International Value-Added Linkages in Development Accounting*

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Abstract

Development accounting evaluates how much of the variation in per-worker incomes across countries can be attributed to quantifiable factor endowments, and how much is due to unobserved TFP differences. We use a standard trade model to generalise the development accounting framework to a setting in which countries are open to trade, and consume both domestic and foreign value added. In addition to differences in factor endowments and TFPs, the generalised framework highlights differences in relative factor costs as source of real-income variation across countries. In turn, countries' relative factor costs are determined by their trade linkages, and the international distribution of factor endowments and expenditures. We use information on value-added trade from international input-output tables for 40 major economies in the period 1995-2011 to back out their relative factor costs in a model-consistent manner. Incorporating this information into the development accounting equation reduces the variation in unobserved TFPs required to explain the distribution of per-worker incomes among our sample countries by more than one half. Our findings suggest that the large international TFP differences found in traditional development-accounting exercises are in part due to their implicit assumption that countries are closed.

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As of now, the answer to the development-accounting question — do observed differences in the factors employed in production explain most of the cross-country variation in income — is: no, way no.

– Francesco Caselli, 2005,
"Accounting for Cross-Country Income Differences,"
Handbook of Economic Growth

1 Introduction

Since Adam Smith's *The Wealth of Nations* (1776), economists have sought to understand the large differences in countries' per-capita incomes and well-being. Economics libraries abound with potential explanations – ranging from the thriftiness and inventiveness of nations to their openness to trade. Over the last two decades, the rise of development accounting has subjected theorising about this old question to the discipline of empirical evidence. Positing plausible aggregate production functions, development-accounting studies provide a quantitative assessment of the share of international income differences which can be attributed to differences in measurable production factors (such as endowments of physical and human capital) and attribute the remainder to unobservable differences in "total factor productivity" (TFP).

A key finding of this literature is that TFP differences appear to explain by far the largest portion of the variation in incomes across countries. As the quote from Caselli (2005) suggests, this is sobering: since TFP is measured indirectly, as the residual determinant of incomes once the contribution of all measurable economic aggregates has been accounted for, it captures all drivers of income differences which elude quantification. It thus represents a "measure of ignorance" (Abramovitz, 1956) about what makes some countries rich, and others poor. Reducing the reliance on this "measure of ignorance" in explaining income differences poses a first-order challenge for macroeconomists.

In this paper we show that a generalisation of the standard development accounting framework, which allows for cross-border linkages between countries through trade and trade imbalances, substantially increases the share of per-capita income differences which can be explained with data. The conventional aggregate production functions used in the development accounting literature implicitly assume that economies are closed, causing any income effect of international economic relations to be absorbed by the TFP residual. We find that the absence of international linkages from these models is an important omission. Using data from the year 2006 for a sample of 40 major economies, a standard development accounting exercise can explain approximately 25% of international income variation as a result of differences in measurable production factors. By contrast, our augmented framework explains at least 50% of the variation as a result of differences in measurable production factors *and* international linkages, and cuts the implied cross-country variation in unobserved TFP by more than one half.[1]

We set up a highly tractable model of value-added trade in the spirit of Eaton and Kortum (2002), which allows us to derive an intuitive expression for countries' incomes in the presence of international linkages. In the model, a country's real GDP not only depends on its own endowments of production factors and productivity, but also on its factor cost relative to the factor costs of its import suppliers, the variation of which reflects – loosely – variation in the terms of trade. In turn, countries' relative factor costs are determined by their trade linkages, and the international distribution of factor endowments and expenditures. For given determinants of international linkages, an increase in foreign factor endowments reduces the relative cost of a country's imported goods. For given factor endowments, stronger demand from abroad for domestic value added raises a country's factor income. Both cause a rise in domestic real GDP. Finally, changes in the geographic distribution of aggregate expenditure levels through trade imbalances affect real GDPs, in a reflection of the "transfer effect" (Keynes, 1929; Ohlin, 1929).

To perform our updated development accounting exercise, we trace the patterns of countries' international trade in value added using data from the new World Input Output Database (WIOD) for 40 major economies in the year 2006. Imposing these in our model, together with information on countries' factor endowments and trade imbalances, we arrive at our new measures of the quantifiable components of countries' income differences. This measure significantly exceeds the traditional measure, based on an implicit closed-economy assumption, in our data sample.

Having established the quantitative relevance of international production linkages for explaining income differences, we highlight the role of trade imbalances and trade linkages in determining real income levels through a number of illustrative counterfactuals. We calibrate our model so as to match countries' incomes in 2006 perfectly for given data on factor endowments and international value-added linkages. Completely eliminating global imbalances reduces the real GDPs of deficit countries (by up to 2% in some cases), and raises the real incomes of surplus countries. Eliminating goods trade worldwide has even stronger implications: it reduces real GDP for all countries, with median losses amounting to 8% of GDP. We also report the results from external-adjustment and autarky scenarios for three large economies – China, the U.S. and Germany – in order to assess the influence of these countries on their key trading partners.

Our paper contributes to the literature on development accounting, popularised by the seminal work of Hall and Jones (1999). Caselli (2005, 2015) offers extensive

[1] The data required to perform our development accounting exercise is available for the period 1995-2011. We choose 2006 as the benchmark year for our study, but results are similar for other years from that period.

reviews of this literature, discussing methodologies and data sources in depth.[2] As described above, by focusing exclusively on countries' own production factors, most conventional development-accounting exercises ignore the potential effects of international linkages on the incomes of countries. Here, we show how a popular Ricardian model of international trade can be used to generalise traditional development-accounting frameworks for use in a setting of open economies.[3] Our model allows for country-pair-specific international linkages through which a country can utilise the value added generated in different countries in varying proportions in its own final production. We discipline it using novel data on countries' international input-output linkages from the WIOD.[4]

The exercise we perform is related with Feenstra et al. (2009, 2015). These papers emphasise that real PPP GDP evaluated at consumer prices – the traditional measure of real GDP in the development accounting literature – may depart from an open economy's productive potential by a measure which captures the price of the economy's output relative to the price of its representative consumption basket. They argue that development accounting ought to allow for differences in this "gap" across countries, and proceed to construct a measure of it based on available micro data on the unit values of countries' exports and imports.[5] We show that an alternative measure of the "gap" can be derived from macro trade data using a standard structural trade model, and that it plays a significant part in accounting for income differences between our sample countries. In this sense, our approach is complementary to Feenstra et al. (2009, 2015). However, since it does not rely on actual price data, instead obtaining the key relative prices as equilibrium objects in a structural model calibrated to match real-world value-added trade flows, it lends itself more readily to counterfactual experiments. We use this feature of our framework to ask how changes in trade costs and trade balances would affect prices and, hence, real

[2] See also Hsieh and Klenow (2010).

[3] Eaton and Kortum (2002) and Waugh (2010) use similar Ricardian models to analyse the effect of trade on countries' incomes. However, these papers ask a different question from ours. Their analyses explore the impact of counterfactual configurations of international trade costs on countries' incomes. As such, they are pre-occupied with quantifying the *gains from trade*, and their contribution to the distribution of incomes across countries. By contrast, we use our trade model to quantify differences in the *terms of trade* across countries, and to demonstrate that accounting for these differences allows us to explain a larger share of cross-country income variations without appealing to unobservable productivity differentials.

[4] Fadinger (2011) and Morrow and Trefler (2014) allow for international trade in estimating total factor productivity in different versions of the Heckscher-Ohlin-Vanek model, in which a country's factor content of trade with the rest of the world summarises all its international economic interactions. However, they do not offer a quantification of the contribution of international trade to the cross-country variation in per-capita incomes.

[5] Specifically, they follow Feenstra and Romalis (2014), who use data on unit values of traded goods to estimate quality-adjusted prices of countries' imports and exports within a monopolistic-competition framework. These prices are then used to calculate a PPP output price index from the traditional PPP consumer price index.

incomes among the countries in our sample.[6]

The main finding of our analysis − that international linkages can help explain income differences between countries − gels with an econometric literature in geography and economics which has studied the economic implications of regional trade behaviour and trading partners.[7] In comparison with these empirical studies, our development accounting approach enables us to compare quantitatively the importance of international trade relations for incomes relative to other "usual suspects" in development economics, such as factor endowments and productivity. Our headline results suggest that the portion of income differences between countries which can be explained as a result of international linkages is at least as large as the portion explained by domestic production factors among our sample of 40 major economies.

The use of data from input-output tables to tackle questions in development and macroeconomics has recently experienced a revival. There are now a number of studies which trace differences in countries' per-capita incomes to differences in their sectoral structure using national input-output tables.[8] Our use of *international* input-output tables places the present paper in a flourishing literature in the realm of international macroeconomics using this new data source to trace international trade in value-added.[9] Among others, Bems et al. (2011), Bems (2014), Johnson (2014) and Duval et al. (2015) have shown that international trade in value added is relevant for understanding short-run fluctuations in incomes and business cycle synchronisation across countries, and that calibrated macroeconomic models which incorporate empirical production linkages can improve our quantitative understanding of these phenomena. Our findings complement this literature by highlighting that value-added trade

[6]Only very few papers have tried to assess the impact of changes in trade balances on incomes in a multi-country setup: Dekle et al. (2007, 2008) produce extensions of the Eaton-Kortum model to asses the extent to which the elimination of the global imbalances of the early 21st century would affect real incomes, finding small effects. However, unlike ours, their calibration assumes that only manufacturing goods are traded and targets gross, not value-added, trade flows.

[7]In geography, empirical analyses of a region's market access through measures of "market potential" have a long tradition reaching back to Harris (1954). In economics, numerous empirical studies have attempted to identify the causal relationship between trade and incomes at the regional and national levels. Famously, Frankel and Romer (1999) use geographic variables to construct an instrument for countries' trade, showing that a percentage-point increase in a country's openness raises its real income by 1%. Redding and Venables (2004) also document that the geography of access to markets and sources of supply is a key predictor of per-capita incomes across countries.

[8]This research agenda was initiated by Jones (2011), who shows that intermediate-input linkages amplify the effects of distortions in the allocation of resources, causing differences in measurements of aggregate TFP at the country level. Fadinger et al. (2015) provide evidence that part of the income differences between rich and poor countries can be attributed to systematic differences in the structure of their input-output matrices. Grobovšek (2015) employs a closed-economy development accounting framework and highlights that low per-capita incomes appear to be related to low levels of productivity in intermediate-input production.

[9]Kose and Yi (2001) and Yi (2003, 2010) were among the first to realise that distinguishing between international trade in "gross" or "value-added" terms is important for analysing aggregate phenomena such as the growth of world trade and the international synchronisation of business cycles.

through international-production linkages also has a role to play in explaining differences in the *level* of incomes across countries.

The remainder of this paper is structured as follows. Section 2 presents the theoretical model that serves as the basis for our open-economy development accounting exercise. Section 3 describes our data sources. Section 4 details the main results of our analysis. Section 5 describes and carries out our counterfactual experiments. Section 6 offers a brief summary and concluding remarks.

2 Model

2.1 Preferences, Technologies and Market Structure

There are many countries, denoted by $n = 1, ..., N$, trading in a continuum of goods, $i \in [0, 1]$. The representative consumer in n assembles goods in amounts $c_n(i)$ to maximise aggregate consumption,

$$C_n = A_n \left[\int_0^1 c_n(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where $\sigma \geq 0$ and A_n is a country-specific productivity term.[10] Countries receive income from their endowments of two production factors − physical capital, K_n, and labour, L_n − as well as from possible net transfers from abroad, T_n. Hence, the representative agent in n maximises (1) subject to

$$\int_0^1 p_n(i)\, c_n(i) di \leq r_n K_n + w_n L_n + T_n, , \tag{2}$$

where $p_n(i)$ is the price of good i in n, r_n and w_n respectively denote the returns to capital and labor, and $\sum_n T_n = 0$.[11]

Country n' can produce goods for n using a country-pair-good-specific production technology,

$$q_{n'n}(i) = Z_{n'n}(i)\, K_{n'n}(i)^{\alpha} \left[h_{n'} L_{n'n}(i) \right]^{1-\alpha}, \tag{3}$$

where $K_{n'n}(i)$ and $L_{n'n}(i)$ represent capital and labour used in n' to produce good i for country n; $h_{n'}$ captures labour productivity in country n'; and $\alpha \in (0, 1)$. The shifter $Z_{n'n}(i)$ describes the efficiency of country n' in producing good i for n. It is the realisation of a random variable $Z_{n'n}$, drawn independently for each i, from the

[10] A_n will play the role of the traditional TFP residual in development accounting.

