren (2010) and Dix-Carneiro (2014). To shed light on what the model predicts relative to the data, we compare the share of value added in services in total GDP (as a measure of the share of equipped labor income in services relative to total labor income in manufacturing and services) and compare it to the share of labor units in all employment, $\ell_{ni,t}$.[16] Overall, the model fares well in predicting the labor income share in services. The correlation coefficients between the actual and predicted values of $\ell_{ni,t}$ over time are high for every country. The average value of these coefficient across countries is 0.63 with a variance of 0.11. In Figure 6 we plot the model predictions for $\ell_{ni,t}$ against the data for selected economies which belong in different income groups and continents. The figure illustrates that the model is capable to replicate well moments of the data on employment shares which had not been used neither to estimate nor to calibrate parameters.

The model here is also consistent with the general results of the macroeconomic growth accounting literature (see Hall and Jones, 1999; Caselli 2005). However, there are a few important differences between the two approaches. First, we use prices, rather than units of labor and capital to calibrate productivity parameters. Second, we account for large input shares of in the manufacturing intermediate in both non-tradable and

[16] Data on the share of the workforce in services versus manufacturing are harder to obtain than ones on the share of value added. See the Appendix for details. In the model, the share of labor income in services is identical to the share of employment in services.

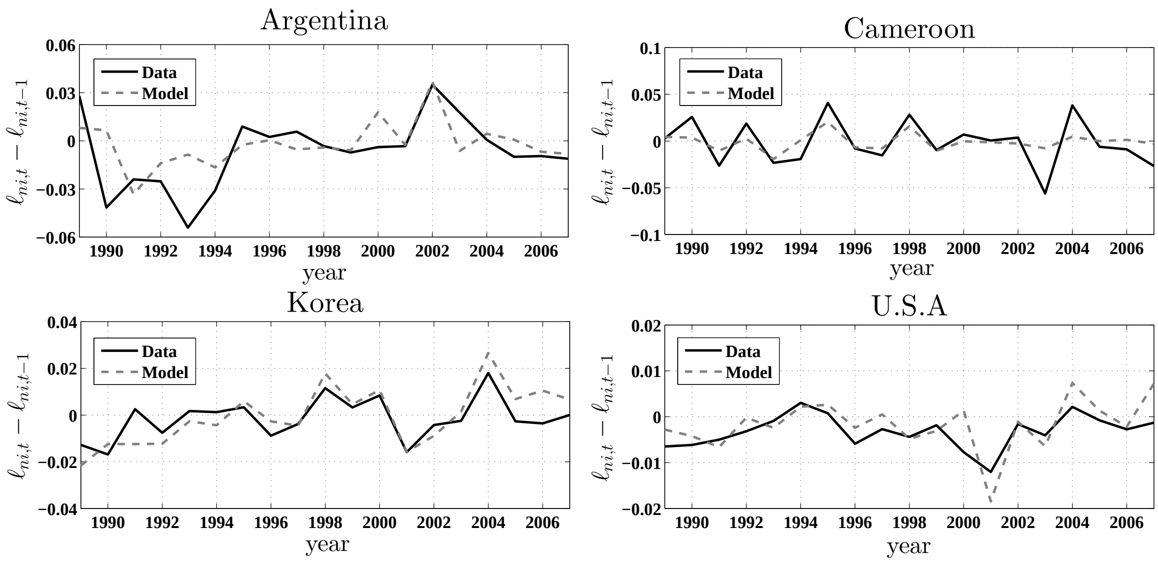

Figure 6: Annual changes in share of valued added in services in GDP for selected countries

tradable sectors, hence we account for trade as a potentially important determinant of TFP parameters. Nevertheless, qualitative predictions of the model here in terms of hanges in productivity (across countries and time) are consistent with those of macroeconomic models. In Figure 7, we plot changes in the calibrated productivity parameter, $\widehat{\phi}_{i,t}$, versus (inverse) changes in TFP provided by the Penn World Tables 8.0.[17]

