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Terms-of-Trade Effects of Productivity Shocks in Developing Economies

Emre Özçelik* Mustafa Tuğan† ‡§

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Abstract

This paper studies the terms-of-trade effects from economy-specific shocks to productivity with a focus on developing economies using a panel vector autoregression model with interactive fixed effects and the "max-share" approach. We find that the terms of trade in developing economies show insignificant dynamics after such shocks. The analysis of a more detailed classification of developing economies reveals a finding of critical importance: a positive economy-specific productivity shock results in a significant improvement in the terms of trade in the developing economies with a high degree of export diversification, indicating a clear violation of the small-country assumption for these economies.

Keywords: Productivity shocks; The terms of trade; The small-country assumption.

JEL Classification Numbers: O19, O47, O57

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1 Introduction

It has been long recognized in the literature that an improvement in productivity in an economy can have international welfare consequences. In this regard, it is of great importance to study the movements in the terms of trade following such an improvement. This stems from the fact an improvement in productivity is less beneficial to an economy if it leads to a terms-of-trade deterioration. Indeed, in the extreme case of 'immiserizing growth', the improvement can even harm the economy by reducing national welfare when the loss due to deteriorating terms of trade outweighs the gain due to increased production, as noted in Bhagwati (1958).

However, in the traditional literature of international macroeconomics, developing economies are modeled as small, implying that these economies are insulated from the aforementioned negative effect of an improvement in productivity on the terms of trade. This results from the situation of a small developing economy facing an economy-specific increase in productivity being a close analogy to that of a competitive firm under perfect competition facing an idiosyncratic fall in its marginal costs. Indeed, faced with lower marginal costs and taking the world price of its exports as given, profit-maximizing exporters in such an economy would increase their output to a larger level without impinging on their export prices: setting an export price below the world price reduces exporters' profits since exporters can sell all their output at the world price. Setting an export price above the world price, on the other hand, would result in no quantity being exported due to the availability of homogeneous products sold at the world price and exported by other small economies. Consequently, export prices would remain unchanged in small developing economies after economy-specific productivity shocks. This together with the negligible effect that developing economies have on import prices under the small-country

assumption imply that the terms of trade in developing economies are completely exogenous since they are determined in the world market. This assumption is universally embraced in the related empirical and theoretical literature, as noted in Schmitt-Grohé and Uribe (2018).

However, this assumption is based to a large extent on conventional wisdom, and its implication that economy-specific improvements in productivity would have no effect on the evolution of the terms of trade in developing economies is controversial on theoretical grounds. For example, as noted in Singer (1987), the Prebisch-Singer hypothesis argues that following an improvement in productivity, developing economies would face more adverse terms-of-trade movements than advanced economies, let alone being completely insulated from such movements, as implied by the small-country assumption. Indeed, the hypothesis proclaims that technical progress would cause a larger fall in export prices in developing economies than in advanced economies due to the presence of more competitive markets and less organized labor in the former.[1] Consequently, while the economic rents due to increased productivity would accrue mostly to home and overseas consumers in the form of lower prices in developing economies, these rents would accrue mostly to producers and labor in the form of higher factor incomes in advanced economies.

In this paper, we aim to address two issues related to the controversial topic in question. First, we provide a test of the small-country assumption by investigating whether productivity shocks have a substantial effect on the terms of trade in developing economies. Second, we assess whether the effects

[1] This emphasis on country factors differs from that which concerns commodity factors in the original form of the hypothesis. Indeed, in its original form proposed independently in Singer (1950) and Prebisch (1950), the hypothesis proclaimed that there would be a secular downward tendency for the relative price of primary commodities vis-avis manufactured goods. This stress on commodity factors in the 1950s can be attributed to the then trade patterns of developing economies, characterized by the export of primary commodities and the import of manufactures. However, following the success of some developing economies to diversify their exports into manufactures in the subsequent decades, the discussion on the Prebisch- Singer hypothesis shifted away from commodity factors to country factors, as noted in Singer (1987).

from such shocks on the terms of trade differ significantly between advanced and developing economies, as implied by the Prebisch-Singer hypothesis. An inherent difficulty in the analysis is that both economy-specific and common shocks engender fluctuations in productivity.[2] A number of papers provides supporting evidence for this. For example, Gregory and Head (1999) find that common fluctuations have a substantial impact on movements in productivity in the G7 countries by considering a model of the form:

$$tfp_{it} = \alpha_i A_t + a_{it} \tag{1.1}$$

where tfp_{it} denotes a measure of total factor productivity for economy i at time t. $\alpha_i A_t$ and a_{it} represent the common and economy-specific components to total factor productivity. Corsetti, Dedola, and Leduc (2008) also confirm a non-negligible role played by the U.S. technology spillovers in the movements in productivity across the other G7 countries. Similarly, Justiniano and Preston (2010) find that foreign-sourced disturbances have a substantial influence on both output and hours worked in Canada, and thus on the Canadian labor productivity.

When both common and economy-specific shocks cause fluctuations in productivity in an economy, are both shocks useful for addressing the two aforementioned issues in question? We argue that common shocks are not. The reason for this is that common shocks, by their very nature, can affect export and import prices of a developing economy in the world. Consequently, a finding of substantial effects on the terms of trade from these shocks would not be at odds with the small-country assumption. Also, by construction, the analysis of the effect on the terms of trade of an economy from common productivity shocks is an involved one since these shocks simultaneously occur in all economies and

[2] To make the abstract concept of common productivity shocks concrete, digital revolution since 1950s and the oil price spike in 2008 can be given as examples.

whether the terms of trade of the economy considered improve or deteriorate is dependent on the degree with which the economy and its trading partners are affected by such shocks. Based on these considerations, we disentangle economy-specific productivity shocks from common productivity shocks and focus only on the former in this paper.

To this end, we develop a panel vector autoregression (VAR) model with interactive fixed effects, which has the desirable feature of including common factors. These factors, affecting each economy differently, represent unobservable global shocks in the model and serve to isolate idiosyncratic shocks from common shocks. Using idiosyncratic shocks, we identify economy-specific structural productivity shocks with the "max-share" approach developed by Francis et al. (2014). This approach has several potential advantages over its alternatives, as noted in Beaudry, Nam, and Wang (2011) and Francis et al. (2014). First, due to its focus on some finite horizon, its estimation precision is likely to be larger than Galí's (1999) long-run identification strategy. Second, while productivity shocks are assumed to play a profound role in labor productivity over some long but finite horizon, other shocks may also cause labor productivity to fluctuate over the horizon considered. Third, as discussed in detail in section 3, it is less subject to limitations on data availability than its alternatives. Indeed, when recuperating economy-specific productivity shocks, the "max-share" approach can be performed by using output per employed person as a measure of labor productivity, which is available for the overwhelming number of economies for the sample period studied.

We find that when developing economies are analyzed as a whole, the economy-specific shocks to productivity cause a substantial impact neither on the terms of trade nor on the export and import prices in developing economies. This finding is consistent with the small-country assumption and stands in con-

trast to the Prebisch-Singer hypothesis. Analyzing the economy-specific productivity shocks in a more detailed classification of developing economies reveals a robust finding of critical importance: a positive economy-specific productivity shock significantly improves the terms of trade in the developing economies with a high degree of export diversification. This finding rejects the hypothesis that the small-country assumption holds for all developing economies. It is also at odds with the argument explaining the Prebisch-Singer hypothesis that productivity improvements cause more unfavorable terms-of-trade dynamics in developing economies than in advanced economies.

Related to our article, there is a large number of studies on the subject of the terms-of-trade effects from productivity shocks. They are, however, almost exclusively confined to advanced economies, as discussed extensively in section 3. These influential studies have greatly contributed to the literature. They have, however, a common unfavorable feature: the common component to productivity is not distinguished from the economy-specific component to productivity when the effects from productivity shocks on the terms of trade are analyzed. For example, both Enders and Müller (2009) and Nam and Wang (2015) arguably infer that the common component to productivity plays a minor role in the movements in the U.S. terms of trade and disregard it in their analysis. A different approach is taken by Corsetti, Dedola, and Leduc (2006), Corsetti, Dedola, and Leduc (2014), and Kamber, Theodoridis, and Thoenissen (2017), who study the effects from productivity shocks by identifying the shocks to *relative* productivity in one of the G7 economies vis-a-vis an output-weighted aggregate of its trading partners. With the presence of both the common and economy-specific components to productivity, this relative productivity can be

written from (1.1) as

$$tfp_{it} - tfp^*_{it} \quad = \quad \left(\alpha_i - \alpha^*_i\right) A_t + a_{it} - a^*_{it} \tag{1.2}$$

where the variables with an asterisk denote the foreign counterparts and $tfp_{it} - tfp^*_{it}$ is the relative productivity. It is easy to see that under the symmetric-country assumption (i.e., $\alpha_i = \alpha^*_i$), the relative productivity is given by the difference in the economy-specific component to productivity between the economy and its trading partners. (i.e., $a_{it} - a^*_{it}$). Consequently, under the symmetric-country assumption, the analysis of identified shocks to the relative productivity would be analogous to that of economy-specific shocks to productivity, as in our study.

However, while commonly made in the literature, the symmetric-country assumption for the G-7 economies is questionable. This is evident from the common finding that a positive shock to the relative productivity are characterized by a substantially heterogeneous terms-of-trade dynamics in these economies. For example, Corsetti, Dedola, and Leduc (2006) find that after such a shock, while the terms of trade in the U.S. and Japan improve, those in Italy and the U.K. depreciate, implying that these economies are not symmetric. Consequently, the identified shocks to the relative productivity in the G7 economies in the studies mentioned previously are likely to include the shocks to both the common and economy-specific components to productivity.

This paper makes an attempt to contribute to the literature by distinguishing between the common and economy-specific components to productivity. A further contribution in our paper is that, unlike the existing literature, which is to a large extent restricted to a sample of advanced economies, it extends the analysis of the effects from productivity shocks on the terms of trade to developing economies, allowing the small-country assumption to be tested.

The organization of the paper is as follows: Section 2 discusses our data and develops an econometric model to study the effect of a surprise economy-specific improvement in productivity on the terms of trade in developing and advanced countries. Section 3 provides a detailed critical review of the related empirical literature. Section 4 presents our findings. Section 5 discusses the implications of our findings and concludes.

2 Data and Empirical Model

This section presents the data and the empirical model used for analyzing structural productivity shocks.

2.1 Data

The focus of this study is to determine whether the effect of productivity shocks on the terms of trade differs between advanced and developing economies. To provide an answer to this, our approach is to divide the world into major groups and to study productivity shocks in these groups. To this end, we use the country classification used in the IMF's *World Economic Outlook*, which classifies countries into two major groups: advanced economies and emerging and developing economies.[3] Table A.1 in Appendix A displays the countries included in each group in our sample. The group of advanced economies includes 36 economies and the group of emerging and developing economies includes 141 economies.

[3]This classification is based on three criteria: (1) an average per capita income level over a number of years, (2) export diversification, and (3) degree of integration into the global financial system. Taking an average in the first criterion is intended to eliminate excessive volatility in per capita income observed in some commodity-dependent countries due to the marked year-to-year effects of commodity prices. Export diversification is useful not to include some largely commodity-dependent countries with high per-capita income in the group of advanced economies. It is remarkable that to classify countries according to their level of economic development, the *World Economic Outlook*'s country classification is more suitable than the country classification of the *World Bank* since while the latter is based only on per capita income, the former also takes into account export diversification.

Let $\mathcal{Y}_{i,t}$ denote the vector of variables contained in our analysis, containing the log of GDP per person employed in constant 2011 purchasing power parity dollars (denoted by $gdp_{i,t}$), the log of export unit value index (denoted by $p^x_{i,t}$), and the log of net barter terms of trade index (denoted by $tot_{i,t}$):[4]

$$\mathcal{Y}_{i,t} = \begin{bmatrix} gdp_{i,t}, & p^x_{i,t}, & tot_{i,t} \end{bmatrix}' \tag{2.1}$$

Our source of yearly data on $\mathcal{Y}_{i,t}$ is the World Bank's *World Development Indicators* and the sample period for our main analysis is 2000-2016.