[11] Following Dornbusch et al. (1977), we use exogenous income transfers to introduce the possibility of trade imbalances in a static model.

country-pair-specific Fréchet distribution

$$F_{n'n}(Z) = Pr(Z_{n'n} \leq Z) = e^{-\gamma_{n'n} Z^{-\theta}}, \tag{4}$$

where $\gamma_{n'n} \geq 0$, $\sum_{n'} \gamma_{n'n} = 1$ and $\theta > 0$. By the law of large numbers, $F_{n'n}(Z)$ is also the fraction of goods in country n for which country-n' efficiency is below Z.[12]

Goods and factor markets are perfectly competitive. We assume that goods are freely tradable between countries. By contrast, production factors can move freely between activities within countries, but cannot move across borders.

The model outlined in this section resembles the Eaton-Kortum model (Eaton and Kortum, 2002) – but departs from it in two important respects. First, equations (1) and (3) imply that countries in our model trade directly in value added: a purchase of goods by country n from country n' implies the use of country-n' factor services of equal value. By contrast, Eaton and Kortum (2002) assume that countries use their own factors as well as (imported) intermediates to produce goods, causing the value of gross imports of by country n from country n' to exceed the country-n' value added embodied in those imports.

Second, given equation (4), the volumes and patterns of value-added trade in our model will be governed by the set of pair-specific technology parameters $\{\gamma_{n'n}\}_{n',n}$. In Eaton and Kortum (2002), the location parameter of the Fréchet distribution is instead only country-specific, and bilateral trade patterns are governed by the combination of country-specific location parameters with country-pair-specific trade costs.

In the appendix, we show that the model presented here can be interpreted as a short-cut representation of a more general model in the spirit of Eaton and Kortum (2002). Although that model has a richer input-output structure and allows for trade costs explicitly, it implies value-added trade flows governed by parameters $\{\gamma_{n'n}\}_{n',n}$ and θ as in the short-cut model, and expressions for countries real incomes as derived below. In that model, the parameters $\{\gamma_{n'n}\}_{n',n}$ capture a combination of technology and trade barriers.[13] For the purpose of our empirical development accounting exercise, it is immaterial whether the value-added trade flows observed in the data arise from the microfoundations of the simple model described above, or the richer model sketched in the appendix.

[12] The country-pair-specific technology parameter $\gamma_{n'n}$ governs the location of the distribution from which productivities are drawn. A bigger $\gamma_{n'n}$ implies that a higher-productivity draw for any good i produced by n' for n is more likely. The parameter θ, common across countries by assumption, determines the amount of variation within the distribution. A smaller θ implies more variability.

[13] However, the relationship between trade costs and the determinants of value-added trade flows, $\{\gamma_{n'n}\}_{n',n}$, is rather nuanced: trade barriers "tax" gross – not value-added – trade. Therefore, bilateral trade in value added will generally depend not only on the trade costs between the country pair in question, but on bilateral trade costs between *all* country pairs.

2.2 Equilibrium

We define country-n factor costs in equilibrium as

$$f_n \equiv \frac{1}{h_n^{1-\alpha}} \left(\frac{r_n}{\alpha}\right)^{\alpha} \left(\frac{w_n}{1-\alpha}\right)^{1-\alpha}. \tag{5}$$

The price to country n of sourcing good i from country n' is

$$p_{n'n}(i) = \frac{f_{n'}}{Z_{n'n}(i)}. \tag{6}$$

In equilibrium consumers in n will pay price $p_n(i)$ for good i which is such that $p_n(i) = \min\{p_{n'n}(i); n' = 1, ..., N\}$. Following Eaton and Kortum (2002), it is straightforward to show that this implies

$$v_{n'n} = \frac{\gamma_{n'n} f_{n'}^{-\theta}}{\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta}}, \tag{7}$$

where $v_{n'n}$ is the share of value added from country n' in final consumption by the representative consumer in country n; and

$$P_n \equiv \frac{1}{A_n} \left[\int_0^1 p_n(i)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}} = \frac{1}{A_n} E\left[p_n(i)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \frac{\xi}{A_n} \left(\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta}\right)^{-\frac{1}{\theta}}, \tag{8}$$

where P_n is the cost of one unit of final consumption in country n, and ξ is a constant.[14] Market clearing in international goods and domestic factor markets implies

$$r_n K_n + w_n L_n = f_n K_n^{\alpha} H_n^{1-\alpha} = \sum_{n' \in N} v_{nn'} \left(f_{n'} K_{n'}^{\alpha} H_{n'}^{1-\alpha} + T_{n'}\right), \tag{9}$$

where $H_n \equiv h_n L_n$ denotes productivity-adjusted labour, or "human capital". A set of equilibrium factor costs $\{f_n\}_n$ satisfies (7) and (9) for given parameters α, θ, $\{\gamma_{n'n}\}_{n',n}$, given stocks of physical and human capital, and given international transfers. By Walras' Law, (7) and (9) uniquely determine factor costs relative to some arbitrarily chosen numeraire.

We define Y_n as the real GDP of country n. Then

$$Y_n \equiv \frac{r_n K_n + w_n L_n}{P_n} = \frac{f_n A_n K_n^{\alpha} H_n^{1-\alpha}}{\xi \left(\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta}\right)^{-\frac{1}{\theta}}}. \tag{10}$$

The real GDP of country n is determined by the familiar Cobb-Douglas functional form over domestic physical and human capital, but corrected by the ratio of domestic

[14] Specifically, $\xi \equiv \left[\Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)\right]^{\frac{1}{1-\sigma}}$, where $\Gamma(\cdot)$ is the gamma function. Note that $\sigma < 1 + \theta$ is required for this to exist. See Eaton and Kortum (2002).

factor costs to consumer prices.

2.3 Relationship with the Development-Accounting Literature

Letting small caps denote variables in per-worker terms, e.g. $x_n \equiv X_n/L_n$, and taking logs, we can write (10) as

$$\ln y_n = -\ln \xi + \ln k_n^{\alpha} h_n^{1-\alpha} + \frac{1}{\theta} \ln \left[\sum_{n'=1}^{N} \gamma_{n'n} \left(\frac{f_n}{f_{n'}} \right)^{\theta} \right] + \ln A_n. \tag{11}$$

Equation (11) shows that the log real income per worker of country n can be decomposed into four parts: i) a constant term, ii) a term depending on the domestic per-worker capital stock and labour productivity, iii) a "relative factor cost" term that captures other countries' influence through trade on the income of country n, and iv) a total factor productivity "residual". Notice that technology differences appear not only in the form of labor-augmenting productivity, h, and total factor productivity, A, but also in the form of parameters $\{\gamma_{n'n}\}_{n',n}$, which determine the access of country-n' value-added exports to country n.

In the special case $\gamma_{nn} = 1$, which implies that country n has no use for foreign goods, equation (11) reduces to

$$\ln y_n = -\ln \xi + \alpha \ln k_n + (1-\alpha) \ln h_n + \ln A_n. \tag{12}$$

This expression corresponds to the standard aggregate Cobb-Douglas production function which is widely used in macroeconomics (up to the value of a constant). The development accounting literature employs (12) to assess what part of income differences between countries can be explained by differences in quantifiable endowments of production factors – notably, per-worker capital stocks and labour productivities – and how much must be attributed to non-observable differences in "total factor productivity". The literature proceeds by obtaining direct measures of production factors, calibrating the parameter α, and treating TFP as a residual.

Equation (11) demonstrates that we can think of (12) as the special case of a more general model which allows for an arbitrary set of international value added linkages between countries. In the more general case, with $\gamma_{nn} < 1$, other countries' production factors and international transfers affect real GDP in country n via (7) and (9). For given technologies underpinning international value-added linkages – i.e. given $\{\gamma_{n'n}\}_{n',n}$ –, the size of the "relative factor cost" term depends positively on other countries' endowments of physical and human capital as these make foreign goods cheaper. It depends negatively on the country's own factor endowments, as their abundance leads to lower domestic factor prices and income. It also depends on the distribution of international transfers: large transfers to countries that absorb a lot of value-added from country n raise f_n, thus raising the consumption possibilities of country n.

Another implication of equation (11) is that there is a component of the "ignorance" TFP residual from earlier development accounting studies which may be attributed to the income effect of international value-added linkages. Using data on the empirical size and structure of such linkages, this component can be quantified directly, potentially allowing us to explain a larger share of income differences across countries as the result of observable country characteristics. We proceed to explore this in the following.

3 Data

3.1 Factor Endowments and Trade Balances

To perform our updated development accounting exercise we require data on countries' endowments of production factors, as used in earlier studies (such as Hall and Jones, 1999; Caselli, 2005, 2015), data on countries' trade balances ("transfers" in our model) and data on countries' international value-added linkages. The latter constitutes a novel feature of our analysis, and we discuss it in detail below.

Data on countries' factor endowments is constructed from two standard sources: the Penn World Tables (PWT, edition 9.0) and the latest edition of the educational attainment database by Barro and Lee (2013). We gauge the size of the capital stock in country n by cumulating PPP-adjusted annual investment data (I_{nt}) from PWT using the perpetual inventory method:

$$K_{nt} = I_{nt} + (1 - \delta)\, K_{nt-1}.$$

In line with Caselli (2005), we set $\delta = .06$. Following Feenstra et al. (2015), we impose that the initial capital stock in the first year in which investment data is available ("year 0") is given by $K_{n0} = 2.6 \times Y_{n0}$.

The stock of human capital in country n for any given year ($h_n L_n$) is calculated by multiplying the size of workforce (L_n), reported directly in PWT, with a "quality adjustment" (h_n) based on the average number of years of schooling in the part of country n's population aged 15 or above. The "quality adjustment" takes a piecewise linear form reflecting qualitative and quantitative evidence on the returns to education from Mincer regressions (for details, see Hall and Jones, 1999).[15]

[15] Barro and Lee (2013) report average years of schooling quinquennially for the period 1950-2010. Since average schooling received changes very slowly over time in all countries, values for years

[Insert Table 1 here]

With the exception of the choice of K_{n0}, the construction of factor endowments data follows Caselli (2005) exactly, and all methods used here are carefully described and justified therein.[16] Table 1 reports summary statistics of the final data on PPP-adjusted GDP per worker (y_n), also taken from the PWT, capital stock per worker (k_n) and human capital per worker (h_n) in the years 1996 and 2006 for the countries in our sample. The size of our country sample is limited to 40 economies (plus "rest of the world") by the coverage of the World Input Output Database (WIOD, see Timmer et al., 2015), our main source of data on international linkages.[17] We also use it to obtain information on countries' trade balances for the years 1996 and 2006.

It is worth noting that the results presented below are insensitive to reasonable variations in the methods used to construct factor-endowment data for our sample countries. In particular, the quantitative findings are almost identical if for reasonable changes in δ, different choices of K_{n0}, and across data from different editions of PWT.[18]

3.2 International Value-Added Linkages

3.2.1 Data Source and Construction

The WIOD contains annual global input-output tables, built from domestic input-output tables and international trade data, which covers 40 broad use categories $-$ 35 industries, and 5 final sectors (covering final consumption expenditure by households, by the public sector and for investment and inventory accumulation). A typical cell represents the current dollar value of expenditure by use category s in country n on use category s' in country n'. The WIOD covers 40 major economies and the "rest of the world", and reports tables for each year in the period 1995-2011.

For a given year, we use this information to derive the final use by country n of value added generated in each country n', corresponding to $v_{n'n}$ in Section 2. In doing so, we follow Johnson and Noguera (2012) and Timmer et al. (2013) whose accounting procedure is briefly outlined here.

Define $\mathbf{q}$ as an $(SN \times 1)$ vector which stacks the dollar values of output in each country-sector, and $\mathbf{e}$ as an $(SN \times 1)$ vector which stacks the dollar values of final expenditure on each country-sector. Then the well known input-output identity states that $\mathbf{q} = \mathbf{B}\mathbf{e}$, where $\mathbf{B}$ is an $(SN \times SN)$ matrix known as the "Leontief inverse"

between these quinquennial observations can reasonably be obtained by interpolation.