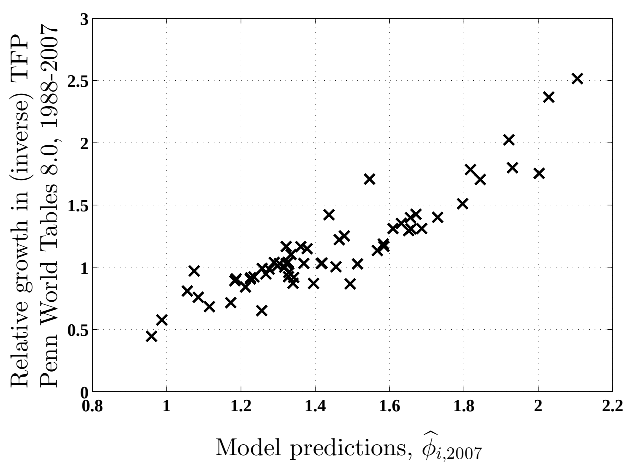

Figure 7: Consistency with macroeconomic growth accounting approach

Figure 7 confirms that qualitatively our productivity estimates are consistent with those from the Penn World Tables. Hence, we conclude that not only is the model here able to exactly match the data in many dimensions but it is also consistent with the data moments not targeted during the calibrated procedure as well as with the general results from the macroeconomic literature.

[17]Note that since we use price data to calibrate $\widehat{\phi}_{i,t}$, our measure is interpreted as an inverse of the TFP parameter. For details on calculating TFP in Penn World Tables 8.0 refer to and calculated in Inklaar and Timmer (2013).

6 Conclusion

We developed a world-trade growth accounting method based on new trade theory models that allows decomposing changes in exports into exogenous factors relating to changes in endowments, technology, trade costs and preferences. We applied this method to real world data on 67 biggest countries for the period between 1988 and 2007 and found that a lion's share of the variation in growth of (log) exports across different country pairs is explained by changes in trade costs. Change in technology, accumulation of endowment and general equilibrium effects turned out to be relatively less important for explaining this type of variation.

We also develop two alternative dynamic general equilibrium models, one featuring exogenous and the other endogenous growth open economy framework. We use these models to quantify the role of changes in fundamentals for total nominal trade flows in the world and across different country groups. Our results suggest that the most important driver of growth in the world trade flows was endowment accumulation followed by reduction in trade costs and technological progress. We also found that reductions in trade costs were of particular importance for the growth in exports from middle-income countries. Depending on the modelling framework, technological change and reductions in trade costs were second and third most important drivers for trade between different country groups.

Appendix A

In this section, we describe our calibration procedure, data sources and the algorithm for computing counterfactual outcomes. Certain calibration steps will be common to both exogenous and endogenous models whereas others are model-specific. We start with specifying the values of preference and production parameters used in the calibration in Table 6.

Factor shares in the production functions were calculated using data on input-output tables from the OECD's STAN database for ARG, AUS, AUT, BEL, BRA, CAN, CHE, CHN, CZE, DEU, DNK, ESP, FIN, FRA, GBR, GRC, HUN, IDN, IRL, ISR, ITA, JPN, KOR, NLD, NOR, NZL, POL, PRT, SWE, THA, TUR, USA, ZAF. The value of θ is from Costinot, Donaldson and Komunjer (2012). The values of ϵ and ξ are from Boppart (2014). With these parameter values in hand that are kept constant and equal across all countries and time periods, we proceed to describing the calibration steps. In what follows we set our benchmark period to 1988 such that $s = 1988$ and t to different years from 1989 to 2007.

STEP 1. Recovering levels and changes in trade costs and prices of manufactures.

Our data on bilateral imports come from COMTRADE. Since we are interested in manufacturing trade we keep *SITC. 1* categories broadly associated with manufactures (main headings 0,1,6,7,8). The vast majority of our trade flows are in *C.I.F.*, when these data are unavailable we supplement them with those reported by exporters. Finally, if neither *C.I.F.* nor *F.O.B.* data are available, we interpret such observation as a zero trade flow. For computational purposes, we set zero trade flows to unity. This is to avoid the problem of infinite trade costs. This procedures gives us $N \times (N-1) \times T$ observations.