2.2 A Panel VAR Model in the Presence of Common Shocks

We consider a panel VAR model with interactive effects which allows economy-specific productivity shocks to be separated from common productivity shocks, as we discuss below. The model is of the form:

$$\Delta\mathcal{Y}_{i,t} = \begin{bmatrix} \alpha_0^{\Delta gdp} \\ \alpha_0^{\Delta p^x} \\ \alpha_0^{\Delta tot} \end{bmatrix} + \sum_{k=1}^{\bar{k}} \begin{bmatrix} \alpha_k^{\Delta gdp'} \\ \alpha_k^{\Delta p^{x'}} \\ \alpha_k^{\Delta tot'} \end{bmatrix} \Delta\mathcal{Y}_{i,t-k} + \begin{bmatrix} \lambda_i^{\Delta gdp'} \\ \lambda_i^{\Delta p^{x'}} \\ \lambda_i^{\Delta tot'} \end{bmatrix} f_t + \begin{bmatrix} u_{i,t}^{\Delta gdp} \\ u_{i,t}^{\Delta p^x} \\ u_{i,t}^{\Delta tot} \end{bmatrix} \tag{2.2}$$

with $\Delta\mathcal{Y}_{i,t} = \begin{bmatrix} \Delta gdp_{i,t} & \Delta p^x_{i,t} & \Delta tot_{i,t} \end{bmatrix}'$. f_t stands for $\bar{r} \times 1$ common factors, representing global shocks in the model, where $\bar{r}$ denotes the number of common factors. $\lambda_i^{\Delta gdp}$, $\lambda_i^{\Delta p^x}$, and $\lambda_i^{\Delta tot}$ represent $\bar{r} \times 1$ factor loadings for the rate of changes in GDP per employed person, the export unit value index, and the net barter terms of trade index, respectively. $u_{i,t}^{\Delta gdp}$, $u_{i,t}^{\Delta p^x}$, and $u_{i,t}^{\Delta tot}$

[4] Net barter terms of trade index is defined as the ratio of export unit value index to import unit value index. Export unit value index expresses the US-dollar price of a unit of exports relative to that in the base year of 2000 and is defined as the ratio of export value index to export volume index.

denote, respectively, idiosyncratic errors in the rate of change in GDP per employed person, the export unit value index, and net barter terms of trade index. The 3×1 vector autoregression coefficients on $\Delta gdp_{i,t}$, $\Delta p^x_{i,t}$, and $\Delta tot_{i,t}$ are given, respectively, by $\alpha_k^{\Delta gdp}$, $\alpha_k^{\Delta p^x}$, and $\alpha_k^{\Delta tot}$. The model can be written more compactly as:

$$\Delta \mathcal{Y}_{i,t} \quad = \quad \alpha_0 + \sum_{k=1}^{\bar{k}} \alpha_k \Delta \mathcal{Y}_{i,t-k} + \lambda_i' f_t + u_{i,t} \tag{2.3}$$

with $\lambda_i = \begin{bmatrix} \lambda_i^{\Delta gdp} & \lambda_i^{\Delta p^x} & \lambda_i^{\Delta tot} \end{bmatrix}'$, $u_{i,t} = \begin{bmatrix} u_{i,t}^{\Delta gdp} & u_{i,t}^{\Delta p^x} & u_{i,t}^{\Delta tot} \end{bmatrix}'$, and $\alpha_k = \begin{bmatrix} \alpha_k^{\Delta gdp} & \alpha_k^{\Delta p^x} & \alpha_k^{\Delta tot} \end{bmatrix}'$ for $k = 0, 1, \ldots, \bar{k}$, . Idiosyncratic errors are assumed to be uncorrelated across the economies and periods:

$$E(u_{i,t} u_{j,\tau}') \quad = \quad \begin{cases} 0 & \text{if } i \neq j \text{ or } t \neq \tau \\ \Sigma & \text{if } i = j \text{ and } t = \tau \end{cases} \tag{2.4}$$

We use the idiosyncratic errors $u_{i,t}$ to identify economy-specific structural shocks denoted by $\epsilon_{i,t}$:

$$u_{i,t} \quad = \quad A \epsilon_{i,t} \tag{2.5}$$

where A is some 3×3 invertible matrix. Consequently, we assume idiosyncratic errors are given by some linear combination of economy-specific structural shocks, as is common in structural VAR analysis; e.g., see Christiano, Eichenbaum, and Evans (1999) and Arias, Rubio-Ramírez, and Waggoner (2018). We denote economy-specific productivity shocks as $\epsilon_{i,t}^{\Delta gdp}$. Before describing our strategy for recuperating $\epsilon_{i,t}^{\Delta gdp}$ in detail, we discuss our panel VAR model's features.

First, f_t, which can be regarded as representing common shocks, plays a

crucial role in recuperating $\epsilon_{i,t}^{\Delta gdp}$. To explain this, let $\eta_{i,t}$ denote the composite error terms in (2.2) given by the sum of interactive fixed effects terms $\lambda_i' f_t$ and idiosyncratic errors $u_{i,t}$:

$$\eta_{i,t} = \lambda_i' f_t + u_{i,t} \tag{2.6}$$

It can be argued that any shock which can be referred to as an economy-specific shock must be recuperated from idiosyncratic errors. However, were f_t absent from the model, productivity shocks identified using the composite errors would not be specific to an economy since apart from economy-specific shocks, these shocks would also contain common shocks affecting all economies. The presence of f_t in the model serves the purpose of obtaining idiosyncratic errors by purging the composite errors of common shocks.

Second, since λ_i varies across all economies in the model, common shocks can have a different effect on different economies. In addition, the model has the desirable feature that common shocks affect each variable of the same economy differently since their factor loadings are not the same (e.g., $\lambda_i^{\Delta gdp} \neq \lambda_i^{\Delta p^x}$). The role played by common shocks in the model can be illustrated by the global financial crisis in 2008. Each economy felt the effect of the crisis differently. For example, while the net barter terms of trade in Australia improved greatly by 5.91% in 2008, Japan suffered from a 4.49% decline in its terms of trade in the same year. The presence of common factors together with economy-specific factor loadings in the model can account for such shocks affecting economies differently and with varying degrees. It is also notable that the only assumption we make about common factors and factor loadings is that their fourth moment is finite. Consequently, common factors, representing global shocks in the model, can have long-lasting effects since they can be serially correlated.

Third, the model is specified in first-differences based on our findings from

appendix B that the endogenous variables are of integrated order one and no linear combination of them is stationary, resulting in that the model represented by finite-order vector autoregression in the differenced data is not misspecified; see Hamilton (1994, p. 574-575). By specifying the model this way, we aim to improve the small sample performance of the estimates from (2.2) and eliminate the non-standard distributions of the estimates, which would result were the model specified in levels, as noted in Hamilton (1994).

Fourth, we assume common slopes in the model for all countries in the same group. To put it more clearly, α_k is assumed to be common across all economies in the same group.[5] Also, the idiosyncratic shocks are assumed to have the same variance Σ for all countries in the same group. While being controversial, we assume common slopes and the same idiosyncratic errors' variance in the same group based on the general finding that heterogeneous panels have worse forecast performance than homogeneous panels; e.g., see Baltagi (2005, chapter 10) who reviews the literature on heterogeneous and homogeneous panels and concludes that in comparison to the more parameter consuming heterogeneous panels, homogeneous panels yield better forecast performance due to their simplicity and parsimony in model estimation. Also, he notes that forecast performance significantly improves in homogeneous panels of international studies whose variables have a large variation.

Five, let μ_i denote additive economy-fixed effects. It is notable that the panel VAR model with additive effects is nested in our panel VAR model as the special case that f_t^r is constant across all periods where f_t^r denotes the rth common factor. Consequently, the least squares estimates from the panel model with only interactive fixed effects are still consistent even when μ_i is present but not imposed in the model since additive economy-fixed effects can be largely accounted for by an estimated common factor with little variation

[5] However, we allow the slopes to differ between developing and advanced economies.

across periods in the model.

2.2.1 The Problem with Pooling All Available Data of Advanced and Developing Economies Together

Consider the following panel VAR model where all available data of advanced and developing economies is pooled together:

$$\Delta\mathcal{Y}_{i,t} \quad = \quad \alpha_0^g + \sum_{k=1}^{\bar{k}} \alpha_k^g \Delta\mathcal{Y}_{i,t-k} + \lambda_i' f_t + u_{i,t} \quad ; \quad g \quad = \quad \text{A or D} \tag{2.7}$$

where g is the group in which economy i is included and is given by either A if economy i is an advanced economy, or by D if economy i is a developing economy.

It is notable that common factors in Model (2.7) can be estimated with a larger number of cross section units than those in Model (2.3), where the two panels of advanced and developing economies are studied separately. Does this result in Model (2.7) being more desirable than Model (2.3)? In our opinion, the answer is no for three essential reasons.

First, the efficiency gain in the estimates of parameters in Model (2.7) from pooling is not likely to be larger than that in Model (2.3). Indeed, in both Model (2.7) and (2.3), the rates of convergence of the least squares estimator of the coefficients and common factors are given by $1/\sqrt{TN_g}$ and $1/\sqrt{T}$, respectively, with N_g denoting the number of economies included in group g; see, Bai (2009), Moon and Weidner (2017), and Tugan (2018).

Second, Model (2.7) is questionable since it imposes the same common factors affecting developing and advanced economies. However, common factors affecting advanced and developing economies can be different in each period. For example, the food-price boom in the 2000s that lasted around a decade may be regarded as a common factor for developing economies, given its sizable effect

on the terms of trade in many developing economies with a large share of food in trade. However, the same boom is unlikely to be termed as a common factor affecting the terms of trade in advanced economies, given their small share of food in trade. Unlike Model (2.7), Model (2.3) allows common factors affecting advanced economies to be different from those affecting developing economies.

Third, in our subsequent analysis, we discuss the results from an extended sample of 1991-2016, for which we have an unbalanced panel due to the unavailability of data between 1991 and 1999 for many economies. Model (2.7) is problematic with this unbalanced panel due to the sample-selection bias. Indeed, only a small fraction of advanced economies have available data between 1991 and 1999, as compared to that of developing economies, as indicated in appendix A.1. This would result in missing observations in Model (2.7) being non-random, inducing a sample-selection problem in Model (2.7).