[16] For a justification of using $K_{n0} = 2.6 \times Y_{n0}$ as the initial value of capital for use in the perpetual inventory method, see Feenstra et al. (2015).

[17] Income and factor endowments for the "rest of the world" are constructed by aggregating the corresponding variables for all countries which report sufficient data in the PWT but do not belong to our sample of 40 economies.

[18] These findings are available from the authors upon request.

(Leontief, 1936) whose typical element gives the production value of category s' in country n' needed to produce one unit of final output in category s of country n.

Defining $\mathbf{R}$ as an $(SN \times SN)$ diagonal matrix whose typical diagonal element is the ratio of value added to output in sector s of country n, $\mathbf{RBe}$ is then an $(SN \times 1)$ vector which stacks the dollar values of value added generated in each country-sector. All information required to construct $\mathbf{q}$, $\mathbf{B}$, $\mathbf{e}$ and $\mathbf{R}$ can be read off the World Input Output tables, and we can now trace the use of value added generated by each country-sector to final demand in every country sector through appropriate decomposition of $\mathbf{RBe}$. In particular,

$$\mathbf{RBe} = \mathbf{RB}\begin{pmatrix} E_{11} \\ \vdots \\ \vdots \\ \vdots \\ 0 \end{pmatrix} + .. + \mathbf{RB}\begin{pmatrix} 0 \\ \vdots \\ E_{sn} \\ \vdots \\ 0 \end{pmatrix} + ... + \mathbf{RB}\begin{pmatrix} 0 \\ \vdots \\ \vdots \\ \vdots \\ E_{SN} \end{pmatrix},$$

where E_{sn} denotes total final expenditure on category s from country n. The summation component

$$\mathbf{RB}\begin{pmatrix} 0 \\ \vdots \\ E_{sn} \\ \vdots \\ 0 \end{pmatrix} = \begin{pmatrix} B_{11sn} \\ \vdots \\ B_{s'n'sn} \\ \vdots \\ B_{SNsn} \end{pmatrix}$$

now represents a $(SN \times 1)$ vector whose typical element reports the value added from category s' in country n' used in providing final use of category s from country n. It follows that $\sum_{s'} B_{s'n'sn}/E_{sn}$ represents the share of value added from country n' used in providing final output of category s from country n.

By summing over the expenditure of all 5 final sectors in country n on category s from n', we obtain the share of country-n expenditure on that category, denoted $E_{sn'n}/E_n$. The final use by country n of value added from country n' is then $v_{n'n} = \sum_s \sum_{n''} \left(\sum_{s'} B_{s'n'sn''}/E_{sn''}\right) \times (E_{sn''n}/E_n)$.[19] The matrix $\{v_{n'n}\}_{n',n}$ represents our measure of international linkages, and the only new piece of empirical data used in the updated development accounting exercise in Section 4. The next subsection highlights some properties of this data.

[19] Note that, unlike Johnson and Noguera (2012), we are not pre-occupied with the value-added content of exports. Instead, like Timmer et al. (2013), we trace countries' value added contributions to the output of different final goods. However, we take their analysis of the data one step further by then attributing these final-good outputs to final expenditure in different countries.

3.2.2 Data Description

Figure 1 offers a graphical overview of the matrix $\{v_{n'n}\}_{n',n}$, calculated for the year 2006. Each dot in the figure represents the share of value added from the vertical-axis country ("country 1") used in final expenditure of the horizontal-axis country ("country 2"), with the size of the dot indicating the magnitude of the share. The magnitude of the entries ranges from almost 0 to .9.

[Insert Figure 1 here]

Two features of the data are immediately apparent from Figure 1. First, even the smallest entry on the diagonal of the matrix (.54) is considerably larger than the largest off-diagonal element (.12), indicating that countries' own value added accounts for the large majority of their overall final use of value added. Second, there are a number of countries whose value added is used to a significant extent in the final expenditure of *all* other countries (resulting in "strong" horizontal lines in the figure). Those countries – notably, the United States, Japan, Germany and China – appear to be large in terms of the shares of world population and GDP. Although Figure 1 is based on data from the year 2006, the same stylised facts are observed in any year covered by the WIOD.

[Insert Figure 2 here]

In Figure 2, we investigate the stability over time of our matrix of international linkages, $\{v_{n'n}\}_{n',n}$. The left-hand panel plots the value of a particular off-diagonal entry in the matrix from the year 2006 against the value of the same off-diagonal entry from 1996. The right-hand panel does the same for on-diagonal entries. No change in a particular entry over time would place it on the forty-five degree line (shown as a dashed lined in both panels). As can be seen from the right-hand panel, the value of nearly all diagonal matrix entries has declined between 1996 and 2006, reflecting a growing integration of international value chains that has been well documented elsewhere.[20] The pattern emerging from the left-hand panel is less clear, showing both increases and decreases in the value-chain integration of individual country pairs. A common feature of both panels is that the magnitude of most changes in $\{v_{n'n}\}_{n',n}$ in the period 1996-2006 appears to have been small.

In Section 4, we will now combine our matrix of international linkages with the factor-endowment and trade-balance data described above in order to perform a development-accounting exercise which accounts for the presence of cross-border production chains.

[20]For example, see Hummels et al. (2001), Yi (2003) and Timmer et al. (2013).

4 Results

4.1 "Traditional" Development Accounting

Equation (11) provides a theory-based decomposition of real per-worker income in the presence of international value-added linkages. Defining $y_n^{ED} \equiv k_n^{\alpha} h_n^{1-\alpha}$ as the portion of income explained only by domestic production factors, we can re-write (11) as

$$\ln y_n = -\ln \xi + \ln y_n^{ED} + \frac{1}{\theta} \ln \left[\sum_{n'=1}^{N} \gamma_{n'n} \left(\frac{f_n}{f_{n'}} \right)^{\theta} \right] + \ln A_n. \tag{13}$$

Given the discussion in Section 2.3, note that y_n^{ED} also constitutes the portion of income which would be explained by traditional development accounting exercises that disregard the role of international linkages. We now calculate y_n^{ED} using per-worker capital stocks and labour productivity from the data described in Section 3.1, and setting the capital share α to the value $1/3$, in line with Caselli (2005) as well as much of the macroeconomics literature.

Define

$$\ln A_n^{ED} \equiv \frac{1}{\theta} \ln \left[\sum_{n'=1}^{N} \gamma_{n'n} \left(\frac{f_n}{f_{n'}} \right)^{\theta} \right] + \ln A_n \tag{14}$$

as the portion of per-worker GDP that would be attributed to TFP in a traditional development accounting framework. A simple variance decomposition yields

$$Var\left(\ln y_n\right) = Var\left(\ln y_n^{ED}\right) + Var\left(\ln A_n^{ED}\right) + 2Cov\left(\ln y_n^{ED}, \ln A_n^{ED}\right). \tag{15}$$

Caselli (2005) measures the "success" of his benchmark development accounting exercise by

$$success^{ED} \equiv \frac{Var\left(\ln y_n^{ED}\right)}{Var\left(\ln y_n\right)}, \tag{16}$$

i.e. by the share of cross-country variation in $\ln y_n$ which can be explained by observed domestic factors. An alternative, inverse measure of the share of income differences explained is

$$ignorance^{ED} \equiv \frac{Var\left(\ln A_n^{ED}\right)}{Var\left(\ln y_n\right)}, \tag{17}$$

i.e. the share of cross-country variation in $\ln y_n$ which must be attributed to variation in the "ignorance" TFP residual. If domestic factors could perfectly explain countries' incomes, the value of $success^{ED}$ would be 1 and the value of $ignorance^{ED}$ would be 0.[21] This highlights the potential importance of incorporating countries' international linkages formally in a development accounting framework: if value-added linkages *are*

[21] Note that, by the nature of variance decompositions, the constant $-\ln \xi$ is irrelevant for development accounting.

an important determinant of countries' incomes, traditional development accounting exercises would incorrectly attribute their effect to domestic total factor productivity, inflating *ignorance* at the expense of *success*.

The first column in the left-hand and right-hand panels of Table 2 replicate's Caselli's (2005) baseline development accounting exercise for our 40 economies using data from the years 1996 (left-hand panel) and 2006 (right-hand panel). As the table shows, the variance of countries' log per-worker incomes is significantly larger than the variance of $\ln y_n^{ED}$, resulting in values of *success* of around one quarter and *ignorance* of around one third in 1996. The values for 2006 are of similar magnitude. Caselli (2005) reports his finding for different country samples in the year 1996. Although none of these samples perfectly overlap with ours, the value of *success* from his "Europe" sample − which covers the largest share of countries contained in our group of 40 economies −is similar to ours at .23. The values of *success* reported here are thus not unusually low compared with earlier development accounting studies.

[Insert Table 2 here]

4.2 Development Accounting with International Linkages

4.2.1 Calibrating and Solving the Model

Our model introduces a range of new parameters − $\{\gamma_{n'n}\}_{n',n}$ and θ − relative to the standard development accounting framework (which only needs to calibrate a single parameter, α). We proceed by calibrating $\{\gamma_{n'n}\}_{n',n}$ so as to match countries' value-added linkages in the data, and presenting results for a range of values of θ. To build intuition, Section 4.2.2 reports results for the special case in which $\theta \to 0$ in detail. Section 4.2.3 reports results for a range of positive values of θ, and discusses plausible choices for this parameter. We find that, for any plausible value of θ, we obtain values of *success* and *ignorance* which improve significantly on the performance of the closed-economy development accounting framework.

For given factor costs and a given value of θ, we can choose $\{\gamma_{n'n}\}_{n',n}$ so that our model matches the matrix of observed value-added linkages $\{v_{n'n}\}_{n',n}$ perfectly using equation (7). These value-added linkages in turn imply a cross-country distribution of factor costs, $\{f_n\}_n$, from equation (9), independently of the value of θ. Choosing country-N factor costs as the numeraire,[22] we can write (9) in matrix form as

$$\begin{bmatrix} f_1 K_1^{\alpha} H_1^{1-\alpha} \\ \vdots \\ f_{N-1} K_{N-1}^{\alpha} H_{N-1}^{1-\alpha} \end{bmatrix} = \mathbf{V} \begin{bmatrix} f_1 K_1^{\alpha} H_1^{1-\alpha} + T_1 \\ \vdots \\ f_{N-1} K_{N-1}^{\alpha} H_{N-1}^{1-\alpha} + T_{N-1} \end{bmatrix} + \mathbf{v_{\cdot N}} \left(K_N^{\alpha} H_N^{1-\alpha} + T_N \right), \tag{18}$$

[22]Throughout, we use "Rest of the World" as our numeraire country.

where

$$\mathbf{V} \equiv \begin{bmatrix} v_{11} & \dots & v_{1,N-1} \\ \vdots & & \vdots \\ v_{N-1,1} & \dots & v_{N-1,N-1} \end{bmatrix} \quad \mathbf{v_{.N}} \equiv \begin{bmatrix} v_{1N} \\ \vdots \\ v_{N-1,N} \end{bmatrix}. \tag{19}$$

Using the fact that $T_N = -\sum_{n \neq N} T_n$, (18) implies

$$f_n = u_n \frac{K_N^{\alpha} H_N^{1-\alpha}}{K_n^{\alpha} H_n^{1-\alpha}}, \tag{20}$$

where u_n is the typical element of the vector

$$\begin{bmatrix} u_1 \\ \vdots \\ u_{N-1} \end{bmatrix} = (\mathbf{I} - \mathbf{V})^{-1} \left\{ (\mathbf{V} - \mathbf{v_{.N}} \mathbf{1}) \begin{bmatrix} t_1 \\ \vdots \\ t_{N-1} \end{bmatrix} + \mathbf{v_{.N}} \right\}, \tag{21}$$

and we define $\mathbf{1}$ as an $N-1$ vector of ones, t_n as country n's trade deficit as a share of numeraire-country GDP, and $u_N = 1$. Put in words, we can express f_n explicitly as a function of country-n factor endowments, country-N factor endowments, the matrix of empirically observed value-added linkages $\{v_{n'n}\}_{n',n}$, and the distribution of empirically observed trade imbalances, $\{t_n\}_n$.