To compute intra-trade flows, we need data on the value of production in each country and year. There are several sources that we use to obtain these data. First, for most OECD countries these data are available in the OECD's STAN database. We supplement them with the data from the United Nation's UNIDO database. Finally, for those countries (years) with no observations available, we impute $X_{ii,t}$ by regressing observable output on valued added in the manufacturing and using the estimated coefficients for prediction. The value added data come from the United Nation Statistics Division. We calculate $X_{ii,t}$ as the difference between total production and total exports. This provides as with $N \times T$ additional observations such that we have a full $N \times N \times T$ matrix of trade flows.

In the first step, we only use data on $X_{ij,t}$ to recover levels of trade costs and prices in the manufactures. For that define total production on the manufactures as $Y_{i,t} = \sum_j X_{ji,t}$ and total expenditures on manufactures as $Y_{i,t} + D_{i,t} = \sum_j X_{ij,t}$. Next, we compute trade shares as follows:

$$\lambda_{ij,t} = \frac{X_{ij,t}}{Y_{i,t} + D_{i,t}}. \tag{6.1}$$

Table 6: Parameter values

α	β	γ	η	μ	ν	θ	ϵ	ξ
0.53	0.06	0.41	0.30	0.29	0.41	6.50	0.22	0.41

Treat $Y_{i,t}$, $D_{i,t}$ and $\lambda_{ij,t}$ as given and solve the following system of equations:

$$\frac{\lambda_{ij,t}}{\lambda_{ii,t}} = \frac{c_{j,t}}{c_{i,t}} \tau_{ji,t}^{-\theta} \text{ and } Y_i = \sum_{j=1}^{J} \frac{c_{i,t} \tau_{ij,t}^{-\theta}}{\sum_{\ell} c_{\ell,t} \tau_{i\ell,t}^{-\theta}} (Y_j + D_j). \tag{6.2}$$

Note that given θ, this system can be solved for $N \times (N-1) + N$ variables for each time period $t \in T$. Hence, with the assumption of $\tau_{ii,t} = 1$ for all i and t, the system is exactly identified. We solve the system separately for each year. Given trade costs and marginal cost of production in the manufacturing sector, we obtain the price of manufacturing goods as:

$$p_{mi,t} = \left(\sum_j c_{j,t} \tau_{ij,t}^{-\theta} \right)^{-\frac{1}{\theta}}. \tag{6.3}$$

We recast all these variables in terms of relative changes as:

$$\widehat{c}_{i,t} = \frac{c_{i,t}}{c_{i,s}}, \quad \widehat{\tau}_{ij,t} = \frac{\tau_{ij,t}}{\tau_{ij,s}}, \quad \widehat{p}_{mi,t} = \frac{p_{mi,t}}{p_{mi,s}}. \tag{6.4}$$

This step is common to both models. Hence, though the interpretation of $Y_{i,t}$ and $c_{i,t}$ will differ across exogenous and endogenous models, their numerical values in both cases directly match the data.

STEP 2. Recovering changes in productivity, investment and consumption

In this step, we calibrate the remaining parameters of the model. This step will be different across two models. Let us start with describing the calibration procedure for the first model with exogenous changes in endowment, productivities and trade costs. We use data from Penn World Tables 8.0 to compute changes in total endowment as:

$$\widehat{\ell}_{i,t} = \left(\frac{ahw_{i,t} \times emp_{i,t} \times hci_{i,t}}{ahw_{i,s} \times emp_{i,s} \times hci_{i,s}} \right)^{r_{i,t}} \times \left(\frac{K_{i,t}}{K_{i,s}} \right)^{1-r_{i,t}}, \tag{6.5}$$

where ahw is average hours worked, $emp_{i,t}$ is number of people employed, $hci_{i,t}$ is human capital index, $K_{i,t}$ capital stock and $r_{i,t}$ share of labor compensation. For countries (years) where data for $ahw_{i,t}$ and $r_{i,t}$ were unavailable we used sample averages in that year. Hence, our equipped labor is a comprehensive measure of effective labor hours and capital stock per country in each period. We further normalize $\ell_{i,t}$ such that the following identity holds:

$$\widehat{Y}_{i,t} = \widehat{w}_{i,t} \widehat{\ell}_{i,t}, \tag{6.6}$$

such that $\widehat{w}_{USA,t} = 1$ for all i, t which we use as a numéraire.