2.3 Empirical Strategy for Identifying Productivity Shocks

Now, we present our identification strategy in detail. Under some general conditions, $\Delta\mathcal{Y}_{i,t}$ has a moving-average representation of the form:

$$\Delta\mathcal{Y}_{i,t} = \overline{\Delta\mathcal{Y}}_i + \sum_{h=0}^{\infty} B(h)\lambda_i' f_{t-h} + \sum_{h=0}^{\infty} B(h)u_{i,t-h} \tag{2.8}$$

where $\overline{\Delta\mathcal{Y}}_i$ denotes the population mean of $\Delta\mathcal{Y}_{i,t}$, the moving-average coefficients given by $B(h)$ can be obtained from (2.2) as:

$$B(h) = \begin{cases} \sum_{k=1}^{\bar{k}} \alpha_k B(h-k) & \text{for } h > 0 \\ I_3 & \text{for } h = 0 \\ 0 & \text{for } h < 0 \end{cases} \tag{2.9}$$

To study the effects of economy-specific productivity shocks on the terms of trade, the variables should be purged of their variation caused by f_t and the forecast error in the variables caused only by idiosyncratic errors should be considered. We refer to the latter as the idiosyncratic variation in the variables. We define the $H - period$ ahead idiosyncratic variation in the variables as:

$$\sum_{h=0}^{H} B(h) u_{i,t+H-h} \tag{2.10}$$

Since $\Delta gdp_{i,t+H}$ is the first element of $\Delta \mathcal{Y}_{i,t+H}$, the idiosyncratic variation in $gdp_{i,t+H}$ can be obtained as that of the cumulative sum of (2.10):

$$I_3^{1'} \sum_{h=0}^{H} \sum_{j=0}^{h} B(j) u_{i,t+H-h} \tag{2.11}$$

where I_3^1 denotes the first column of I_3. Let $C(h)$ denote the $h - period$ ahead moving average coefficients for *the level of the variables* which can be written as:

$$C(h) \quad = \quad \sum_{j=0}^{h} B(j) \tag{2.12}$$

Using (2.11) and (2.12), the $H - period$ ahead idiosyncratic forecast error variance of gdp_i can be written as:

$$I_3^{1'} \left(\sum_{h=0}^{H} C(h) \Sigma C(h)' \right) I_3^1 \tag{2.13}$$

Next, we discuss how economy-specific productivity shocks are identified in our analysis. We begin with rewriting (2.5) as

$$u_{i,t} \quad = \quad \tilde{A} Q \epsilon_{i,t} \tag{2.14}$$

where Q is some orthogonal matrix and $\tilde{A} = AQ'$. As is common, we assume

that idiosyncratic structural shocks are uncorrelated and have unit variance, $E\left(\epsilon_{i,t}\epsilon'_{i,t}\right) = I_3$. Consequently, $\tilde{A}$ must satisfy the following:

$$\tilde{A}\tilde{A}' \quad = \quad \Sigma \tag{2.15}$$

For example, $\tilde{A}$ can be given by the Cholesky decomposition of Σ. Let productivity shocks be given by the jth element of $\epsilon_{i,t}$. Then, the $H - step$ ahead forecast error variance of $gdp_{i,t}$ due to productivity shocks can be written from (2.11) and (2.12) as

$$I_3^{1'}\left(\sum_{h=0}^{H} C(h)\tilde{A}q^j q^{j'}\tilde{A}'C(h)'\right)I_3^1 \tag{2.16}$$

where q^j is the jth column of Q. Since $I_3^{1'}C(h)\tilde{A}q^j$ is scalar, (2.16) can be rewritten as:

$$q^{j'}\left(\sum_{h=0}^{H} \tilde{A}'C(h)'I_3^1 I_3^{1'}C(h)\tilde{A}\right)q^j \tag{2.17}$$

Let $G(H)$ be given by

$$G(H) \quad = \quad \frac{\sum\limits_{h=0}^{H} \tilde{A}'C(h)'I_3^1 I_3^{1'}C(h)\tilde{A}}{I_3^{1'}\sum\limits_{h=0}^{H} C_h \Sigma C_h' I_3^1} \tag{2.18}$$

Using the "max-share" approach developed by Francis et al. (2014), we identify economy-specific productivity shocks by maximizing the share of the $H - step$ ahead *idiosyncratic* forecast error variance for gdp_i attributable to economy-specific productivity shocks. This involves selecting q^j as the vector ensuring the role played by productivity shocks in the $H - step$ ahead idiosyn-

cratic forecast error variance for gdp_i is greatest:

$$\max_{q^j} \qquad q^{j'} G(H) q^j \quad \text{subject to } q^{j'} q^j = 1. \tag{2.19}$$

From this constrained maximization, it is easy to show q^j can be obtained as the eigenvector of $G(H)$ corresponding to its largest eigenvalue.

3 Relation with the Existing Literature

The impact of a surprise improvement in productivity on the terms of trade in advanced economies is empirically analyzed by a number of recent papers. In this section, we critically review the strategies used for identifying productivity shocks and briefly summarize the findings in these studies.

3.1 The Existing Empirical Literature Based on Galí's (1999) strategy

Both Enders and Müller (2009) and Miyamoto and Nguyen (2017) study international transmission of U.S. technology shocks identified by following the strategy in Galí (1999), which assumes that only technology shocks have a permanent effect on the level of labor productivity in the United States. Regarding the effect of a positive productivity shock on the U.S. terms of trade, the findings from these studies are contrasting. Indeed, while Enders and Müller (2009) find that a positive productivity shock in the U.S. is associated with an appreciation in the US terms of trade vis-a-vis an aggregate of industrialized countries, Miyamoto and Nguyen (2017) find that it causes a depreciation in the U.S. terms of trade vis-a-vis Canada. The former finding can be reconciled with the latter finding when the appreciation in the U.S. terms of trade vis-a-vis other industrialized countries outweighs the depreciation in the U.S. terms of trade

vis-a-vis Canada following the shock.

Similarly, Corsetti, Dedola, and Leduc (2006) identify shocks to relative productivity in manufacturing in the five G7 countries assuming that only these shocks have a permanent effect on relative productivity. They find that the terms of trade following such shocks improve in the U.S. and Japan, show no significant change in Germany, and deteriorate in the the U.K. and Italy.[6]

3.2 The Existing Empirical Literature Based on Sign Restrictions

Enders, Müller, and Scholl (2011) identify productivity shocks with robust sign restrictions on impulse responses of several variables from a two-country general equilibrium model. They find that the U.S. terms of trade vis-a-vis an aggregate of industrialized countries, whose responses are left unrestricted, show an initial improvement after a positive productivity shock. This strategy for recuperating productivity shocks is impractical for our study since it may require imposing sign restrictions on impulse responses of some variables whose data is unavailable for many developing economies for much of the sample. For example, the identification strategy for disentangling positive productivity shocks from expansionary monetary shocks in Enders, Müller, and Scholl (2011) requires the comovement between inflation and nominal interest rates following the former

[6]It is notable that some concerns regarding the long-run identification strategy have been raised in the literature. On theoretical grounds, the identification assumption in Galí's (1999) strategy that only technological shocks have a permanent effect on labor productivity is controversial. For example, Uhlig (2004) and Christiano, Eichenbaum, and Vigfusbson (2004) argue that persistent shocks to the capital income tax rate may distort indirect estimates of permanent shocks to technology implied by Galí's (1999) strategy. Galí (2004) responds to this critique by showing that the former and latter shocks are uncorrelated. Apart from this critique, both Faust and Leeper (1997) and Christiano, Eichenbaum, and Vigfusson (2007) note that with a typical sample size utilized in empirical studies, the sum of the VAR coefficients required by the long-run identification scheme is notoriously difficult to estimate precisely. This difficulty presents itself as a substantial bias in the impulse responses from a shock to productivity identified by Galí's (1999) strategy, as Erceg, Guerrieri, and Gust (2005) show by using synthetic data sets generated from standard real business cycle models or New Keynesian sticky-price models.

shocks and the latter shocks to be positive and negative, respectively. Since data on neither money-market nor monetary-policy-related rates in many developing economies is available during a large part of the sample period, such a strategy is not viable for our study.

By pursing a similar strategy, Corsetti, Dedola, and Leduc (2014) also find that a positive productivity shock in the U.S. results in an improvement in its terms of trade vis-a-vis an aggregate of industrialized countries.

Related to these studies, Kamber, Theodoridis, and Thoenissen (2017) also identify shocks to productivity with the sign restrictions, as implied by an open-economy version of Jermann and Quadrini's (2012) model in four small advanced economies: Australia, Canada, New Zealand, and the United Kingdom. They find that while such shocks lead to an improvement in the terms of trade in Canada and the United Kingdom, they have no significant impact on the terms of trade in Australia and New Zealand.

3.3 The Existing Empirical Literature Based on Barsky and Sims's (2011) strategy

Nam and Wang (2015) study the effects from the U.S. productivity shocks by implementing Barsky and Sims's (2011) strategy. This strategy requires fluctuations in total factor productivity to be caused either by contemporaneous shocks or news shocks to technology over all forecast horizons from the impact period up to a truncation horizon. They find that a positive contemporaneous shock to total factor productivity induces an initial depreciation and insignificant dynamics thereafter in the U.S. terms of trade. In contrast, a positive news shock to total factor productivity results in an initial improvement in the U.S. terms of trade, followed by insignificant dynamics thereafter. It is notable that their measure of productivity is total factor productivity adjusted for capacity

utilization and labor effort in the United States. As noted in Nam and Wang (2015), using a factor-utilization-adjusted productivity measure is required for the validity of Barsky and Sims's (2011) strategy. This can be explained by noting that news shocks, which are supposed to carry information only about future productivity, can have a contemporaneous effect on any productivity measure not adjusted for factor utilization by causing an increase in both capacity utilization and labor effort. This would in turn violate the identifying assumption of the strategy that news shocks have a delayed effect on the productivity measure. In addition, fluctuations in an unadjusted measure of total factor productivity can be caused by shocks to fiscal and monetary policies at high frequencies. This can also invalidate the strategy since its essential assumption requires fluctuations in the productivity measure to be accounted for by only the aforementioned productivity shocks at all frequencies, including high frequencies; see Beaudry, Nam, and Wang (2011). Constrained by the unavailability of a factor-utilization-adjusted measure of total factor productivity for all the economies in our sample except the United States, we opted not to use this strategy.

4 Results

In this section, we present the main results of the paper. We begin by reporting the baseline results. Next, we investigate whether these results are robust to changes in the model specification, the sample period, and the measure of productivity in an economy. Then, we classify and group developing economies in more detail into the developing economies with a high degree of export diversification and the remaining developing economies and the effects from an increase in productivity are analyzed in the former and the latter separately to see whether increased productivity affects the economies in the former differ-

ently from those in the latter.

4.1 Baseline Results

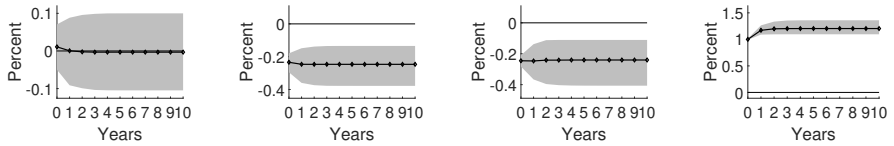
In this section, we discuss the results from a positive productivity shock. Without loss of generality, we normalize the impact effect of the shock on output per employed person ($gdp_{i,t}$) to unity. In the benchmark specification, we select the lag length in the model as one ($\bar{k} = 1$) and the horizon at which the idiosyncratic forecast-error variance share of productivity in gdp_i is maximized as 10 years for our annual data ($H = 10$). The lag length of one in our model with our annual data is consistent with four lags selected by Christiano, Eichenbaum, and Evans (2005) for their quarterly data and approximately corresponds to 13 lags selected by Bernanke, Boivin, and Eliasz (2005) and Boivin, Giannoni, and Mihov (2009) for their monthly data. Moreover, the selection of 10 years as the horizon in the max-share approach in our study matches the selection of 40 quarters in Francis et al. (2014).

Figure 1 displays the impulse response functions (IRFs) of the terms of trade (denoted by tot), the export unit value index (denoted by p^x), the import unit value index (denoted by p^m), and output per employed person (denoted by gdp) to a positive productivity shock, resulting in an unexpected one percent increase in output per employed person in the impact period.[7] In Figure 1, the IRFs of p^m are calculated by subtracting the IRFs of the terms of trade (tot) from those of the export unit value index (p^x). As is evident from Figure 1, we find that a positive productivity shock

- results in an insignificant change in the terms of trade in both advanced and developing economies;

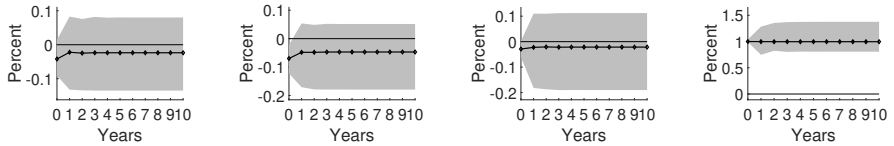
[7] An impulse response of a variable shows the change in the variable caused by the productivity shock over some horizon. A positive (negative) impulse response indicates that the variable would attain (fall to) a high (low) level in the presence of the shock, as compared to that in the undistorted path.