Using $\{f_n\}_n$ thus derived, a value for θ, and the calibrated values of $\{\gamma_{n'n}\}_{n',n}$ to reconcile (7) with the data, we obtain an expression for the "relative factor cost" term in (11). Defining

$$y_n^{EL} \equiv \frac{f_n k_n^{\alpha} h_n^{1-\alpha}}{\xi \left(\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta} \right)^{-\frac{1}{\theta}}} \tag{22}$$

$$A_n^{EL} \equiv \frac{y_n}{y_n^{EL}}, \tag{23}$$

were are ready to calculate the values of *success* and *ignorance* in the presence of international value-added linkages, and for a given value of θ.

4.2.2 Special Case: Cobb-Douglas Linkages ($\theta \to 0$)

In the special case $\theta \to 0$, calibrating the parameters $\{\gamma_{n'n}\}_{n',n}$ to match value-added trade flows amounts to

$$v_{n'n} = \gamma_{n'n}. \tag{24}$$

A low θ implies a large amount of variation in productivity draws $Z_{n'n}$: even country pairs with low $\gamma_{n'n}$ are now likely to get high draws for $Z_{n'n}$. This leads each country n' to earn a share of country-n final expenditure proportional to the parameter $\gamma_{n'n}$.

It is straightforward to show that

$$\lim_{\theta \to 0} \ln y_n = -\ln \xi + \ln k_n^{\alpha} h_n^{1-\alpha} + \ln \left[\prod_{n'=1}^{N} \left(\frac{u_n}{u_{n'}} \frac{K_{n'}^{\alpha} H_{n'}^{1-\alpha}}{K_n^{\alpha} H_n^{1-\alpha}} \right)^{v_{n'n}} \right] + \ln A_n. \qquad (25)$$

The third term on the right-hand side of Equation (25) illustrates what underlies the trade-linkages term's contribution to per-capita income in our model. Country-n own factor abundance has a negative impact on its own income, as it depresses the price its production factors command. By contrast, the factor u_n has a positive effect on y_n, as it summarises "world demand" for country-n value added. The factor abundance of foreign countries affects country-n real income positively, as it reduces country-n consumer-price level, whereas the terms $u_{n'}$ have a negative effect: a larger demand for country-n' value added raises the factor cost of country n' and, hence, the consumer-price level of country n. Notice that the effect of each individual country n' on country-n price level is moderated by $v_{n'n}$, which determines the importance of each country in country-n final-consumption basket.

The second column in the left-hand and right-hand panels of Table 2 reports *success* and *ignorance* if we engage in development accounting using equation (25) to determine the relationship between incomes and production factors. We obtain values of *success* equal to .49 in 1996 and .50 in 2006. Thus, the incorporation of the "relative factor cost" term doubles the share of the of cross-country variation in incomes which our updated development accounting framework can explain. The value of *ignorance* is reduced to .14 in 1996, and .11 in 2006. Hence, our "relative factor cost term" reduces income variation attributed to unobserved TFP differences by more than half.

[Insert Figure 3 here]

Figure 3 offers a graphical representation of our findings. For the year 2006, it plots $\ln y_n$ against $\ln y_n^{ED}$ (left-hand panel) and against $\ln y_n^{EL}$ (right-hand panel). For domestic factors (domestic factors and relative factor costs) to explain the variation in log per-capita incomes perfectly, $\ln y_n$ would have to equal $\ln y_n^{ED}$ ($\ln y_n^{EL}$) up to the value of a constant term – that is, the observations in the left-hand (right-hand) panel should be aligned along a line with an arbitrary intercept, and a slope of one. Clearly, this is not the case in either panel. However, the red line of best fit between $\ln y_n$ and $\ln y_n^{EL}$ has a slope of 1.3, while the line of best fit between $\ln y_n$ and $\ln y_n^{ED}$ has a slope of 1.9. The difference in slopes is statistically significant at the 1% level, implying that our model with linkages comes significantly closer to explaining cross country income variations as a result of observables than the traditional closed-economy framework. The figure also verifies that this result is not driven by a few "outlier" countries.

[Insert Figure 4 here]

To illustrate why the incorporation of the "relative factor cost" term improves results compared to conventional development accounting, we split the term into two components for the year 2006 − the log factor cost of each country, $\ln f_n$, and the log weighted factor costs of its value-added sources, $\left(\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta}\right)^{-\frac{1}{\theta}}$ − and plot both against countries' observed real PPP-adjusted GDP in that year. The left-hand panel of Figure 4 displays the correlation of log model-implied factor costs with log per-worker real GDP in the data, the right-hand panel the correlation of log weighted source factor costs with log per-worker real GDP of that country.[23] The left-hand panel demonstrates that the relative success of our open-economy development accounting exercise is owed to the strong positive correlation between model-implied country factor costs and per-worker real GDPs. Since countries rely largely but not exclusively on their own value added, the relationship between model-implied source factor costs (which "work against" own factor costs) and per-worker GDPs is weaker, as seen in the right-hand panel. As a result, the net effect of introducing both terms in the development accounting framework is to raise the correlation of the right-hand-side observables with actual log per-worker GDPs, boosting *success* and reducing *ignorance*.

[Insert Figure 5 here]

Figure 5 shows that accounting for international value-added linkages in the calculation of country's productivity levels causes us to revise downward our assessment of TFP for some countries, and upwards for others, so that TFP levels become more similar overall. High model-implied factor costs (as in the cases of Luxembourg, Ireland and Denmark) are associated with downward revisions of TFP, while low model-implied factor costs (as in the cases of Cyprus, Malta and Bulgaria) are associated with upward revisions. This is intuitive: our framework attributes part of the relatively high per-worker GDP in Luxembourg to high factor costs, and part of the relatively low per-worker GDP in Bulgaria to relatively low factor costs. Without the "relative factor cost" term, a closed-economy development accounting exercise would attribute these income differences to differences in TFP. Consequently, it would overstate Luxembourg's TFP and understate Bulgaria's.

4.2.3 General Case ($\theta > 0$)

The Cobb-Douglas special case explored above is illustrative but highly stylised: it suggests that the patterns of international value-added linkages are explained entirely by technologies, and unresponsive to changes in the relative cost of goods sourced from different origin countries. Based on the evidence presented in Figure 1, this may

[23] Note that a country's consumer price index is distinct from the index of weighted source factor costs, as it depends both on source factor costs *and* the country's aggregate productivity, A_n.

not do justice to some of the determinants of international linkages: in the figure, countries with large endowments of physical and human capital (e.g. the U.S.) ship more value added to all foreign destinations than smaller countries. Once we allow for the possibility that θ may be strictly positive, our model would predict that such countries ship more goods abroad for given $\{\gamma_{n'n}\}_{n',n}$, as their factor costs would be relatively low. Hence, permitting $\theta > 0$ allows us to capture a portion of the patterns in Figure 1 without relying on exogenous differences in $\{\gamma_{n'n}\}_{n',n}$.

While a strictly positive θ seems plausible, the appropriate interpretation of the parameter − and, hence, the correct choice of parameter value − is made difficult by the highly stylised nature of the model presented in Section 2. However, in the appendix we show that our benchmark model can be thought of as a short-cut representation of a standard Eaton-Kortum model, in which θ represents the elasticity of (gross) trade flows with respect to trade costs. Several studies (including Eaton and Kortum, 2002) have attempted to estimate θ using data on bilateral trade flows and goods prices, obtaining values of θ around 4 (see Simonovska and Waugh, 2014). We thus adopt $\theta = 4$ as our baseline parameter calibration. At the same time, in Figure 6 we present results for a range of θ between 0 and 8, using 2006 data, to illustrate how the choice of θ affects our findings.

[Insert Figure 6 here]

The left-hand panel plots values of *success*, and the right-hand panel values of *ignorance*, against θ (dashed lines provide the reference values from the standard development accounting framework). As can be seen from the figure, over a plausible range of θ, the Cobb-Douglas special case turns out to present a conservative picture of the relative success of our development accounting exercise with value-added linkages: higher values of θ yield higher values of *success* and, up to a point, lower values of *ignorance*. Beyond θ-values of 2, *success* exceeds 1 − implying that our framework predicts *more* variation in incomes that observed in the data. At this point, variation in TPF once again becomes necessary to explain why some countries are *not* as rich relative to others as our accounting exercise would suggest, which raises *ignorance*.

[Insert Figure 7 here]

Figure 7 provides an intuition for this finding. It contrasts the income correlations of model-implied country factor costs and the country's weighted source factor costs for the case $\theta \to 0$, already seen in Figure 4, with the case $\theta \to \infty$. As noted in Section 4.2.1, given data on international value-added linkages, model-implied factor costs can be calculated independently of the value of θ. For this reason, the left-hand panel of Figure 7 is identical in both cases. Yet this is not true for source factor costs: as $\theta \to \infty$, all countries' source factor-cost indices converge to the maximum global factor cost.[24] As this reduces the cross-country variation in the denominator of the "relative factor cost" term (which "works against" the positive correlation between the numerator and real per-worker GDPs), it increases the overall correlation of that term with actual incomes, thereby boosting the ability of our framework to explain the cross-country variation in incomes.

[Insert Table 3 here]

Table 3 reports values of *success* and *ignorance* for different values of θ. The case $\theta = 1.8$ results in the smallest value of *ignorance*, i.e. the least reliance on TFP differences in explaining income variation in the data (the value of *success* is .94 in this case). The case $\theta = 4$ corresponds to our preferred calibration of the parameter. The Cobb-Douglas special case ($\theta \to 0$) and our preferred calibration ($\theta = 4$) yield as similar reduction in the reliance on TFP differences in explaining cross-country income variation compared with closed-economy development accounting, with any value of θ between these cases resulting in even less *ignorance*. Therefore, our conclusion from Section 4.2.2 remains unaltered: accounting for relative factor costs among open economies reduces income variation attributed to unobserved TFP differences by more than half.

In the next section, we explore the impact on incomes and consumption of a number of counterfactual changes in the international environment, imposing our preferred calibration, $\theta = 4$.

5 Counterfactuals

5.1 Calibration

Having shown that a large share of the variation in GDP per worker across countries can be explained with a model which allows for international influences on the relationship between domestic production factors and incomes, it seems natural to ask how barriers to international transactions would affect incomes across countries. In the following, we calibrate our model to data from the year 2006. We then proceed to consider two types of scenarios: i) barriers to international transfers only, which force balanced trade on a country or a group of countries; and ii) barriers to international transfers *and* prohibitive trade costs, which also make it impossible for a country or a group of countries to trade goods with the rest of the world. We will refer to the latter scenario as autarky for the country or countries affected.

[24]For given $\{\gamma_{n'n}\}_{n',n}$, a rise in θ would cause countries to source relatively more value added from locations with *lower* factor costs. This implies that, in order for our calibration to match the observed $\{v_{n'n}\}_{n',n}$ as θ increases, $\gamma_{n'n}$ needs to rise disproportionally for n' with relative high factors costs. In the limit, this implies that $\gamma_{n*n} \to 1$ for all n, where $n^* \in \arg_{n\in N} \max \{f_1, ..., f_N\}$.

[Insert Table 4 here]

We choose $\alpha = 1/3$, $\theta = 4$ (see the discussion in Section 4.2.3), and calibrate $\{\gamma_{n'n}\}_{n',n}$ using empirical 2006 value-added trade linkages as described in Section 4.2.1. Table 4 reports summary statistics for the resulting set of technology parameters. We then attribute the residual part of income not explained by 2006 factor endowments and relative factor costs to aggregate TFP differences, $\{A_n\}_n$.

5.2 Global Scenarios

5.2.1 Balanced Trade

We first consider the impact on per-capita real GDPs if trade imbalances were eliminated worldwide. The intuition of the "transfer effect" tells us that countries with trade deficits are likely to suffer losses in such a scenario, whereas trade-surplus countries should experience increases in income. The logic for this result is well known in international economics: in the presence of home-biased consumption patterns (here, high values of v_{nn}), trade imbalances raise real GDP in favour of deficit countries, as more expenditure is allocated to their goods, raising the relative price of their exports. By the same token, the terms of trade of net exporters deteriorate. If trade imbalances are corrected, the reversal of the "transfer effect" should result in a rise in the real GDP of surplus countries, and a fall in the real GDP of deficit countries.