We use one additional data vector from the Penn World Tables 8.0 – level of consumption prices which, in terms of the first model, can be interpreted as $p_{ni,t}$. This allows as calculating $\widehat{p}_{ni,t}$. Then, we can isolate changes in the productivity parameters in the two sectors as:

$$\widehat{\phi}_{i,t} = \widehat{p}_{ni,t}^{1-\gamma} \widehat{w}_{i,t}^{-\alpha} p_{mi,t}^{-\beta} \quad \text{and} \quad \widehat{\varphi}_{i,t} = \widehat{c}_{i,t} (\widehat{w}_{i,t}^{\eta} \widehat{p}_{mi,t}^{\mu} \widehat{p}_{ni,t}^{\nu})^{\theta}. \tag{6.7}$$

This completes calibration of all exogenous parameters in the first model. Then, we can compute counterfactual outcomes for various scenarios. Here, we use an example of constant trade costs experiment to describe our computation procedure of the counterfactual equilibrium. Constant trade costs entails setting $\widehat{\tau}_{ij,t} = 1$ for all i, j and t. Given this assumption and the vector of remaining exogenous parameters, we can calculate the counterfactual outcome using the hat algebra approach and the data for the benchmark year s. We solve the following system of equations:

$$\widehat{\lambda}_{ij,t} = \widehat{\varphi}_{j,t}\left(\frac{\widehat{w}_{j,t}^{\eta}\widehat{p}_{mj,t}^{\mu}\widehat{p}_{nj,t}^{\nu}}{\widehat{p}_{mi,t}}\right)^{-\theta}, \tag{6.8}$$

$$\widehat{p}_{ni,t} = \widehat{\phi}_{i,t}\widehat{w}_{i,t}^{\alpha}\widehat{p}_{mi,t}^{\beta}\widehat{p}_{ni,t}^{\gamma}, \tag{6.9}$$

$$\widehat{p}_{mi,t} = \left(\sum_{k}\lambda_{ik,s}\widehat{\varphi}_{k,t}(\widehat{w}_{k,t}^{\eta}\widehat{p}_{mk,t}^{\mu}\widehat{p}_{nk,t}^{\nu})^{-\theta}\right)^{-\frac{1}{\theta}}, \tag{6.10}$$

$$\widehat{w}_{i,t} = \sum_{j}\frac{\lambda_{ji,s}\widehat{\varphi}_{i,t}(\widehat{w}_{i,t}^{\eta}\widehat{p}_{mi,t}^{\mu}\widehat{p}_{ni,t}^{\nu}\widehat{\tau}_{ji,t})^{-\theta}}{\widehat{p}_{mj,t}^{-\theta}\widehat{\ell}_{i,t}Y_{i,s}}\widehat{\ell}_{j,t}\widehat{w}_{j,t}Y_{j,s}\left(1+d_{j,t}\right), \tag{6.11}$$

where we keep $w_{USA,t} = 1$ as a numéraire.

Next, we turn to describing the calibration procedure for the model with endogenous endowment accumulation, R&D expenditures and non-homothetic preferences. The results from STEP 1 can be readily used in the calibration procedure for this model. However, there are important differences in STEP 2 that require clarification. First, given calculated changes in endowments, $\widehat{\ell}_{i,t}$, we now calculate the implied changes in wages using changes in GDP rather than the manufacturing absorption such that:

$$\widehat{w}_{i,t} = \frac{\widehat{GDP}_{i,t}}{\widehat{\ell}_{i,t}}, \tag{6.12}$$

as before we make sure to keep $w_{USA,t}$ as a numéraire and normalize $\widehat{\ell}_{i,t}$ accordingly. We also now interpret data on final prices differently. As a matter of accounting, we calculate model implied $\widehat{p}_{ni,t}$ by normalizing the data on the consumption index by the expenditure share on services observed in the data. Next, we calculate the share of income in i devoted to consumption of the manufacturing goods and services:

$$\varsigma_{mi,t} = \frac{1+d_{i,t}-\mu-\frac{\beta}{\alpha}\left(GDP_{i,t}/Y_{mi,t}-\eta\right)}{GDP_{i,t}/Y_{mi,t}+d_{i,t}}, \tag{6.13}$$

where GDP_i, $Y_{mi,t}$ and $d_{i,t}$ are observable. Next, we use these data on $\varsigma_{mi,t}$ to calculate $\ell_{mi,t}$ from equation (4.11) as:

$$\ell_{mi,t} = \frac{\frac{\beta\eta}{\mu}+\varsigma_{i,t}}{1+d_{i,t}-\mu+\frac{\beta\eta}{\alpha}-\varsigma_{i,t}d_{i,t}}. \tag{6.14}$$

These two equations provide us with the following calibrated values $\widehat{\varsigma}_{mi,t}$, $\widehat{\ell}_{mi,t}$ and $\widehat{\ell}_{ni,t}$. At this point we can recover the preference shock $\widehat{\upsilon}_{i,t}$ from (4.7) as follows:

$$\widehat{\upsilon}_{i,t} = \widehat{\varsigma}_{mi,t}\left(\widehat{\ell}_{i,t}\widehat{w}_{i,t}\right)^{\epsilon}\widehat{p}_{ni,t}^{\xi-\epsilon}\widehat{p}_{mi,t}^{-\xi}. \tag{6.15}$$

Next, we calibrate the values of the investment shocks and the share of labor devoted to production using the following system of equations:

$$z_{i,t} = \left(1 + \delta_{i,t}^{\frac{\epsilon}{1-\epsilon}} \left[\frac{\widehat{w}_{i,t}}{\widehat{p}_{ni,t}}\right]^{\frac{\epsilon}{1-\epsilon}}\right)^{-1} \quad \text{and} \quad \widehat{\ell}_{i,t} = \delta_{i,t}\frac{(1-z_{i,t})}{z_{i,t}}, \tag{6.16}$$

which gives us the value of the investment shock, $\delta_{i,t}$, in each period. Finally, we recover two exogenous technology shocks $e_{\phi i,t}$ and $e_{\varphi i,t}$ using the following two equations:

$$e_{\phi i,t} = \frac{\left(1+\alpha^{-1}\widehat{\ell}_{ni,t}\widehat{w}_{i,t}\right)^{-\alpha}}{\widehat{\phi}_{i,t}\left(1-\left(1+\alpha^{-1}\widehat{\ell}_{ni,t}\widehat{w}_{i,t}\right)^{-1}\right)}, \quad \text{and} \quad e_{\varphi i,t} = \frac{\left(1+\eta^{-1}\widehat{\ell}_{mi,t}\widehat{w}_{i,t}\right)^{-\eta}}{\widehat{\varphi}_{i,t}\left(1-\left(1+\eta^{-1}\widehat{\ell}_{mi,t}\widehat{w}_{i,t}\right)^{-1}\right)}, \tag{6.17}$$

where $\widehat{\phi}_{i,t}$ and $\widehat{\varphi}_{i,t}$ are treated as given. At this point we have recovered all exogenous shocks for simulating the model, $\{\widehat{\varsigma}_{mi,t}, \delta_{i,t}, e_{\phi i,t}e_{\varphi i,t}, d_{i,t}, \widehat{\tau}_{ij,t}\}$. Next, we describe how we calculate counterfactual outcomes using example of constant trade costs $\widehat{\tau}_{ij,t} = 1$. Given this assumption and the remaining series of exogenous shocks, we solve the following system of equations:

$$\widehat{\lambda}_{ij,t} = \widehat{\varphi}_{j,t}\left(\frac{\widehat{w}_{j,t}^{\eta}\widehat{p}_{mj,t}^{\mu}\widehat{p}_{nj,t}^{\nu}}{\widehat{p}_{mi,t}}\right)^{-\theta}, \tag{6.18}$$

$$\widehat{p}_{ni,t} = \widehat{\phi}_{i,t}\widehat{w}_{i,t}^{\alpha}\widehat{p}_{mi,t}^{\beta}\widehat{p}_{ni,t}^{\gamma}, \tag{6.19}$$