Panel A: Advanced Economies



(a) tot **(b)** p^x **(c)** p^m **(d)** gdp

Panel B: Developing Economies



(a) tot **(b)** p^x **(c)** p^m **(d)** gdp

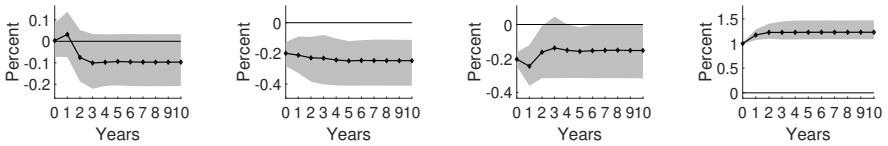
Note: Our calculations are based on the World Bank's *World Development Indicators*. Solid lines with diamonds indicate the median IRFs. Grey areas are 68 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 1: *IRFs to a Positive Productivity Shock (Baseline Results)*

- gives rise to a large and persistent fall and a largely insignificant and transitory fall in the export unit value index in advanced and developing economies, respectively;
- causes a large fall and an insignificant change in the import unit value index in advanced and developing economies, respectively; and
- induces a permanent increase in output per employed person in advanced and developing economies, which is significant at all horizons that we compute the IRFs.

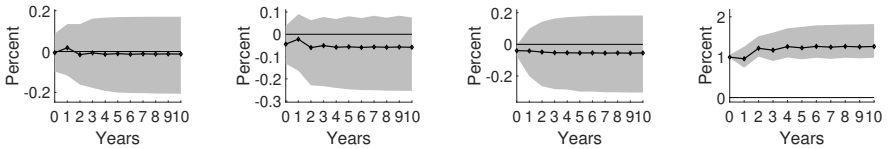
To sum up, our findings are consistent with the small-country assumption since we find that economy-specific shocks in developing economies considered as a whole affect neither the terms of trade, nor the export and import prices

Panel A: Advanced Economies



(a) tot **(b)** p^x **(c)** p^m **(d)** gdp

Panel B: Developing Economies



(a) tot **(b)** p^x **(c)** p^m **(d)** gdp

Note: Our calculations are based on the World Bank's *World Development Indicators*. Solid lines with diamonds indicate the median IRFs. Grey areas are 68 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 2: *IRFs to a Positive Productivity Shock*
(First Robustness Check: An Alternative Specification with $\bar{k} = 2, H = 10$*)*

in a significant manner with the exception of their significant effect on the export prices in the impact period. However, our findings reject the argument put forward to explain the Prebisch-Singer hypothesis that an increase in productivity leads to more unfavorable terms-of-trade dynamics in developing economies than in advanced economies since we find that an unexpected economy-specific increase in productivity in neither developing nor advanced economies causes a significant change in the terms of trade.

4.2 Robustness Checks

4.2.1 Different Model Specifications

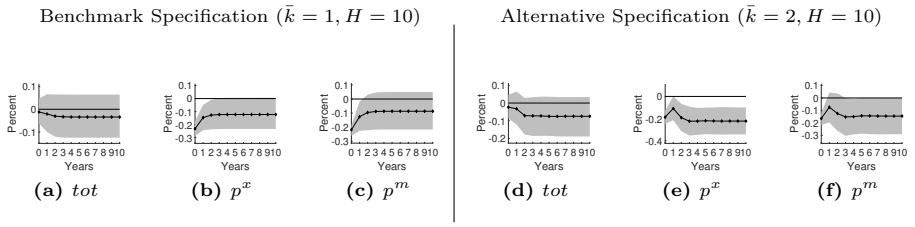
In this section, we consider two robustness checks. In the first robustness check, we use the specification that $H = 10$ and $\bar{k} = 2$. Consequently, in this alternative specification, while the horizon at which the forecast-error variance share of productivity in output per employed person is maximized is the same as in the benchmark specification, we allow for richer dynamics by selecting the lag length in Model (2.3) as two instead of one as in the benchmark specification.

Figure 2 displays the IRFs from the alternative specification allowing for richer dynamics. It is discernible that the fall in the terms of trade in advanced economies is more pronounced under this specification than under the benchmark specification; see Figure 1 and Figure 2. Apart from this, the results differ little between the two specifications. Consequently, the results under this alternative specification are also consistent with the small-country assumption for developing economies when considered as a whole. They reject the Prebisch-Singer hypothesis, however, more strongly. Indeed, they indicate that a positive productivity shock causes more unfavorable terms-of-trade dynamics in advanced economies than in developing economies, let alone causing less unfavorable terms-of-trade dynamics in the former, as implied by the Prebish-Singer hypothesis.

As a second robustness check, the specification that $H = 20$ and $\bar{k} = 1$ is considered. In this alternative specification, while the lag length in Model (2.3) is the same as in the benchmark specification, the anticipation horizon is longer than that in the benchmark specification. Since the results implied by this alternative specification are almost identical to those implied by the benchmark specification, they are not reported for reasons of brevity.[8]

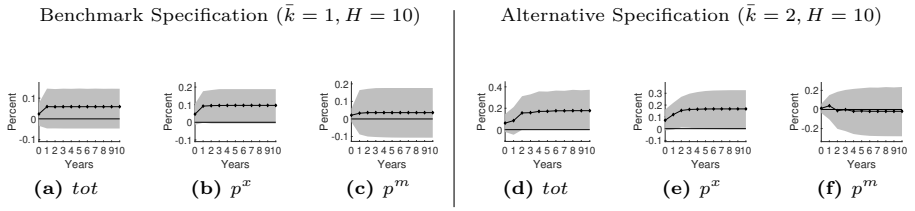
[8] In the subsequent analysis, the results from this specification are also obtained but not

Panel A: Advanced Economies



(a) *tot* **(b)** p^x **(c)** p^m **(d)** *tot* **(e)** p^x **(f)** p^m

Panel B: Developing Economies



(a) *tot* **(b)** p^x **(c)** p^m **(d)** *tot* **(e)** p^x **(f)** p^m

Note: Our calculations are based on the World Bank's *World Development Indicators*. Solid lines with diamonds indicate the median IRFs. Grey areas are 90 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 3: *IRFs to a Positive Productivity Shock*
(Second Robustness Check: Extended Sample Period)

4.2.2 Results from a Longer Sample Period

In this section, we extend our sample period back to 1991 for developing and advanced economies and discuss the results under both the benchmark specification and the specification that allows for richer dynamics. It is notable that the responses to a productivity shock can be more preciously estimated

reported to save on space. They are, however, almost identical to the corresponding results from the benchmark specification.

when the sample period is extended back to 1991. However, doing so results in an unbalanced panel since data is available only for a small fraction of advanced economies and about half of developing economies between 1991-1999. To eliminate the sample selection bias, the additional assumption that selection is unrelated to the idiosyncratic errors $u_{i,t}$ in Model (2.3) must be made for the longer unbalanced panel; see Wooldridge (2002, chapter 17.7). Our decision to study the sample period of 2000-2016 in our main analysis stems from the fact that our panel for 2000-2016 is balanced, and, by construction, free of sample-selection bias, which may plague the results from the longer unbalanced panel if the assumption that selection is unrelated to the idiosyncratic errors is violated.

It is also notable that in the unbalanced panel, estimating common factors in Model(2.3) requires imputing some missing values. We impute these values using the expectation-maximization algorithm suggested by Stock and Watson (2002) and Bai (2009). As simulation studies done in Bai, Liao, and Yang (2015) show, this algorithm yields consistent estimates, converging rapidly to their true values for both smooth and stochastic factors.

Before discussing the results from the longer sample, a caveat must be discussed. Four out of 36 advanced economies in our sample have data between 1991-1999, resulting in the unbalanced panel of advanced economies having only 36 more observations than the balanced panel of advanced economies. Consequently, a small gain in precision from extending the sample period back to 1991 may not be worth the risk of introducing sample-selection bias in the estimates from the unbalanced panel, causing them to be inconsistent.

Panel A of Figure 3 illustrates the IRFs to a positive productivity shock in advanced economies from the unbalanced panel as estimated using the benchmark specification and the specification that allows for richer dynamics ($\bar{k} = 2$). There are two findings which are in general robust to the different selections of

$\bar{k}$ and are similar to those seen in the shorter balanced panel. First, the terms of trade in advanced economies show insignificant dynamics after a positive productivity shock. Second, the export and import prices in advanced economies experience a large fall after the shock.

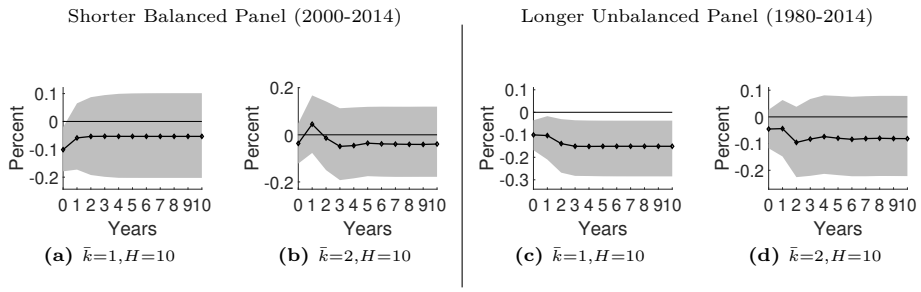
Panel B of Figure 3 displays the IRFs to an unexpected increase in productivity in developing economies in the unbalanced panel as estimated using the aforementioned specifications. In the unbalanced panel, the IRFs of the terms of trade in developing economies in the benchmark specification are not significant. This finding is consistent with our baseline results. In the specification allowing for richer dynamics, on the other hand, the terms of trade in developing economies show barely significant increases after a positive productivity shock, caused largely by an increase in the export prices. This finding slightly differs from the baseline results and provide some weak evidence against both the small-country assumption and the Prebisch-Singer hypothesis since while the former predicts no terms-of-trade change, the latter predicts a definite terms-of-trade decline following such a shock in developing economies.

4.2.3 TFP at Constant National Prices as a Different Measure of Productivity

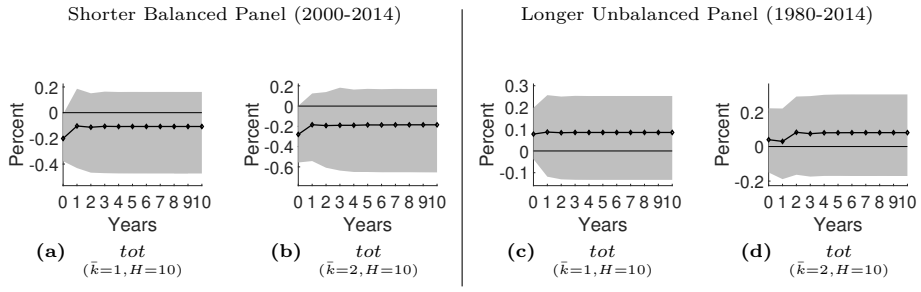
In our main analysis, we opted to use output per employed person as a measure of productivity due to the larger availability of data for a large number of economies. However, a better measure of productivity in an economy is total factor productivity at constant national prices (denoted by tfp_{it}), on which Feenstra, Inklaar, and Timmer (2015) have data only for about half of the economies included in our sample; see Table A.1.

This section presents the results using the log of tfp_{it} as a measure of productivity. In line with the previous analysis, we do robustness checks by considering different model specifications and different sample periods. In-

Panel A: Advanced Economies



Panel B: Developing Economies



Note: Our calculations are based on data from the World Bank's *World Development Indicators* and Feenstra, Inklaar, and Timmer (2015). Solid lines with diamonds indicate the median IRFs. Grey areas are 90 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 4: *IRFs of the Terms of Trade to a Positive Productivity Shock (Third Robustness Check: TFP as a Different Productivity Measure)*

deed, we obtain the results from both the benchmark specification, given by $\bar{k} = 1, H = 10$, and the alternative specification allowing for richer dynamics, given by $\bar{k} = 2, H = 10$. In addition, we consider two panels: the balanced panel

spanning the period of 2000-2014 and the unbalanced panel spanning the period of 1980-2014 with about half of the developing economies and only four of the advanced economies in our sample having data between 1980-1999. Figure 4 shows the IRFs of the terms of trade to a productivity shock identified by selecting tfp_{it} as a measure of productivity.[9] Apart from a decisive terms-of-trade fall in advanced economies when the benchmark specification in the unbalanced panel is considered, the IRFs of the terms of trade in Figure 4 are largely similar to the baseline results displayed in Figure 1.