[Insert Figure 8 here]

The left-hand panel of Figure 8 reports the impact on real GDPS from imposing balanced trade $-$ $t_n = 0$ for all n $-$ in our model. The changes range from -2.3% (Cyprus) to $+2.0\%$ (Luxembourg). Not surprisingly, these correlate strongly and positively with countries' trade balances as a share of their GDP. Although in our multi-country setting a move to balance in a surplus country n could, in principle, *improve* the terms of trade of a closely linked (here, high $v_{n'n}$) deficit country n', counteracting or even overturning the effect of balanced trade on the GDP of n', such effects appear to be of second order in practice.

The right-hand panel of Figure 8 reports the effect of the change on real consumption levels. Although the latter represent the appropriate measure of welfare in our model, the figures need to be interpreted with care: the trade balances which account for the difference between real GDP and real consumption are treated as exogenous transfers in our static framework. A more robust welfare analysis would need to endogenise them as part of a fully dynamic model. Doing so is beyond the scope of the present paper. We thus report the consumption figures for completeness, but focus on real GDP changes in the discussion below.

5.2.2 Autarky

So far, we have assumed that goods can be traded between countries at no cost. In addition to eliminating trade balances, we now also impose that the cost of trading goods between countries is prohibitive. The resulting changes in real GDPs are displayed in the left-hand panel of Figure 9. Unlike the adjustment to balanced trade, a move to autarky has a negative and economically significant effect on the GDPs of all countries, ranging from -15.6% (Malta) to -2.8% (Japan).

[Insert Figure 9 here]

Since our model permits a simple gravity representation of value-added trade flows, the GDP loss from autarky can be calculated using the formula of Arkolakis et al. (2012): $\ln\left(Y_n^{Autarky}/Y_n\right) = \frac{1}{\theta}\ln v_{nn}$. Therefore, the average magnitude of the losses shown in the left-hand panel of Figure 9 hinges crucially on the choice of θ, while their distribution reflects differences in countries' observed use of domestic value added.

5.3 Regional Scenarios

We now subject a selected group of "large" countries to the same experiments we performed for the world above. First, we impose balanced trade in the country in question. We do so by assuming that the country's trade surplus/deficit is absorbed by all other countries in proportion to their share of rest-of-the-world GDP. Formally, if we impose $t_n = 0$,

$$\triangle t_{n'} = -t_n \frac{Y_{n'}}{\sum_{n'\neq n} Y_n} \quad \forall\, n' \neq n. \tag{26}$$

Second, we impose complete autarky on the country, balancing its trade and setting prohibitive costs of trading between the country in question and the rest of the world. This allows us to demonstrate how country-specific shocks to trade balances and trade costs might be transmitted to other regions of the world.

5.3.1 China

The left-hand panel of Figure 10 reports real GDP changes resulting from external adjustment in China. The most substantial effect of this experiment is a Chinese income increase, in line with the "transfer effect". Perhaps more interestingly, Taiwan also experiences a (smaller) increase in real GDP. The relatively high share of value added from Taiwan absorbed in China implies that a repatriation of Chinese consumption benefits Taiwanese factor income. All other countries suffer GDP losses from ending China's transfer to the rest of the world. Notably, however, these losses are small – not exceeding a fifth of a percentage point for any country – and fairly evenly distributed.

[Insert Figure 10 here]
[Insert Figure 11 here]

The rest-of-the-world losses from complete Chinese autarky (shown in the left-hand panel of Figure 11) are significantly larger. Yet in this scenario, China itself and Taiwan are the biggest losers, with Chinese income losses from autarky of 5.4%.

5.3.2 United States

The left-hand panels of Figures 12 and 13 display the results of the balanced-trade and autarky counterfactuals for the United States. Figure 12 suggests that the income effects of U.S. external adjustment would be small everywhere quantitatively.[25] Qualitatively, we observe that – like U.S. GDP – the GDP of the U.S.'s closest trading partner, Canada, would be adversely affected by U.S. adjustment. Indeed, Figure 13 suggests the combined loss of U.S. demand and value-added inputs as a result of complete U.S. autarky would have a larger adverse effect on Canada than on the U.S. itself.

[Insert Figure 12 here]
[Insert Figure 13 here]

5.3.3 Germany

The left-hand panels of Figures 14 and 15 display the results of the balanced-trade and autarky counterfactuals for Germany. Unsurprisingly, Germany is the biggest loser from a counterfactual move to autarky, with a number of neighbouring EU countries also suffering significant real GDP losses. The quantitative effects of eliminating Germany's trade surplus are small outside of Germany. Notably, however, some neighbouring countries (Czech Republic, the Netherlands) would benefit more from such an adjustment than the 2006 deficit countries Italy, Greece and Spain.

[Insert Figure 14 here]
[Insert Figure 15 here]

6 Conclusion

Allowing for international trade linkages in an otherwise standard development accounting framework enables us to paint a more complete picture of the sources of

[25] Dekle et al. (2008) also explore the potential economic effects of a reduction in the U.S. trade deficit on American income and wages. Their trade model, just as ours, is based on Eaton and Kortum (2002). Unlike ours, it allows for a richer sectoral structure, and an extensive and an intensive margin of international trade. However, they find similarly small effects on U.S. real GDP from external adjustment (up to a 2% decline in their least favourable calibration).

international income differences. We have shown that this generalisation is quantitatively significant: it at least doubles the share of variation in income levels which can be explained with measurable aggregates. Our exercise unpacks part of the uncomfortably large black box of "residual" TFP differences between countries, which constitutes a key finding of earlier development accounting studies under the implicit assumption that countries are autarkic. It shows that international linkages have an important role to play in explaining why some countries are richer than others. In the model that forms the basis for our analysis, a country's income depends not only on its own endowments of production factors and productivities, but also on those of all other countries and the international distribution of aggregate expenditures. The quantitative effects of these open-economy forces vary by country, depending on the nations with which a country enjoys strong trade linkages.

The existence of such linkages means that shocks in one economy may affect incomes elsewhere. To illustrate the implications of this transmission in the face of changes in the international environment, we present the results of some evocative counterfactual experiments. Our model allows us to explore the global impact of shifts in aggregate expenditure, via changes in trade balances, and of shocks to trade costs. Simulating external adjustment for all countries simultaneously, and for selected larger economies, we show that the "transfer effect" may be economically significance in the light of contemporary value-added linkages. Under reasonable calibrations of our model, we also find that the gains from international integration are large, with autarky reducing real income by 8% for the median country in our sample.

A skeptical reader might observe that we reduce the need for aggregate-TFP variation in explaining international income differences by introducing yet another layer of technology: the patterns of technological comparative advantage which we assume underpin observed value-added linkages. Yet the technological differences between countries on which our framework relies differ from aggregate TFP in conventional development accounting exercises in an important respect: they can be disciplined with international trade data. Moreover, they help us provide a clearer interpretation of perceived macro-level technology differences in an integrated world: our paper highlights that these may arise, in part, due to factor cost differences resulting from countries' technological advantages at the level of goods or industries. If we accept the quantitative relevance of this source of income variation across countries, future endeavours to understand international income differences ought to shift their attention towards the origins of comparative advantage at that level.

		1996				2006			
		y_n (2011 I\$)	k_n (2011 I\$)	h_n	t_n	y_n (2011 I\$)	k_n (2011 I\$)	h_n	t_n
Main Sample	Mean	48,122	145,399	2.8	.001	61,032	172,575	3.0	-.000
	St. Dev.	23,965	78,935	0.4	.003	26,898	88,545	0.4	.010
	Min.	4,525	8,325	1.8	-.011	7,034	13,633	2.0	-.019
	Max.	102,302	304,323	3.5	.010	120,815	366,606	3.6	.051
	Obs.	40	40	40	40	40	40	40	40
RoW		14,492	36,900	2.0	.043	18,701	39,745	2.2	.012

Table 1: Per-capita GDPs and factor endowments, summary statistics

	D	L ($\theta \to 0$)
$Var(\ln y_n)$	.501	.501
$Var\left(\ln y_n^{E\cdot}\right)$	.130	.244
$Var\left(\ln A_n^{E\cdot}\right)$	.162	.070
success	.26	.49
ignorance	.32	.14

1996

	D	L ($\theta \to 0$)
$Var(\ln y_n)$	.401	.401
$Var\left(\ln y_n^{E\cdot}\right)$	.101	.200
$Var\left(\ln A_n^{E\cdot}\right)$	.113	.046
success	.25	.50
ignorance	.28	.11

2006

Table 2: Development accounting – without and with value-added linkages

	D	L ($\theta \to 0$)	L ($\theta = 1.8$)	L ($\theta = 4.0$)
$Var(\ln y_n)$	.401	.401	.401	.401
$Var\left(\ln y_n^{E\cdot}\right)$	.101	.200	.375	.614
$Var\left(\ln A_n^{E\cdot}\right)$	.113	.046	.014	.041
success	.25	.50	.94	1.53
ignorance	.28	.11	.03	.10

2006

Table 3: Development accounting – different values of θ

		2006			
		$\gamma_{n'n}$ $(n' \neq n)$	γ_{nn}	θ 4	α 1/3
$n \in$ Main Sample	Mean	.014	.432		
	St. Dev.	.040	.363		
	Min.	.000	.001		
	Max.	.625	.969		
	Obs.	1,600	40		
$n =$ RoW	Mean	.025	.016		
	St. Dev.	.068	0		
	Min.	.000	.016		
	Max.	.417	.016		
	Obs.	40	1		