$$\widehat{p}_{mi,t} = \left(\sum_k \lambda_{ik,s}\widehat{\varphi}_{k,t}(\widehat{w}_{k,t}^{\eta}\widehat{p}_{mk,t}^{\mu}\widehat{p}_{nk,t}^{\nu})^{-\theta}\right)^{-\frac{1}{\theta}}, \tag{6.20}$$

$$\widehat{\ell}_{i,t} = \delta_{i,t}\frac{(1-z_{i,t})}{z_{i,t}}; \quad z_{i,t} = \left(1 + \delta_{i,t}^{\frac{\epsilon}{1-\epsilon}}\left[\frac{\widehat{w}_{i,t}}{\widehat{p}_{ni,t}}\right]^{\frac{\epsilon}{1-\epsilon}}\right)^{-1}, \tag{6.21}$$

$$\widehat{\ell}_{mi,t} = \frac{\ell_{mi,t}}{\ell_{mi,s}}, \quad \widehat{\ell}_{ni,t} = \frac{1-\ell_{mi,t}}{1-\ell_{mi,s}}, \quad \ell_{mi,t} = \frac{\frac{\beta\eta}{\mu} + \widehat{\varsigma}_{i,t}\varsigma_{i,s}}{1+d_{i,t}-\mu+\frac{\beta\eta}{\alpha}-\widehat{\varsigma}_{i,t}\varsigma_{i,s}d_{i,t}}, \tag{6.22}$$

$$\kappa_{ni,t} = \left(1+\alpha^{-1}\widehat{\ell}_{ni,t}\widehat{w}_{i,t}\right)^{-1}, \quad \kappa_{mi,t} = \left(1+\eta^{-1}\widehat{\ell}_{mi,t}\widehat{w}_{i,t}\right)^{-1}, \tag{6.23}$$

$$\widehat{\phi}_{i,t} = \frac{\kappa_{ni,t}^{\alpha}}{e_{\phi i,t}(1-\kappa_{ni,t})}, \quad \widehat{\varphi}_{i,t} = \frac{\kappa_{mi,t}^{\eta}}{e_{\varphi i,t}(1-\kappa_{mi,t})}, \tag{6.24}$$

$$\widehat{w}_{i,t} = \sum_{j=1}^{J}\lambda_{ji,s}\widehat{\lambda}_{ji,t}\frac{\widehat{w}_{j,t}\widehat{\ell}_{j,t}\widehat{\ell}_{jm,t}Y_{j,s}(1+d_{j,t})}{\widehat{\ell}_{i,t}\widehat{\ell}_{im,t}Y_{i,s}}, \tag{6.25}$$

where we keep $\widehat{w}_{USA,t} = 1$ as a numéraire.

Appendix B

We classify countries into low-income, middle-income and high-income groups according to the following Table.

The method is based on the average per-capita income observed in 1988. We discus the exact bounds for each

Table 7: *Country group classification*

country	group	country	group	country	group
Bangladesh	L	Fiji	M	Finland	H
Bolivia	L	Hungary	M	France	H
Cameroon	L	Jamaica	M	Germany	H
Ghana	L	Jordan	M	Greece	H
Guatemala	L	Malaysia	M	Iceland	H
Honduras	L	Malta	M	Ireland	H
India	L	Mauritius	M	Israel	H
Indonesia	L	Mexico	M	Italy	H
Kenya	L	Oman	M	Japan	H
Madagascar	L	Peru	M	Korea, Rep.	H
Morocco	L	South Africa	M	Kuwait	H
Nepal	L	Thailand	M	Netherlands	H
Pakistan	L	Trinidad and Tobago	M	New Zealand	H
Philippines	L	Tunisia	M	Norway	H
Senegal	L	Turkey	M	Portugal	H
Sri Lanka	L	Uruguay	M	Singapore	H
Argentina	M	Venezuela, RB	M	Spain	H
Barbados	M	Australia	H	Sweden	H
Chile	M	Austria	H	Switzerland	H
China	M	Belgium	H	United Kingdom	H
Colombia	M	Canada	H	United States	H
Costa Rica	M	Cyprus	H		
Ecuador	M	Denmark	H		

L – low-income country, M – middle-income country, H – high-income country

group in footnote 8.

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