4.3 A More Detailed Classification of Developing Economies

Prebisch (1964) argues that developing economies can prevent their terms of trade from deteriorating over time by diversifying their exports into manufactured products. The success in export diversification widely vary across developing economies. This is evident from the fact that the group of developing economies has substantial heterogeneity in the structure of their exports. For example, commodities accounted for more than two thirds of merchandise exports in the overwhelming majority of the least developed countries between 2013-2015, as noted in UNCTAD (2016). In contrast, in the same period, 90 percent of total exports in Poland was manufactured exports, and more than 50 percent of which was medium- and high-tech manufactured exports. This substantial heterogeneity in the structure of exports brings about the question of whether an unexpected improvement in productivity causes notable heteroge-

[9] The analysis similar to appendix B indicates that tfp, p^x, and tot in both advanced and developing economies are of integrated order one and there is no linear combination of the series which is stationary. Consequently, the panel VAR model for both groups is specified in first-differences to eliminate all non-standard distributions that would result were the model specified in levels. The results are not reported for reasons of brevity. Also, to save on space, the IRFs of the other variables are not reported. They are, however, largely similar to the corresponding ones reported in Figure 1-3 with gdp_{it} as the measure of productivity.

neous dynamics in the group of developing economies. We study this question by further dividing this group into two sub-groups: the developing economies with a high degree of export diversification—whose average index between the years 2000 and 2010 ranks in the first quartile of the IMF's *export diversification index* among developing economies—and the remaining developing economies which have a lower degree of export diversification. The numbers of the economies in the former and the latter are 33 and 98, respectively.[10] Table A.1 in the appendix presents the economies on the list of the developing economies with a high degree of export diversification.

Figure 5 displays the IRFs of the variables to a positive productivity shock in the developing economies with a high degree of export diversification and the remaining developing economies.[11] Consistent with the previous analysis, we consider the benchmark specification given by $(\bar{k} = 1, H = 10)$ and the specification with richer dynamics given by $(\bar{k} = 2, H = 10)$. Regarding the developing economies with a high degree of export diversification, we find that an unexpected increase in productivity leads to an improvement in the terms of trade.[12] In contrast, an unexpected increase in productivity in the remaining developing economies results in no significant change in the terms of trade.

As a second robustness check, we consider the longer sample period of 1991-2016. Since data is unavailable for a large number of developing economies between 1991-1999, the panel is unbalanced. Consequently, the consistency

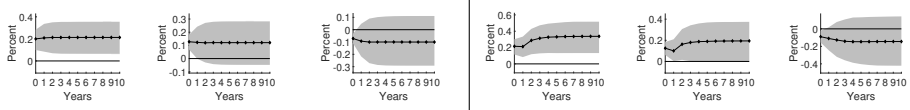
[10] Data on the export diversification index is available for 131 out of 141 developing economies in our sample. In this section, we only include the developing economies having data on the export diversification index.

[11] The analysis similar to appendix B indicates that gdp, tot, and p^x in the developing economies with a high degree of export diversification and the remaining developing economies are of order one and there is no stationary linear combination of the series. Consequently, the panel VAR model is specified in first-differences to eliminate all non-standard distributions that would result were the model specified in levels. The results are not reported for reasons of brevity.

[12] For the sake of brevity, the IRFs of output per employed person, which stay positive and are distinguishable from zero across all the periods that we compute IRFs, are not shown in Figure 5.

Panel A: Developing Economies with a High Degree of Export Diversification

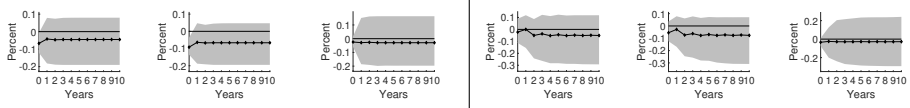
The Benchmark Identification ($\bar{k} = 1, H = 10$) | Robustness Check ($\bar{k} = 2, H = 10$)



(a) tot **(b)** p^x **(c)** p^m **(d)** tot **(e)** p^x **(f)** p^m

Panel B: Remaining Developing Economies

The Benchmark Identification ($\bar{k} = 1, H = 10$) | Robustness Check ($\bar{k} = 2, H = 10$)



(a) tot **(b)** p^x **(c)** p^m **(d)** tot **(e)** p^x **(f)** p^m

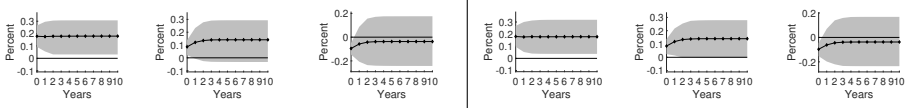
Note: Our calculations are based on the World Bank's *World Development Indicators*. Solid lines with diamonds indicate the median IRFs. Grey areas are 90 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 5: *IRFs to a Positive Productivity Shock (Baseline Results and First Robustness Check)*

of the results requires the additional assumption that selection is unrelated to idiosyncratic errors. The IRFs to an unexpected increase in productivity in the developing economies with a high degree of export diversification and the remaining developing economies as estimated using both of the aforementioned specifications in the unbalanced panel are shown, respectively, by *Panel A* and *Panel B* of Figure 6. As is evident from the figure, our main finding from

Panel A: Developing Economies with a High Degree of Export Diversification

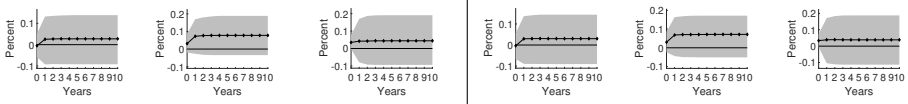
The Benchmark Identification ($\bar{k} = 1, H = 10$) | Robustness Check ($\bar{k} = 2, H = 10$)



(a) tot **(b)** p^x **(c)** p^m **(d)** tot **(e)** p^x **(f)** p^m

Panel B: Remaining Developing Economies

The Benchmark Identification ($\bar{k} = 1, H = 10$) | Robustness Check ($\bar{k} = 2, H = 10$)



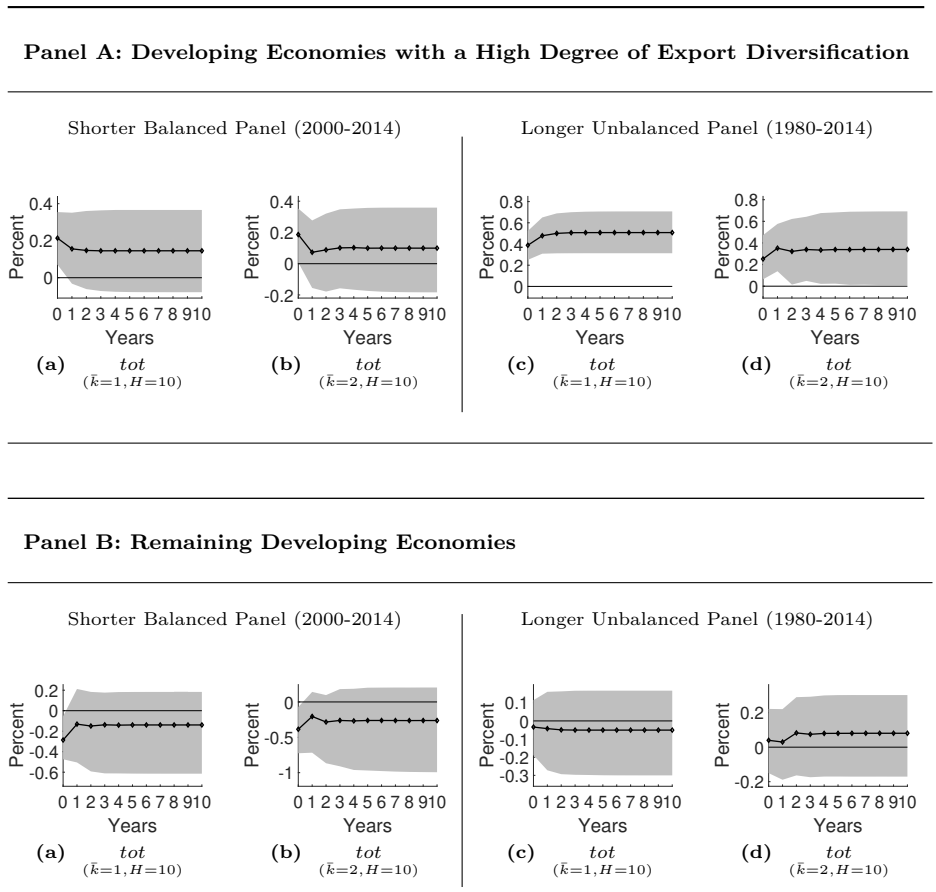
(a) tot **(b)** p^x **(c)** p^m **(d)** tot **(e)** p^x **(f)** p^m

Note: Our calculations are based on the World Bank's *World Development Indicators*. Solid lines with diamonds indicate the median IRFs. Grey areas are 90 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 6: *IRFs to a Positive Productivity Shock*
(Second Robustness Check: Extended Sample Period)

this section that the terms of trade experience a significant improvement in the developing economies with a high degree of export diversification following an unexpected increase in productivity is robust to extending the sample period and using an alternative specification with richer dynamics.

As a third robustness check, we perform a similar analysis to section 4.2.3 by selecting total factor productivity at constant national prices (denoted by tfp_{it})



Note: Our calculations are based on data from the World Bank's *World Development Indicators* and Feenstra, Inklaar, and Timmer (2015). Solid lines with diamonds indicate the median IRFs. Grey areas are 90 percent confidence intervals estimated using the Monte Carlo method presented in appendix C.

Figure 7: *IRFs of the Terms of Trade to a Positive Productivity Shock (Third Robustness Check: TFP as a Different Productivity Measure)*

as the measure of productivity.[13] Consistent with the baseline results, our com-

[13]The panel VAR model including tfp, tot, and p^x is specified in first-differences for the developing economies with a high degree of export diversification and the remaining developing economies since an analysis similar to appendix B indicates that tfp, tot, and p^x are of order one and there is no stationary linear combination of the series.

mon finding in this analysis is that an increase in productivity is associated with a significant terms-of-trade improvement (no significant terms-of-trade change) in the developing economies with a high degree of export diversification (the remaining developing economies).[14] This finding provides evidence against both the small-country assumption and the Prebisch-Singer hypothesis. Its critical significance in the literature lies in that putting all developing economies in the same basket can be misleading since the developing economies with a high degree of export diversification can positively distinguish themselves from the remaining developing economies regarding the effect of productivity shocks on the terms of trade.

5 Discussion and Conclusions

In this paper, we studied the effects from economy-specific shocks to productivity on the terms of trade with a focus on developing economies. We obtained the results with the various model specifications, the different sample periods, and the different measures of productivity. Our robust finding in this analysis is that such an increase results in insignificant dynamics in the terms of trade in both developing and advanced economies. While this finding support the small-country assumption for developing economies when considered as a whole, it rejects the Prebisch-Singer hypothesis, predicting more adverse terms-of-trade dynamics in developing economies than in advanced economies following a surprise increase in productivity. However, studying the terms-of-trade effects from a positive economy-specific shock to productivity in a more detailed classification of developing economies revealed another robust finding in our study that

[14] The only exception is the results from the specification ($\bar{k} = 2, H = 10$) in the unbalanced panel, which indicate that the terms of trade in the developing economies with a high degree of export diversification and in the remaining developing economies show insignificant dynamics and an initial decline, respectively, after the positive productivity shock. Even in this case, it can be asserted that an increase in productivity affects the terms of trade in the former more favorably than that in the remaining developing economies.

such a shock is associated with a significant improvement in the terms of trade in the developing economies with a high degree of export diversification.

Consequently, it is questionable to maintain the small-country assumption for the developing economies with a high degree of export diversification. An essential step to accounting for our finding of a significant appreciation in the terms of trade after a positive economy-specific shock to productivity in these economies is to drop the assumption that they export homogeneous products, as implied by the small-country assumption in the literature and assume instead that they also produce differentiated products in international markets. This can be based on the fact that the share of differentiated goods exported by the developing world to the OECD countries increased considerably between 1980 and 2006, as noted in Artopoulos, Friel, and Hallak (2013). This can result either from the success of some developing economies to move up in the ladder of economic development or simply from these economies involving in the low-skill assembly stages of global production chains organized by multinational firms headquartered in the developed world.