Table 4: Parameter calibration for 2006 counterfactuals

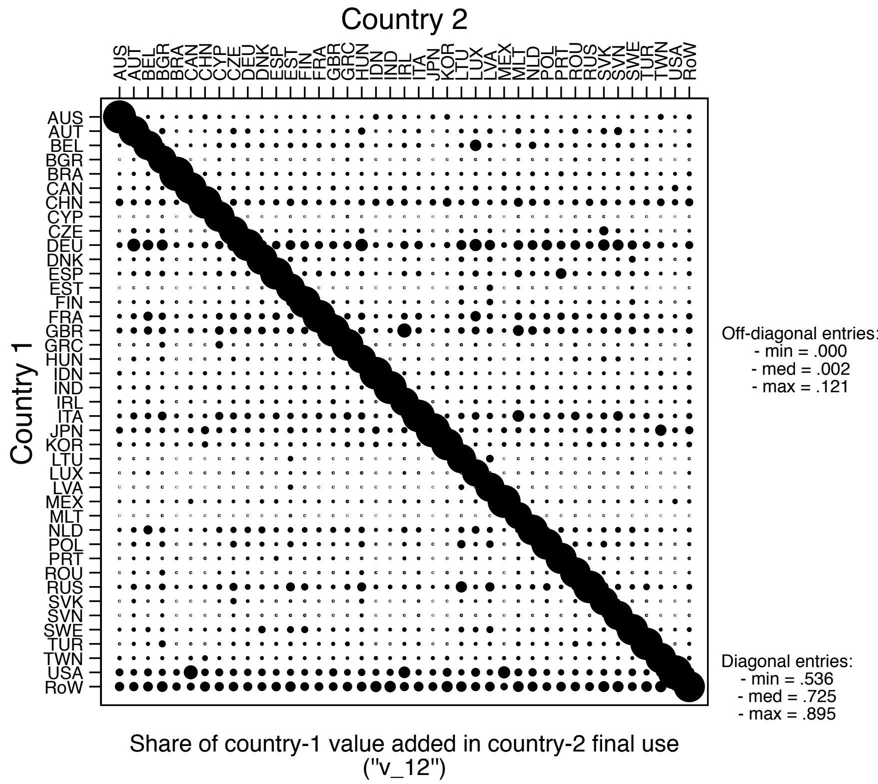

Figure 1: Matrix of international value-added linkages

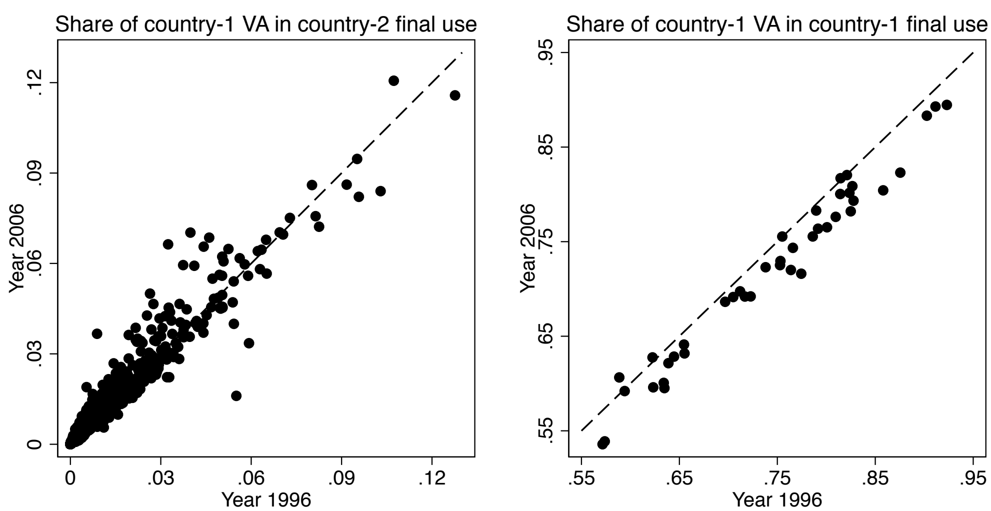

Figure 2: Change in value-added linkages over time

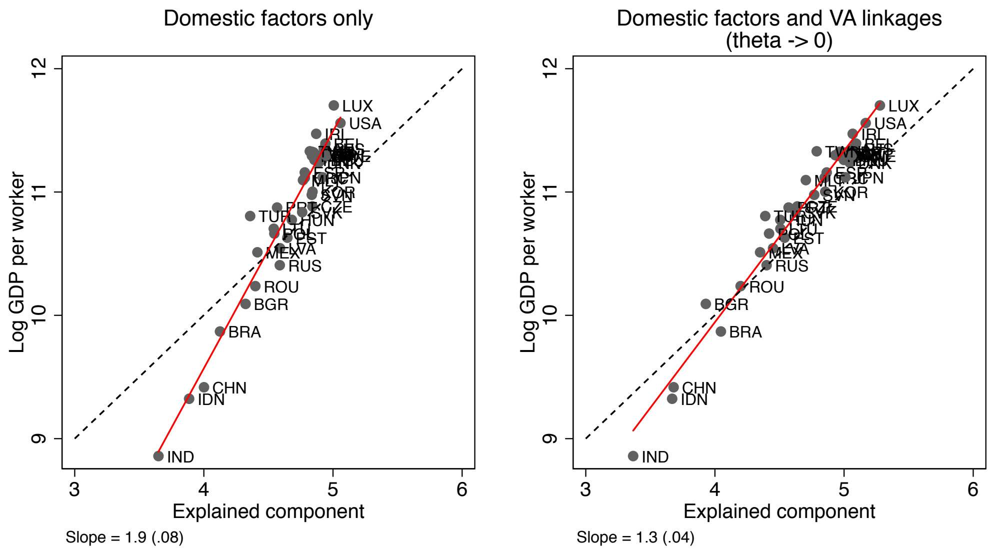

Figure 3: Explained component of log per-worker GDP

– without and with value-added linkages

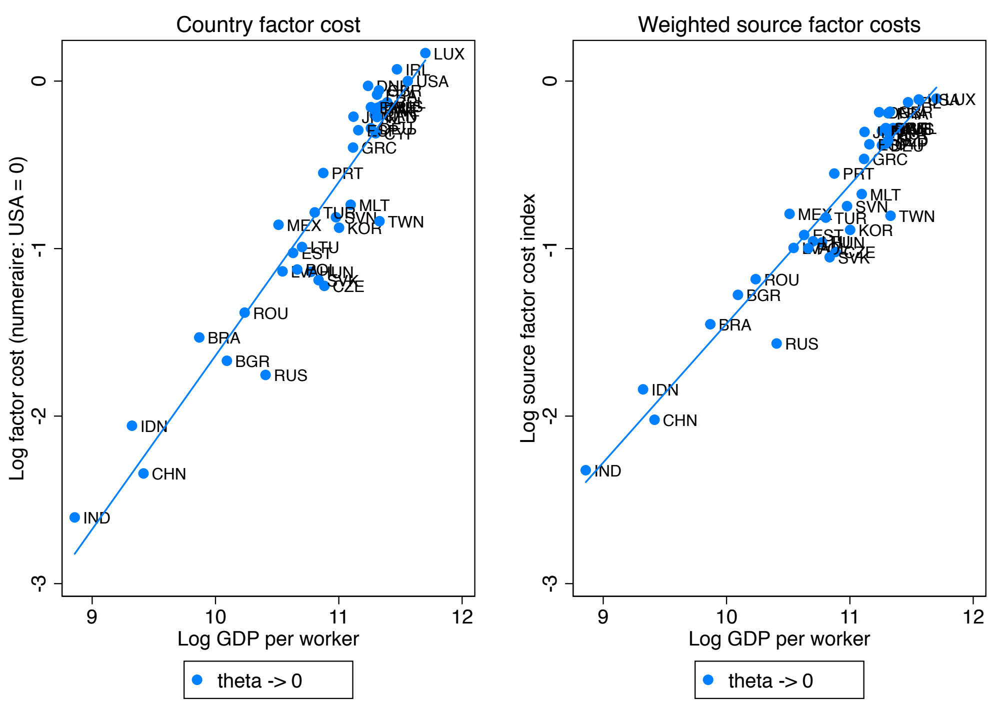

Figure 4: Correlation of model-implied home-country and weighted source factor costs with actual per-worker GDP

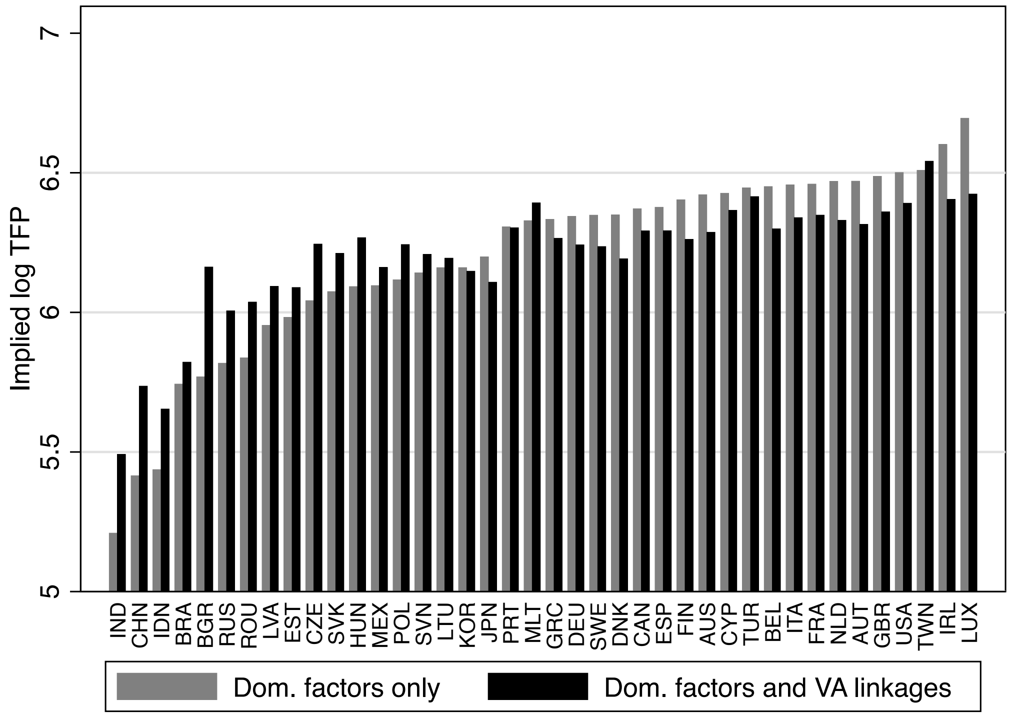

Figure 5: Implications of international value-added linkages for measured TFP ($\theta \to 0$)

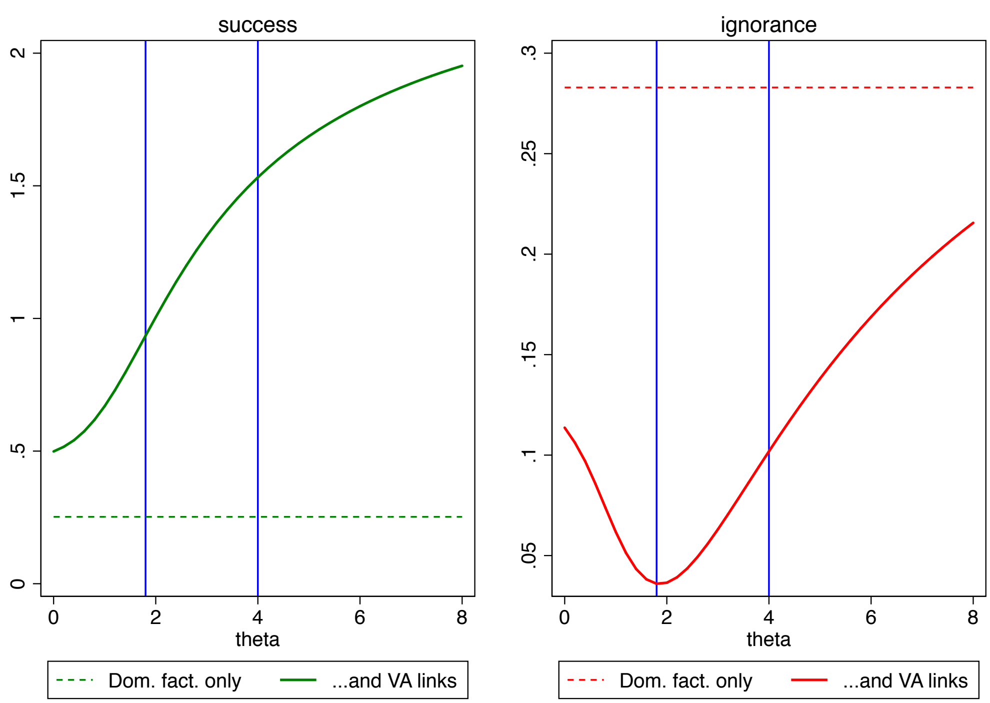

Figure 6: *success* and *ignorance* for different values of θ

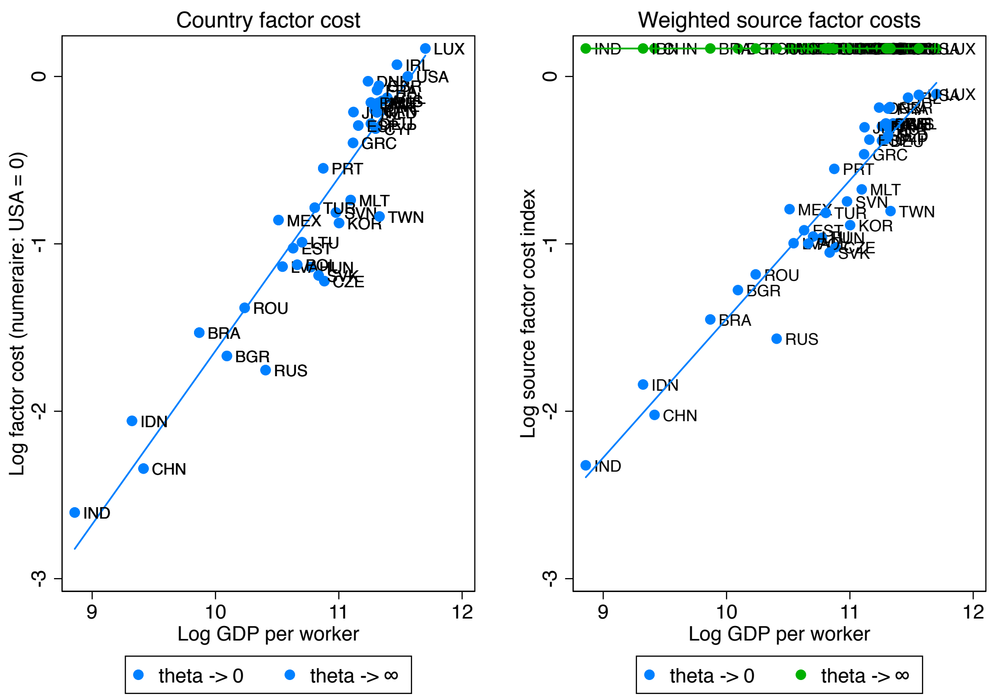

Figure 7: Correlation of model-implied home-country and weighted source factor costs with actual per-worker GDP (for $\theta \to 0$ and $\theta \to \infty$)

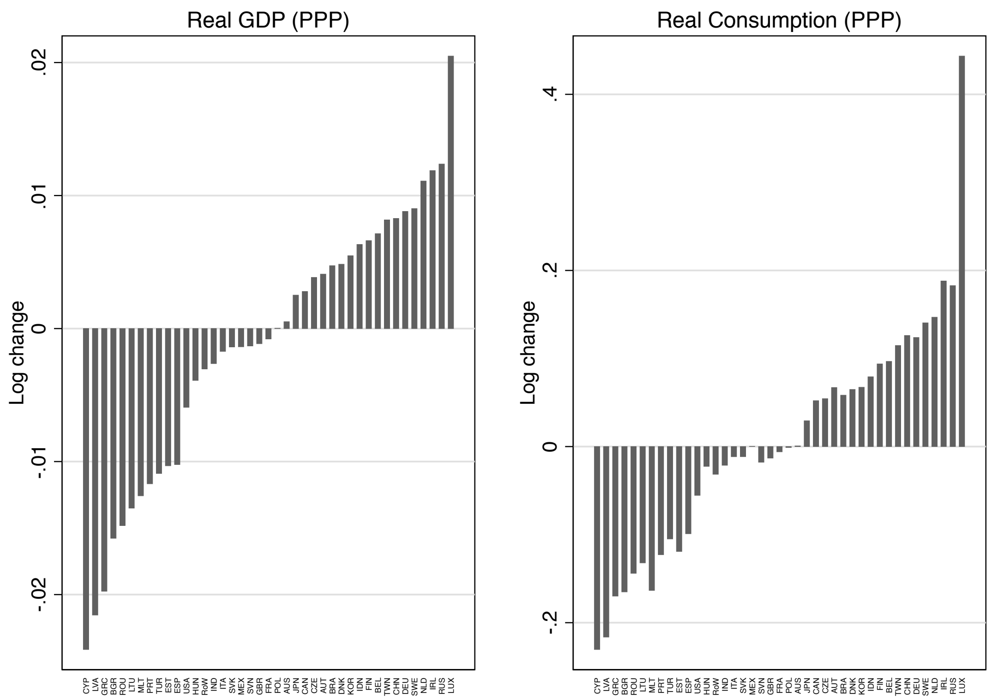

Figure 8: Universally balanced trade counterfactual

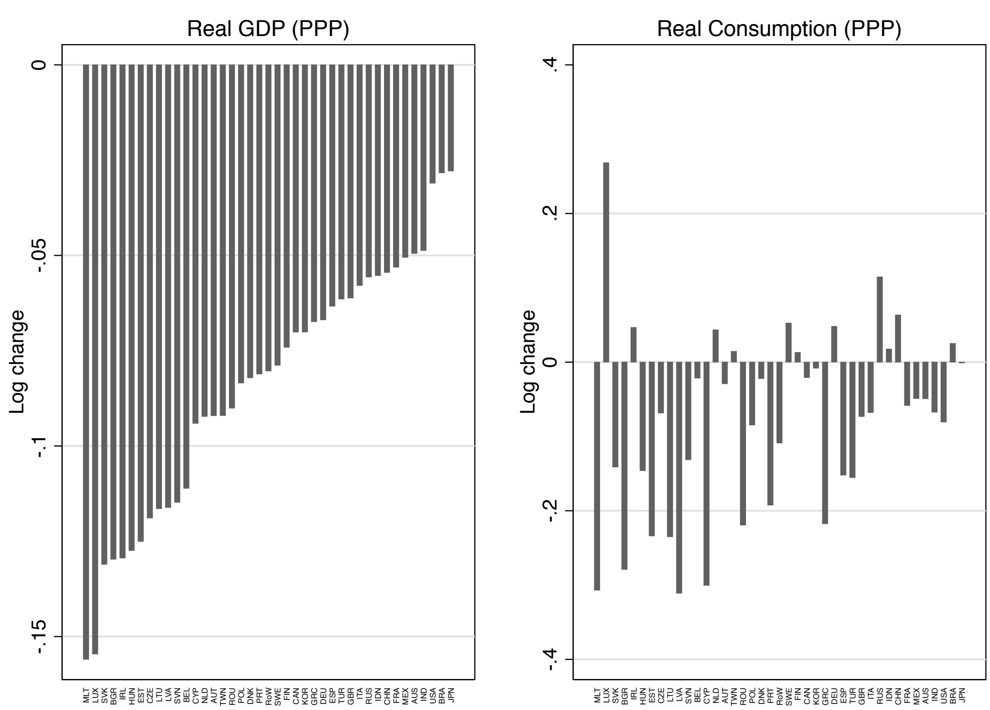

Figure 9: Global autarky counterfactual

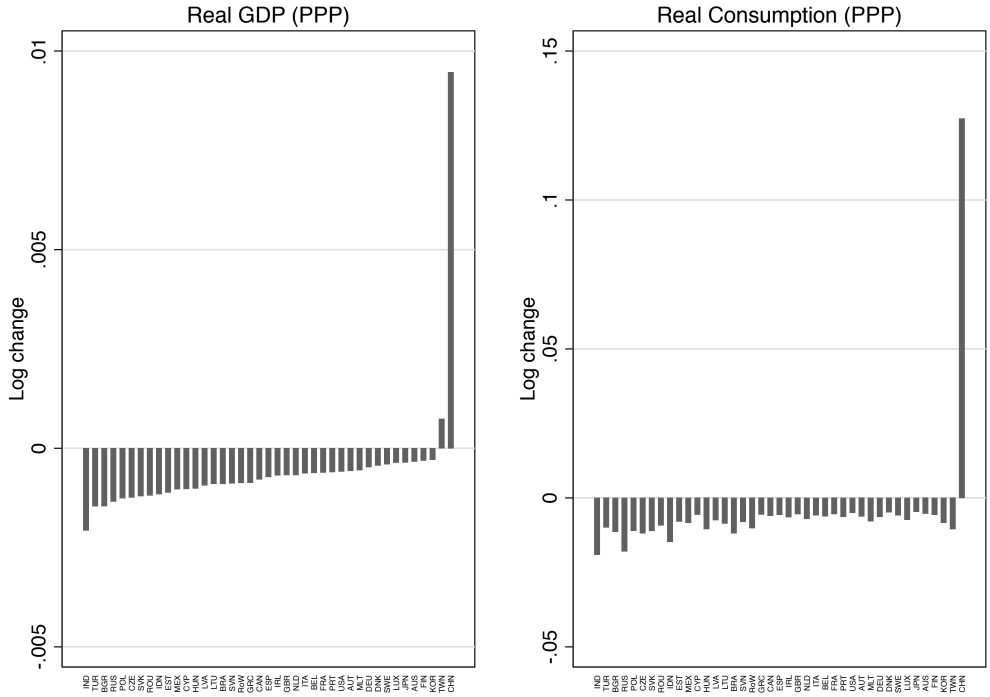

Figure 10: China trade balance counterfactual

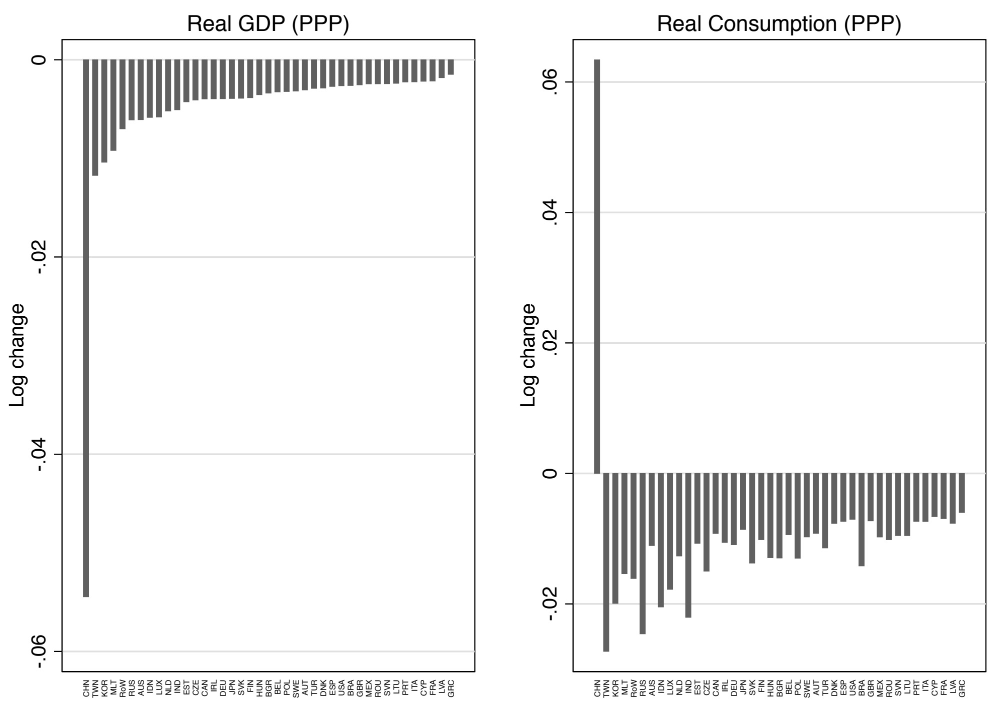

Figure 11: China autarky counterfactual

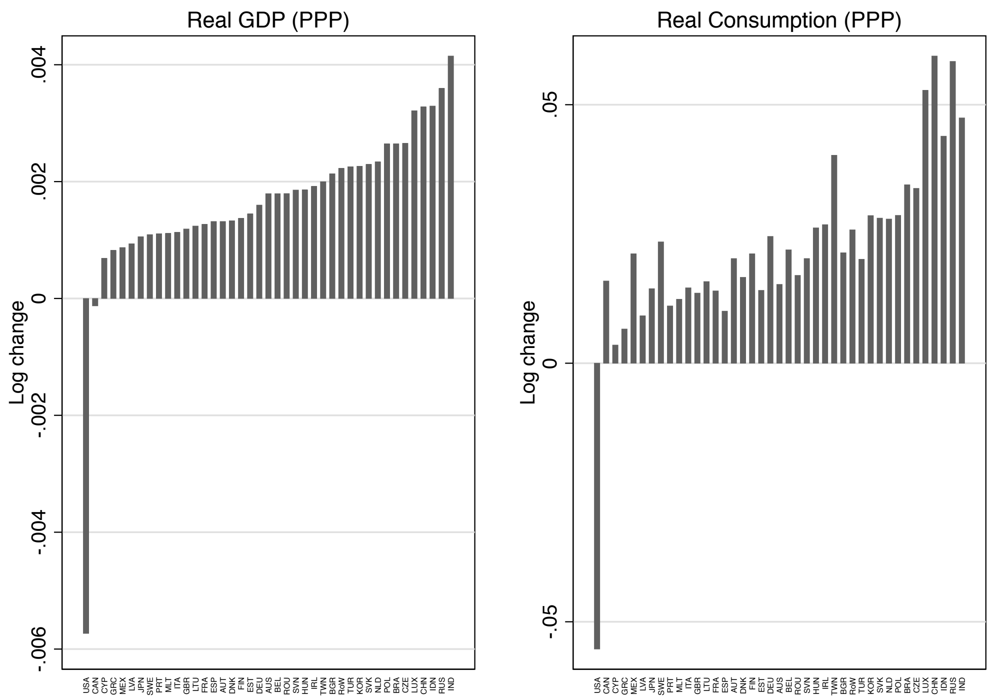

Figure 12: U.S. trade balance counterfactual

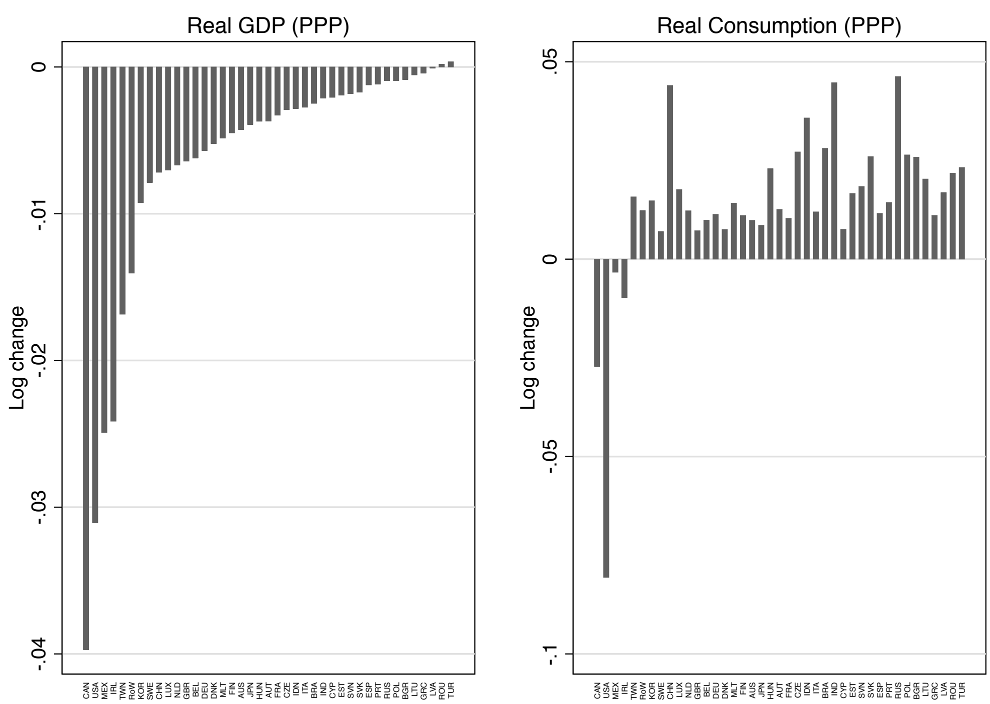

Figure 13: U.S. autarky counterfactual

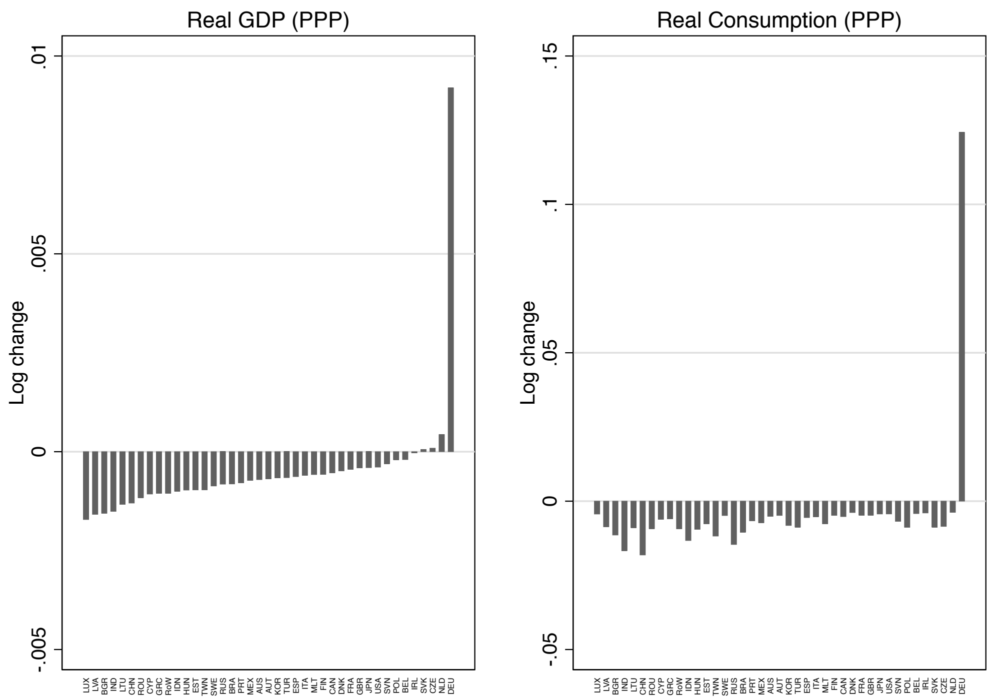

Figure 12: Germany trade balance counterfactual

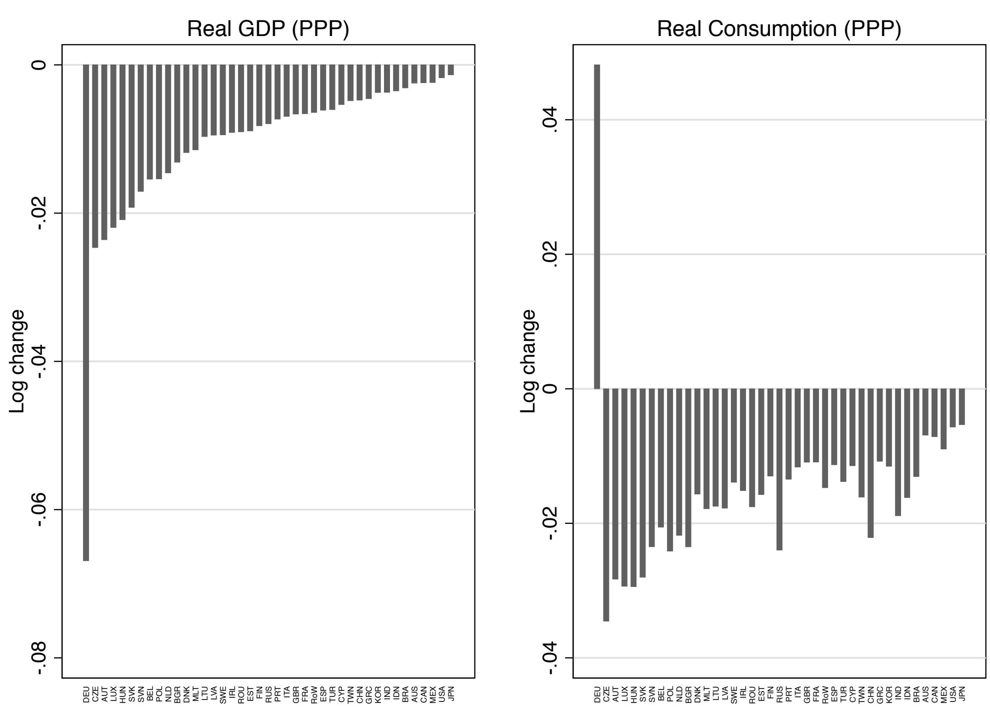

Figure 13: Germany autarky counterfactual

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A Appendix: Value Added and Gross Trade Flows

We extend our benchmark model of Section 2 by introducing input-output linkages and trade barriers explicitly. This helps us clarify the role of gross and value-added trade and prices. The resulting model has the same implications in terms of value-added outcomes and offers a justification for some of our key assumptions.

A.1 Technologies

Most of our new assumptions affect the production technology for goods. Country n' can now produce goods for n using the following country-pair-good-specific production technology:

$$q_{n'n}(i) = Z_{n'n}(i) \left\{ (1-\beta_n)^{\frac{1}{\varepsilon}} \left[K_{n'n}(i)^{\alpha} H_{n'n}(i)^{1-\alpha} \right]^{\frac{\varepsilon-1}{\varepsilon}} + \beta_n^{\frac{1}{\varepsilon}} Q_{n'n}(i)^{\frac{\varepsilon-1}{\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}}, \qquad (27)$$

where $\beta_n \in [0,1)$, and $Q_{n'n}(i)$ denotes an aggregator of goods used as intermediates by n' to produce good i for country n. $Q_{n'n}(i)$ has the same form (and price) as $C_{n'}$. As in our benchmark model, we think of shifter $Z_{n'n}(i)$ as a random variable, drawn independently for each i from the country-pair-specific Fréchet distribution

$$F_{n'n}(Z) = \Pr(Z_{n'n} \leq Z) = e^{-\omega_{n'n} Z^{-\theta}}, \qquad (28)$$

where $\omega_{n'n} \geq 0$. Finally, international trade is subject to *ad-valorem* taxes $t_{n'n} \geq 0$ that lead to price wedges $\tau_{n'n} \equiv 1 + t_{n'n} \geq 1$. The rest of the model remains as discussed in Section 2.

Note that the generalisation of (3) represented by (27) implies that countries no longer ship simply their own value added, but a combination of own value added and intermediates produced elsewhere – with the parameter β_n representing the intensity of intermediate use. As a result, the value of gross trade flows will exceed value added trade between countries in this model.

A.2 Prices

Define

$$p_n \equiv \left[(1-\beta_n) f_n^{1-\varepsilon} + \beta_n P_n^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \qquad (29)$$

The price to country n of sourcing good i from country n' is[26]