When the possibility that developing economies can export differentiated goods is taken into account, Ghironi and Melitz's (2005) model of international trade with endogenous entry of firms can rationalize our finding of a non-negligible improvement in the terms of trade due to an increase in productivity in the developing economies with a high degree of export diversification. In this model, the country with an increase in productivity attracts more prospective entrants due to its increased size. The new firms entering the country due to increased productivity induce a large demand for labor, resulting in a rise in the relative cost of effective labor in the country vis-a-vis its trading partners. Accordingly, the terms of trade appreciate in the country. Alternatively, our finding can also be accounted for by standard international macroeconomics

models with suitable calibration of model parameters. For example, Corsetti, Dedola, and Leduc (2008) show in such a model that a sufficiently low trade price elasticity together with substantial home bias in consumption can result in an increase in productivity causing a permanent appreciation in the terms of trade. This results from the demand for domestic goods raising above supply due to strong wealth effects brought about by increased productivity.

A favorable effect from an increase in productivity on the terms of trade in developing economies with differentiated exports can also result from a more structural reason. Indeed, differentiated exports are likely to have a larger price elasticity of demand and supply than homogenous exports. This implies that an increase in productivity in developing economies with differentiated exports can lead to increased export earnings by causing an increase in export volumes larger than a fall in the prices of their traditional exports. Increased export earnings, in turn, can relieve the balance of payment constraints on the imports of required capital goods and allow developing economies to upgrade their exports by moving from their traditional exports of primary and labor-intensive goods to medium- and high-technology intensive goods. Since the latter is less subject to the fallacy of composition problem, increased productivity in developing economies with differentiated exports can also have a favorable effect on the terms of trade through this additional channel.

Appendix A Economies in Our Sample

Panel A. Developing Economies included in Our Sample		
Afghanistan†	*Gabon*	*Nigeria*
Albania†	*Gambia, The*†	Oman†
Algeria†	Georgia†	*Pakistan*†
Angola†	*Ghana*†	***Panama***
Argentina	Guam†§	Papua New Guinea†
Armenia	***Guatemala***	*Paraguay*
Azerbaijan†	*Guinea*†	*Peru*
Bahamas, The†	*Guinea-Bissau*†	*Philippines*
Bahrain	Guyana†	**Poland**
Bangladesh†	*Haiti*†	Qatar
Barbados	*Honduras*	**Romania**
Belarus†	**Hungary**	Russian Federation
Belize†	***India***	*Rwanda*
Benin	***Indonesia***	Samoa†
Bhutan§	Iran, Islamic Rep.	*Sao Tome and Principe*†§
Bolivia†	Iraq	Saudi Arabia
Bosnia and Herzegovina†	Jamaica	*Senegal*
Botswana§	***Jordan***	Sierra Leone
Brazil	Kazakhstan	Solomon Islands†
Brunei Darussalam†§	***Kenya***	Somalia†
Bulgaria	**Korea, Dem. People's Rep.**†	***South Africa***
Burkina Faso	Kuwait	*Sri Lanka*
Burundi	**Kyrgyz Republic**	St. Lucia†
Cabo Verde†	Lao PDR	St. Vincent and the Grenadines†
Cambodia†	**Lebanon**†	Suriname†
Cameroon	*Lesotho*§	*Swaziland*§
Central African Republic	Liberia†	Syrian Arab Republic†
Chad†	Libya†	Tajikistan
Chile	Macedonia, FYR†§	***Tanzania***
China	*Madagascar*†	***Thailand***
Colombia	*Malawi*†	*Togo*
Comoros†	*Malaysia*	Tonga†
Congo, Dem. Rep.†	Maldives†	Trinidad and Tobago
Congo, Rep.	*Mali*†	*Tunisia*
Costa Rica	*Mauritania*	***Turkey***
Cote d'Ivoire	*Mauritius*	Turkmenistan†
Croatia	***Mexico***	*Uganda*†
Djibouti†	**Moldova**	**Ukraine**
Dominican Republic	Mongolia	United Arab Emirates†
Ecuador	*Morocco*	***Uruguay***
Egypt, Arab Rep.	*Mozambique*	Uzbekistan†
El Salvador†	*Myanmar*†	Vanuatu†§
Equatorial Guinea†	*Namibia*§	*Venezuela, RB*
Eritrea†	**Nepal**†	**Vietnam**†
Ethiopia†	New Caledonia†	Yemen, Rep.†
Fiji	*Nicaragua*	*Zambia*†
French Polynesia†	*Niger*	*Zimbabwe*
Panel B: Advanced Economies Included in Our Sample		
Australia	*Hong Kong SAR, China*	Netherlands
Austria	Iceland	New Zealand
Belgium	Ireland	Norway
Canada	Israel	Portugal
Cyprus	Italy	*Singapore*
Czech Republic	Japan	Slovak Republic
Denmark	*Korea, Rep.*	Slovenia
Estonia	Latvia	Spain
Finland	Lithuania	Sweden
France	Luxembourg	Switzerland
Germany	Macao SAR, China	United Kingdom
Greece	Malta	*United States*

Note:

- The sample period of those economies *emphasized* is 1991-2016. Economies not emphasized have data between 2000-2016.
- Economies in **bold** characters are the developing economies ranking in the first quartile of the IMF's *Export Diversification Index* among developing economies between 2000-2010.
- Economies with a † are the developing economies whose data on TFP at constant national prices is unavailable.
- Economies with a § are the developing economies whose data on the IMF's Export Diversification Index is unavailable.

Table A.1: *Economies in Our Sample*

Appendix B Specifications Issues

While estimating a vector autoregression often provides a convenient way of describing dynamics of variables, it involves making a number of critical decisions which may have a significant impact on inference. For example, when some variables included in the VAR contain a unit root, should they be included in levels or in differences? Hamilton (1994, p. 651-653) discusses this issue in detail. He notes if the true process is VAR in differences, differencing should improve the small-sample performance of all estimates and can eliminate non-standard distributions associated with certain hypothesis testing. However, differencing all variables in a VAR can result in a misspecified regression in such cases where some variables are already stationary or there is a stationary linear relationship between *I(1)* variables included in the VAR.[15]

We represent our system with a panel VAR with interactive fixed effects in differences based on two findings. First, using a panel unit root test, we reveal all variables included in our panel VAR model are *I(1)*. Second, we show that there is no linear combination of the variables which is stationary.

B.1 Panel Unit Root Tests in the Presence of Common Shocks

We investigate whether the series' contain a unit root or not using the modified Sargan–Bhargava test (the MSB test) proposed by Stock (1999) and discussed extensively in Bai and Carrion-I-Silvestre (2009) and Bai and Ng (2010) in the context of a panel data with cross-sectional dependence. The model on which the *MSB* test is based is given by

$$\begin{aligned} y_{i,t} &= \mu_i + \nu_i t + f_t' \lambda_i + u_{i,t} \\ i = 1, 2, \ldots, N \quad &; \quad t = 1, 2, \ldots, T \end{aligned} \tag{B.1}$$

where $y_{i,t}$ denotes one of the three variables contained in $\mathcal{Y}_{i,t}$. μ_i and ν_i represent economy-specific intercept and trend terms, respectively. λ_i, f_t, and $u_{i,t}$ represent

[15] In fact, as shown in Hamilton (1994, p. 574-575), a cointegrated system cannot be represented by a VAR in differences.

factor loadings, common factors, and idiosyncratic errors, respectively.

The error structure in the *MSB* test is useful for two reasons. First, it is notable that since λ_i is an economy-specific parameter, the error structure allows common shocks to have a different effect on individual economies. This assumption is useful in our analysis since common shocks can affect individual economies differently. For example, the unprecedented increase in the IMF's crude oil price index from its trough of 19.54 to its peak of 249.66 between 1998:12 and 2008:7 can be regarded as a global oil shock. It may be argued that while this shock favorably affected the terms of trade of oil-exporting economies, it had an unfavorable effect on the terms of trade of oil-importing economies. Second, since common shocks are likely to cause high cross-section dependence, the assumption of uncorrelated error terms across countries, as in Choi (2001), would result in large size distortion; see Pesaran (2007).

One can write the differenced form of (B.1) in matrix notation as

$$\begin{aligned} \Delta y_i &= \iota_T \nu_i + \Delta f \lambda_i + \Delta u_i \\ i = 1, 2, \ldots, N \quad &; \quad t = 2, 3, \ldots, T \end{aligned} \tag{B.2}$$

where ι_T is a $T \times 1$ vector of ones. Let $M_{\iota_T} = I_T - \frac{1}{T}\iota_T \iota_T'$. Multiplying (B.2) with M_{ι_T} eliminates the constant from this equation:

$$\begin{aligned} \Delta y_{i,t}^* &= \Delta f_t^{*'} \lambda_i + \Delta u_{i,t}^* \\ i = 1, 2, \ldots, N \quad &; \quad t = 2, 3, \ldots, T \end{aligned} \tag{B.3}$$

where $\Delta y_{i,t}^* = M_{\iota_T} \Delta y_{i,t}$, $\Delta f_t^* = M_{\iota_T} \Delta f_t$, and $\Delta u_{i,t}^* = M_{\iota_T} \Delta u_{i,t}$. Let $\hat{u}_{i,t}^*$ be the least squares estimates of $\sum_{s=2}^{T} \Delta u_{i,s}^*$. The $MSB_{\bar{u}^*}(i)$ test statistics is defined by

$$MSB_{\bar{u}^*}(i) = \frac{(T-2)^2 \sum_{t=3}^{T} \hat{u}_{i,t-1}^{*^2}}{\hat{\sigma}_{u_i^*}^2} \tag{B.4}$$

where $\hat{\sigma}_{u_i^*}^2$ denotes an estimator of the long-run variance of u_i^*. As suggested by Bai and Carrion-i Silvestre (2013), $\hat{\sigma}_{u_i^*}^2$ can be estimated as

$$\hat{\sigma}_{u_i^*}^2 = \frac{\hat{\sigma}_{k_i,i}^2}{1 - \widehat{\phi}_{i,1}} \tag{B.5}$$

with $\hat{\sigma}^2_{k_i,i} = (T-3)^{-1}\sum_{t=4}^{T}\hat{\nu}_{i,t}$, where $\widehat{\phi}_{i,1}$ and $\hat{\nu}_{i,t}$ are the least squares estimates from the following equation:

$$\begin{aligned} \Delta\hat{u}^*_{i,t} &= \phi_{i,0}\hat{u}^*_{i,t-1} + \phi_{i,1}\Delta\hat{u}^*_{i,t-1} + \nu_{i,t} \\ i = 1,2,\ldots,N \quad &; \quad t = 4,5,\ldots,T \end{aligned} \tag{B.6}$$

The MSB test discussed in Bai and Carrion-I-Silvestre (2009), which asymptotically has standard normal distribution, is given by

$$MSB_{\bar{u}^*} = \sqrt{N}\frac{\overline{MSB_{\bar{u}^*}} - \frac{1}{6}}{\sqrt{\frac{1}{45}}} \tag{B.7}$$

with $\overline{MSB_{\bar{u}^*}} = N^{-1}\sum_{i=1}^{N} MSB_{\bar{u}^*}(i)$.

Panel A and *Panel B* of Table B.1 report the *MSB* test statistics of $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ for advanced and developing economies, respectively. It is notable that when obtaining the $MSB_{\bar{u}^*}$ test statistics, the number of common factors in (B.3) is treated as unknown and is estimated using the eigenvalue ratio estimator suggested by Ahn and Horenstein (2013) allowing up to five common factors. The number of factors selected based on the eigenvalue ratio estimator is one for $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ in our sample of both advanced and developing economies. From the *p-values* reported in *Panel A*, it is evident that the null hypothesis of a unit root in neither $gdp_{i,t}$, nor $p^x_{i,t}$, and nor $tot_{i,t}$ across all advanced economies cannot be rejected. Similarly, we fail to reject the null in the sample of developing economies for $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ since the p-values of the $MSB_{\bar{u}^*}$ test statistics reported in Panel B are larger than the 5% significance level selected in our analysis.