$$p_{n'n} = \frac{\tau_{n'n} p_{n'}}{Z_{n'n}(i)}. \qquad (30)$$

[26] Under the assumption that Z is not pair- but country-specific, equation (30) corresponds exactly to the pricing equations in Eaton and Kortum (2002).

Again following Eaton and Kortum (2002), we obtain

$$P_n = \frac{\xi}{A_n} \left(\sum_{n'=1}^{N} \omega_{n'n} \tau_{n'n}^{-\theta} p_{n'}^{-\theta} \right)^{-\frac{1}{\theta}} \tag{31}$$

as the cost of final consumption C_n and of the composite intermediate Q_n. Assuming $\theta = \varepsilon - 1$,

$$P_n = \frac{\xi}{A_n} \left[\sum_{n'=1}^{N} \omega_{n'n} \tau_{n'n}^{-\theta} \left[(1 - \beta_{n'}) f_{n'}^{-\theta} + \beta_{n'} P_{n'}^{-\theta} \right] \right]^{-\frac{1}{\theta}} \equiv \frac{\xi}{A_n} \left(\sum_{n'=1}^{N} \gamma_{n'n} f_{n'}^{-\theta} \right)^{-\frac{1}{\theta}}, \tag{32}$$

where

$$\begin{bmatrix} \gamma_{11} & \dots & \gamma_{N1} \\ \vdots & & \vdots \\ \gamma_{1N} & \dots & \gamma_{NN} \end{bmatrix} \equiv \tag{33}$$

$$\equiv \left(I - \begin{bmatrix} \left(\frac{A_1}{\xi}\right)^{\theta} & \dots & 0 \\ \vdots & & \vdots \\ 0 & \dots & \left(\frac{A_N}{\xi}\right)^{\theta} \end{bmatrix} \begin{bmatrix} \omega_{11}\tau_{11}^{-\theta}\beta_1 & \dots & \omega_{N1}\tau_{N1}^{-\theta}\beta_N \\ \vdots & & \vdots \\ \omega_{1N}\tau_{1N}^{-\theta}\beta_1 & \dots & \omega_{NN}\tau_{NN}^{-\theta}\beta_N \end{bmatrix} \right)^{-1} \cdot$$

$$\cdot \begin{bmatrix} \omega_{11}\tau_{11}^{-\theta}(1-\beta_1) & \dots & \omega_{N1}\tau_{N1}^{-\theta}(1-\beta_N) \\ \vdots & & \vdots \\ \omega_{1N}\tau_{1N}^{-\theta}(1-\beta_1) & \dots & \omega_{NN}\tau_{NN}^{-\theta}(1-\beta_N) \end{bmatrix}.$$

The "gross-output" and "value-added" models thus yield the same functional form for the consumption price index.

A.3 Implications

It is easy to show that (32) implies that both have the same predictions for value-added trade patterns as long as $\{\gamma_{n'n}\}_{n',n}$ coincide in both models.[27] In other words, for a given set of parameters $\{A_n, \omega_{n'n}, \tau_{n',n}, \beta_n\}$, there exists a set of parameters $\gamma_{n'n}$, given by equation (33), such that the corresponding models yield the same equilibrium outcomes f_n and $v_{n'n}$.[28]

Moreover, equation (31) highlights that we can think of θ as the (gross) trade elasticity in the spirit of a standard Eaton-Kortum model.

[27] One can see this by applying Shephard's Lemma to both (31) and (33) and comparing the resulting market-clearing conditions. For convenience, we assume that any tax revenue is transferred to the exporter.

[28] Note that, given our data, the terms $\omega_{n'n}$ and $\tau_{n'n}$ cannot be identified separately. However, the parameter restrictions $\gamma_{n'n} \geq 0$ and $\sum_{n'} \gamma_{n'n} = 1$ made in Section 2 imply a number of restrictions on $\omega_{n'n}$, $\tau_{n'n}$ and $\beta_{n'}$.