B.2 A Panel Cointegration Test in the Presence of Common Shocks

Can there be a linear combination of $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ that is stationary and suggests a long-run equilibrium relationship between $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ despite the presence of a unit root in the series? Put differently, are $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$

Panel A: Advanced Economies			
	$gdp_{i,t}$	$p^x_{i,t}$	$tot_{i,t}$
	4.68	-0.62	0.37
	(1.00)	(0.27)	(0.64)
Panel B: Developing Economies			
	$gdp_{i,t}$	$p^x_{i,t}$	$tot_{i,t}$
	5.10	-1.08	0.14
	(1.00)	(0.14)	(0.55)

Note: Panel A and Panel B report the *MSB* test statistics of the *log-level* of the variables for advanced and developing economies, respectively. Numbers in parenthesis refer to the p-values of the *MSB* test statistics.

Table B.1: *Panel Unit Root Test Results*

cointegrated? The answer to this question is instrumental in specifying the panel VAR model discussed in section 2.1. Indeed, when a linear combination of the series is stationary, the level specification must be preferred since a panel VAR in differences is not consistent with a cointegrated system, as shown in Hamilton (1994). Before explaining how we test for cointegration, it is useful to review two well-known economic models related to the terms of trade determination: a standard international macro model with differentiated goods and the Prebisch-Singer model. In the former, the terms of trade between any two countries are largely determined by differences in productivity in their tradable sectors and an increase in productivity is most likely associated with a fall in export prices. The latter argues that apart from differences in productivity in tradables sectors, the goods and labor market structures also play a key role in the determination of the terms of trade. Indeed, according to the latter, the effect that increased productivity has on export prices would be more unfavorable in economies with more competitive goods and labor markets. Can $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ have a cointegration relation based on either the former or the latter? When common factors are omitted from the analysis, in our opinion, the answer is no since the series in our analysis include neither a measure of productivity in the foreign trade sector nor a measure of competition in the goods and labor markets. However, in the presence of

common factors, the answer is more complex. Indeed, when common factors are added to the analysis, a measure of changes in productivity in the foreign trade sector can be reflected in a linear combination of common factors, possibly yielding that a long-run relationship between $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ can exist up to some common global trends represented by these factors.

Next, we discuss the issue from the statistical point of view. We test whether the series in our analysis are cointegrated with the panel cointegration test developed by Bai and Carrion-i Silvestre (2013), which allows cross-sectional dependence with common factors. The model we consider can be written as

$$\begin{aligned} gdp_{i,t} &= \mu_i + X'_{i,t}\beta + f'_t\lambda_i + u_{i,t} \\ i = 1, 2, \ldots, N \quad &; \quad t = 1, 2, \ldots, T \end{aligned} \tag{B.8}$$

where $X_{i,t} = \begin{bmatrix} tot_{i,t} & p^x_{i,t} \end{bmatrix}'$. This equation has the desirable feature that a cointegration relationship is tested in the presence of dynamic common factors, f_t. Such factors in the model can substitute for some important missing variables not included in our analysis due to the unavailability of such data as the unobservable common changes in productivity affecting many countries. In addition, we test for cointegration under the assumption that idiosyncratic errors, $u_{i,t}$, are independent across economies and allow cross-section correlation in the error terms by means of common factors included therein. Were such factors omitted from the errors, there would be no cross-section correlation. This can be viewed as implausible given that common shocks are likely to result in a large correlation in the error terms across economies.

The cointegration equation in (B.8) has the normalization that the coefficient on $gdp_{i,t}$ in a possible long-run equilibrium relation is one since $gdp_{i,t}$ is specified as the dependent variable in (B.8). As suggested by Hamilton (1994), it is important to test for cointegration with alternative normalizations. In our study, these alternative normalizations are the cointegration equations given by (B.8) with $tot_{i,t}$ as the dependent variable and $X_{i,t} = \begin{bmatrix} gdp_{i,t} & p^x_{i,t} \end{bmatrix}'$ or $p^x_{i,t}$ as the dependent variable and $X_{i,t} = \begin{bmatrix} gdp_{i,t} & tot_{i,t} \end{bmatrix}'$.

It is notable that the presence of a cointegration relationship between the se-

ries is studied with (B.8) under the assumption of *homogeneous slopes*. Indeed, β is assumed to be common across all economies of the same group, implying that a homogeneous cointegration relationship between the series is assumed. The assumption of homogeneous slopes in the cointegration equations is made to be consistent with the assumption of *homogeneous slopes* in the panel VAR model which we use in forecasting the effects of an improvement in productivity on the terms of trade in advanced and developing economies, as discussed in section 2.1. Assuming homogeneous slopes in our panel VAR model can be defended by the fact that the models with homogeneous slopes are shown to have better forecast performance due to their parsimonious representation and does not suffer from parameter estimate instability which occurs in heterogeneous slope models due to estimating several parameters with short time series; see Baltagi (2005, chapter 10).

Now, we can discuss the panel cointegration test statistics in our analysis, which is based on the following equation:

$$\begin{aligned} \Delta gdp_{i,t} &= \Delta X_{i,t}\beta + \sum_{j=-1}^{1} \Delta^2 X'_{i,t+j} A_j + \Delta f'_t \lambda_i + \Delta \xi_{i,t} \\ & \\ & i = 1, 2, \ldots, N; \; t = 3, 4, \ldots, T-1 \end{aligned} \tag{B.9}$$

This equation can be regarded as the differenced form of the model given by (B.8) with the additional term $\sum_{j=-1}^{1} \Delta^2 X'_{i,t+j} A_j$, which is added to the equation since we augment the model using the dynamic least squares method, as in Bai and Carrion-i Silvestre (2013). (B.9) can be rewritten more compactly as

$$\begin{aligned} \Delta gdp_{i,t} &= x'_{i,t}\delta + \Delta f'_t \lambda_i + \Delta \xi_{i,t} \\ i = 1, 2, \ldots, N \quad &; \quad t = 3, 4, \ldots, T-1 \end{aligned} \tag{B.10}$$

where $x_{i,t} = \begin{bmatrix} \Delta X_{i,t} & \Delta^2 X_{i,t+1} & \Delta^2 X_{i,t} & \Delta^2 X_{i,t-1} \end{bmatrix}$ and $\delta = \begin{bmatrix} \beta & A_{-1} & A_0 & A_1 \end{bmatrix}'$. Let $\hat{\xi}_{i,t}$ be the least squares estimates of $\sum_{s=3}^{t} \Delta \xi_{i,s}$ from (B.9). As noted in Bai and Carrion-i Silvestre (2013), the least squares estimates of $\sum_{s=3}^{t} \Delta \xi_{i,s}$ can be obtained with an iterative procedure. Indeed, Δf_t can be estimated for given δ. With this estimate of Δf_t, δ can be estimated and used in

the next iteration. The same steps in iteration are performed until convergence. It is notable that in this iterative estimation, the number of common factors must first be selected. To decide on the number of common factors in the context of such iterative estimation, Bai (2009) suggests two criteria, referred to as the IC and PC criteria. We allow up to five common factors in estimation, as in Byrne, Fazio, and Fiess (2013), and select the number of common factors as the simple average of the numbers of common factors selected by the aforementioned two criteria.

Next, using computed $\hat{\xi}_{i,t}$, we define the $MSB_{\bar{\xi}}(i)$ statistics as

$$MSB_{\bar{\xi}}(i) \quad = \quad \frac{(T-4)^2 \sum_{t=4}^{T-1} \hat{\xi}_{i,t-1}^2}{\hat{\sigma}_i^2} \tag{B.11}$$

where $\hat{\sigma}_i^2$ is the estimate of the long-run variance of $\xi_{i,t}$, which is obtained using the method discussed in (B.5).

Next, we define the $MSB_{\bar{\xi}}$ statistics which is obtained by pooling $MSB_{\bar{\xi}}(i)$ from (B.11) across economies under the assumption of no cross-section correlation in the idiosyncratic errors:

$$MSB_{\bar{\xi}} \quad = \quad \sqrt{N}\frac{\overline{MSB_{\bar{\xi}}(i)} - \frac{1}{2}}{\sqrt{\frac{1}{3}}} \tag{B.12}$$

with $\overline{MSB_{\bar{\xi}}(i)} = N^{-1}\sum_{i=1}^{N} MSB_{\bar{\xi}}(i)$. To test for cointegration between the series in our analysis, we use the $MSB_{\bar{\xi}}$ statistics, which has the standard normal distribution, as shown in Bai and Carrion-I-Silvestre (2009).

Now, we can discuss the results on cointegration. *Panel A* and *Panel B* in Table B.2 present the results for advanced and developing economies, respectively. The variables in the rows indicate the normalized variable in the cointegration equation, as discussed above. For each normalization, the test for cointegration is performed with and without common factors. In the case that common factors are contained in the analysis, we report the number of common factors, estimated as indicated above. Also, we compute the number of stochastic trends in common factors with the MQ_c

Panel A: Advanced Economies

Normalized Variable	With factors			Without factors
	$MSB_{\bar{\xi}}$	# of factors	# of stochastic trends in factors	$MSB_{\bar{\xi}}$
$\mathbf{gdp_{i,t}}$	-2.669 (.004)	4	2	1.208 (.887)
$\mathbf{p^x_{i,t}}$	1.091 (.862)	3	3	3.570 (1.000)
$\mathbf{tot_{i,t}}$	2.509 (.994)	3	3	2.896 (.998)

Panel B: Developing Economies

Normalized Variable	With factors			Without factors
	$MSB_{\bar{\xi}}$	# of factors	# of stochastic trends in factors	$MSB_{\bar{\xi}}$
$\mathbf{gdp_{i,t}}$	-7.968 (.000)	3	3	31.726 (1.000)
$\mathbf{p^x_{i,t}}$	3.472 (1.000)	3	3	6.461 (1.000)
$\mathbf{tot_{i,t}}$	5.590 (1.000)	3	3	4.366 (1.000)

Note: Numbers in parenthesis are the p-values of the $MSB_{\bar{\xi}}$ statistics.

Table B.2: *Panel Cointegration Test Results*

test proposed by Bai and Ng (2004).

When common factors are contained in the analysis and $gdp_{i,t}$ is selected as the normalized variable in (B.10), the null hypothesis that $\xi_{i,t}$ is of integrated order one can be rejected for advanced and developing economies at the 5% significance level (the p-values of the $MSB_{\bar{\xi}}$ statistics are .004 and .000, respectively). However, with this normalization, we estimate there are four common factors having two stochastic trends for advanced economies and three common factors having three stochastic trends for developing economies. Consequently, we conclude that the variables are cointegrated

only up to some global stochastic trends with this normalization.

Can there be a stationary linear combination of $gdp_{i,t}$, $p^x_{i,t}$, and $tot_{i,t}$ when they are cointegrated up to some global stochastic trends? To answer this question, we first write from (B.9) that

$$gdp_{i,t} - \mu_i + X_{i,t}\beta - \sum_{j=-1}^{1} \Delta X'_{i,t+j} A_j - f'_t \lambda_i \quad = \quad \xi_{i,t} \tag{B.13}$$

While we find that $\xi_{i,t}$ in (B.13) is stationary when $gdp_{i,t}$ is the normalized variable, $gdp_{i,t} - \mu_i + X_{i,t}\beta$ is not. This results from f_t including stochastic trends and λ_i differing across economies. Consequently, even when we find $\xi_{i,t}$ is stationary, there cannot be a linear combination of the variables that is stationary if common factors have stochastic trends.

For the alternative normalizations for cointegration with common factors, we find that the $MSB_{\bar{\xi}}$ statistics have large p-values. For example, with $p^x_{i,t}$ as the normalized variable, the p-values of the estimated $MSB_{\bar{\xi}}$ statistics are .862 and 1.000 for advanced and developing economies, respectively, implying that the null that $\xi_{i,t}$ contains a unit root is true with a large probability. Consequently, we find no cointegration in this case even when global stochastic trends in common factors are allowed in the cointegration equation. Similar results hold when $tot_{i,t}$ is selected as the normalized variable, as is evident from Table B.2.

Lastly, we discuss the $MSB_{\bar{\xi}}$ statistics from the model omitting common factors in (B.9). The results from this model should be interpreted with caution since the $MSB_{\bar{\xi}}$ statistics are obtained by pooling individual $MSB_{\bar{\xi}}\,(i)$ statistics from (B.11) under the implausible assumption of no cross-section correlation in the error terms. In contrast, the model with common factors has $\Delta f'_t \lambda_i$ in the error terms, allowing the error terms to be correlated across economies. With this caution in mind, the results from the model without common factors indicate that regardless of the normalized variable in the cointegration equation, the $MSB_{\bar{\xi}}$ statistics have a large p-value. Consequently, we find that the hypothesis of no cointegration between the series is likely to hold in this model.

Appendix C Calculating Standard Errors for IRFs

In this section, we describe the Monte Carlo method with which the standard errors for IRFs to a positive idiosyncratic shock are calculated.

First, let $\xi_{i,t}$, $z_{i,t}$, β, and F_t are defined by

$$\underset{3\times(3+9\bar{k})}{z_{i,t}} = \begin{bmatrix} I_3 & I_3 \otimes \xi'_{i,t} \end{bmatrix};$$

$$\underset{(3+9\bar{k})\times 1}{\beta} = \begin{bmatrix} \alpha'_0 & \alpha_1^{\Delta gdp'} \dots \alpha_{\bar{k}}^{\Delta gdp'} & \alpha_1^{\Delta p^{x'}} \dots \alpha_{\bar{k}}^{\Delta p^{x'}} & \alpha_1^{\Delta tot'} \dots \alpha_{\bar{k}}^{\Delta tot'} \end{bmatrix}';$$

$$\underset{3\bar{k}\times 1}{\xi_{i,t}} = \begin{bmatrix} \Delta\mathcal{Y}'_{i,t-1} \dots \Delta\mathcal{Y}'_{i,t-\bar{k}} \end{bmatrix}' \quad ; \quad \underset{3\times 3r}{F_t} = \begin{bmatrix} I_3 \otimes f'_t \end{bmatrix}$$

Our panel vector autoregression model with interactive fixed effects in (2.3) can be written more compactly as

$$\Delta\mathcal{Y}_{i,t} = z_{i,t}\beta + F_t\lambda_i + u_{i,t} \tag{C.1}$$

Stacking economy i's observations in (C.1) yields

$$\Delta\mathcal{Y}_i = Z_i\beta + F\lambda_i + u_i \tag{C.2}$$

where

$$\begin{aligned} \underset{3T\times 1}{\Delta\mathcal{Y}_i} &= \begin{bmatrix} \Delta\mathcal{Y}'_{i,1} \dots \Delta\mathcal{Y}'_{i,T} \end{bmatrix}' \quad ; \quad \underset{3T\times(3+9\bar{k})}{Z_i} = \begin{bmatrix} z'_{i,1} \dots z'_{i,T} \end{bmatrix}' \\ \underset{3T\times(3r)}{F} &= \begin{bmatrix} F'_1 \dots F'_T \end{bmatrix}' \quad ; \quad \underset{3T\times 1}{u_i} = \begin{bmatrix} u'_{i,1} \dots u'_{i,T} \end{bmatrix}' \end{aligned} \tag{C.3}$$

The least squares estimates $\widehat{\beta}$ and $\widehat{f_t}$ can iteratively be computed, as discussed in Tugan

(2018). Indeed, for given F, $\widehat{\beta}$ can be written as

$$\widehat{\beta} \quad = \quad \left(\sum_{i=1}^{C} Z_i' M_F Z_i\right)^{-1} \sum_{i=1}^{C} Z_i' M_F Y_i \tag{C.4}$$

with $M_F = I_{3T} - F\left(F'F\right)^{-1} F'$. Next, using $\widehat{\beta}$, $\widehat{f}_t$ can be obtained as the eigenvectors corresponding to the largest r eigenvectors of $1/T\left(\sum_{i=1}^{C} \widehat{v}_i \widehat{v}_i'/3C\right)$:

$$\left[\frac{1}{T}\left(\frac{\sum_{i=1}^{C} \widehat{v}_i \widehat{v}_i'}{3C}\right)\right] \widehat{f} = \widehat{f}\, \widehat{\mu}_{vv'} \tag{C.5}$$

where $\widehat{\mu}_{vv'}$ is a diagonal matrix whose diagonal elements are given by the eigenvalues of $1/T\left(\sum_{i=1}^{C} \widehat{v}_i \widehat{v}_i'/3C\right)$ with $\widehat{v}_i$ and $\widehat{f}$ defined by

$$\underset{T\times 3}{\widehat{v}_i} \quad = \quad \left[\Delta\mathcal{Y}_{i,1} - z_{i,1}\widehat{\beta} \quad \ldots \quad \Delta\mathcal{Y}_{i,T} - z_{i,T}\widehat{\beta}\right]' \quad ; \quad \underset{T\times r}{\widehat{f}} \quad = \quad \left[\widehat{f}_1 \quad \ldots \quad \widehat{f}_T\right]' \tag{C.6}$$

Beginning with $F = 0$, the steps above are repeated until the estimates converge. However, in this iterative estimation, the number of factors denoted by r must first be selected. Bai (2009) suggests the IC and PC criteria for selecting the number of common factors in the context of such an iterative procedure. We select r as the simple average of the numbers of common factors selected by these two criteria allowing up to five common factors. For known r, Tugan (2018) shows that under some minimal assumptions

$$\sqrt{TC}\left(\widehat{\beta} - \beta^0\right) = N\left(\widehat{B}_\Gamma + \widehat{B}_\Psi, \underline{\mathcal{D}}(\widehat{F}, \widehat{\underline{\lambda}})^{-1}\, \widehat{\Omega}\, \underline{\mathcal{D}}(\widehat{F}, \widehat{\underline{\lambda}})^{-1'}\right) + o_p(1) \tag{C.7}$$

where $\underline{\mathcal{D}}(\widehat{F}, \widehat{\underline{\lambda}})$ is defined by

$$\underline{\mathcal{D}}(\widehat{F}, \widehat{\underline{\lambda}}) \quad = \quad \left(\frac{1}{3TC}\sum_{i=1}^{C} Z_i' M_{\widehat{F}} Z_i - \frac{1}{9TC^2}\sum_{i,c=1}^{C} Z_i' M_{\widehat{F}}\left[I_T \otimes \widehat{\underline{\lambda}}_i{}'\left(\frac{\widehat{\underline{\lambda}}'\widehat{\underline{\lambda}}}{3C}\right)^{-1} \widehat{\underline{\lambda}}_c\right] Z_c\right) \tag{C.8}$$

with

$$\underset{r\times 3}{\widehat{\underline{\lambda}_i}} = \left[\lambda_i^{\Delta gdp} \quad \lambda_i^{\Delta p^x} \quad \lambda_i^{\Delta tot}\right], \quad \underset{3C\times r}{\widehat{\underline{\lambda}}} = \left[\widehat{\underline{\lambda}_1} \quad \widehat{\underline{\lambda}_2} \quad \dots \quad \widehat{\underline{\lambda}_C}\right]' \tag{C.9}$$

; $\widehat{B}_\Gamma$ is defined by

$$\widehat{B}_\Gamma = -\underline{\mathcal{D}}(\widehat{F},\widehat{\underline{\lambda}})^{-1}\left(\frac{1}{\sqrt{\rho}}\frac{1}{3TC}\sum_{i=1}^{C}\sum_{t=1}^{T-1}\sum_{\tau=t+1}^{t+\overline{G}}\left(z'_{i,\tau}\widehat{u}_{i,t}\right)\widehat{f}'_\tau\left(\frac{\widehat{f}'\widehat{f}}{T}\right)^{-1}\widehat{f}_t\right) \tag{C.10}$$

with $\rho \longrightarrow T/C$, $\overline{G} = O_p\left(T^{\frac{1}{3}}\right)$, and

$$\widehat{u}_{i,t} = \Delta\mathcal{Y}_{i,t} - z_{i,t}\widehat{\beta} - (I_3 \otimes \widehat{f}'_t)\widehat{\lambda}_i \tag{C.11}$$

; $\widehat{B}_\Psi$ is defined by

$$\widehat{B}_\Psi = \underline{\mathcal{D}}(\widehat{F},\widehat{\underline{\lambda}})^{-1}\left(\widehat{\Psi}^* - \widehat{\Psi}^{**}\right) \tag{C.12}$$

with

$$\widehat{\Psi}^* = -\sqrt{\rho}\frac{1}{3C}\sum_{i=1}^{C}\left(\frac{Z'_i\widehat{F}}{T}\right)\left(I_N \otimes \left(\frac{\widehat{\underline{\lambda}}'\widehat{\underline{\lambda}}}{3C}\right)^{-1}\widehat{\underline{\lambda}_i}\right)\left(\frac{1}{TC}\sum_{t=1}^{T}\sum_{i=1}^{C}\widehat{u}_{i,t}\otimes\widehat{u}_{i,t}\right) \tag{C.13}$$

and

$$\widehat{\Psi}^{**} = -\sqrt{\rho}\frac{1}{3C}\sum_{i=1}^{C}\frac{1}{3C}\sum_{k=1}^{C}\frac{Z'_k\widehat{F}}{T}\left(\widehat{\underline{\lambda}_k}'\left(\frac{\widehat{\underline{\lambda}}'\widehat{\underline{\lambda}}}{3C}\right)^{-1}\widehat{\underline{\lambda}_i}\otimes\left(\frac{\widehat{\underline{\lambda}}'\widehat{\underline{\lambda}}}{3C}\right)^{-1}\widehat{\underline{\lambda}_i}\right)\left(\frac{1}{TC}\sum_{t=1}^{T}\sum_{i=1}^{C}\widehat{u}_{i,t}\otimes\widehat{u}_{i,t}\right) \tag{C.14}$$

Lastly, $\widehat{\Omega}$ is defined by

$$\widehat{\Omega} = \frac{1}{TC}\sum_{i=1}^{C}\sum_{t=1}^{T}\widehat{\Gamma}^Z_{i,t}\widehat{u}_{i,t}\widehat{u}'_{i,t}\widehat{\Gamma}^{Z\prime}_{i,t} \tag{C.15}$$

with

$$\Gamma^{Z}_{i,t} \quad = \quad \frac{1}{3}\left(Z_i' M_{\widehat{F}} - \frac{1}{3C}\sum_{k=1}^{C} Z_k' M_{\widehat{F}}\left[I_T \otimes \underline{\widehat{\lambda}_k}'\left(\frac{\underline{\widehat{\lambda}}'\underline{\widehat{\lambda}}}{3C}\right)^{-1}\underline{\widehat{\lambda}_i}\right]\right)\left(I_T^t \otimes I_3\right) \tag{C.16}$$

where I_T^t is the tth column of I_T.

To calculate the 90 percent confidence bands, we use a Monte Carlo method: let β^n be a random draw from

$$N\left(\widehat{\beta} - \frac{\widehat{B}_\Gamma + \widehat{B}_\Psi}{\sqrt{TC}}, \frac{1}{TC}\underline{\mathcal{D}}(\widehat{F},\underline{\widehat{\lambda}})^{-1}\ \widehat{\Omega}\ \underline{\mathcal{D}}(\widehat{F},\underline{\widehat{\lambda}})^{-1'}\right) \tag{C.17}$$

Next, F^n and Σ^n corresponding to β^n are obtained using (C.5) and (C.11). Then, using β^n and Σ^n, the IRFs to a positive productivity shock are obtained using the max-share approach over the horizon selected, as described in section 2.3. The number of random draws we use in estimating the confidence bands is 500. We sort the IRFs from these 500 IRFs for each period that we compute IRFs. The lower and upper confidence bands for each period displayed in the figures corresponds to the $.05 \times 500^{th}$ and $.95 \times 500^{th}$ of the sorted IRFs, respectively.

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