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Abstract

In this paper we analyse how the terms of trade (TOT) – the ratio of export prices to import prices – affect total factor productivity (TFP). We provide empirical macroeconomic evidence for the European Union countries based on the times series SVAR analysis and microeconomic evidence based on industry level data from the Competitiveness Research Network (CompNet) database which shows that the terms of trade improvements are associated with a slowdown in the total factor productivity growth. Next, we build a theoretical model which combines open economy framework with the endogenous growth theory. In the model the terms of trade improvements increase demand for labour employed in exportable goods production at the expense of technology production (research and development – R&D) which leads to a shift of resources from knowledge development towards physical exportable goods. This reallocation has a negative impact on the TFP growth. Under a plausible calibration the model is able to replicate the observed empirical pattern.

Keywords: total factor productivity, terms of trade, R&D

JEL Classification: F41, O32, O41, O47

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1 Introduction

Terms of trade (TOT) - the ratio of export prices to import prices - is one of the most important variables in open economies. Studies (Mendoza, 1995, Kose, 2002) show that the terms of trade shocks are important drivers of business cycles and explain significant fraction of output variability. Total factor productivity (TFP), often treated as an exogenous process, is a key driving force of growth models, while TFP shocks play a crucial role in business cycles models. In this paper we analyze whether and how total factor productivity in an open economy responds to changes in the terms of trade. This inquiry allows to improve the understanding of TFP determinants in open economies.

Clearly, the relationship between the terms of trade and TFP can work both ways. When TFP is treated as exogenous it cannot be affected by the terms of trade, while improvements in TFP decrease marginal costs and therefore reduce domestic prices. In this paper, however, we focus on the reverse relationship and isolate the impact of the terms of trade on endogenously determined TFP. One may think of two ways how TFP may be affected by the terms of trade. On the one hand, given limited resources improvements of the terms of trade might increase the incentives to put more resources in physical goods production (as it is more profitable to produce goods for exports and imported inputs are cheaper) at the expense of spending on research and development (R&D), which slows down the TFP growth (substitutability channel). On the other hand, it might be the case that since an improvement in the terms of trade makes the whole economy richer it allows to expand both physical goods production and R&D activities (complementarity channel).

We show that the first channel is more empirically relevant (the terms of trade improvements slow down the TFP growth) and explore a substitution between physical goods production and investment in research and development. In our setting once the terms of trade improve, a country exports more and shifts resources away from knowledge production sector, which decreases the TFP growth. On the contrary, when for instance foreign competition drives down the prices of goods which a country sells (its exports) more investment in productivity is needed and desired in order to break even.

The research question of this paper - whether changes in the terms of trade explain total factor productivity development - is addressed both empirically and theoretically. First, we test the relationship between the terms of trade and TFP in twelve European Union (EU) open economies using a structural vector autoregressive (SVAR) model applied to these macroeconomic time series from the OECD database and show that on impact detrended TFP responds negatively to the positive structural terms of trade shocks. We also provide microeconomic evidence based on industry-level data from the Competitiveness Research Network (CompNet) database and show that improvements in the terms of trade are associated with a slowdown in TFP growth at the level of particular sectors in the EU countries considered.

Next, we show how this empirical pattern can be explained in a theoretical framework. We build a model which combines open economy framework including importable, exportable and nontradable goods with the endogenous growth theory. Open economy setting allows us to gain additional insights of how and when technology determining TFP is developed. In the model there is a separate knowledge-producing sector.

Terms of trade improvements increase demand for labor in physical exportable goods production at the expense of labor employed in R&D sector. In the latter employment decreases, which has a negative impact on TFP.

Finally, we ask how well this theoretical model matches with the empirical evidence. We show that under a plausible calibration the model produces the desired responses and is able to replicate the above-mentioned empirical relationship. At the same time since the terms of trade shocks increase output and decrease endogenously-determined component of TFP (via lower R&D employment) the latter is countercyclical in the model. This is at odds with the data in which both TFP and R&D are procyclical. The negative correlation between endogenous component of TFP and output is a result of the terms of trade shocks studied in isolation. Once the exogenous TFP shocks are included in the model, the positive correlation between output and overall TFP is restored, while the terms of trade shocks only weaken it.

This paper relates to several strands of literature. Our theoretical model builds upon the endogenous growth literature which endogenizes technological change process. Similarly to the seminal contributions of Romer (1986, 1990) the technological progress in our model is a result of profit maximizing behavior. The structure of the economy which features a physical goods production sector and a separate knowledge producing sector relates our work to Uzawa (1965), Lucas (1988) and Rebelo (1991). In our setting this framework is embedded into an open economy model with importable, exportable and non-tradable goods as in Schmitt-Grohé and Uribe (2018) which builds on the classic work of Mendoza (1995). The main theoretical contribution of our paper comes from combining these two strands of literature to explain how TFP responds to changes in the terms of trade.

This paper provides also empirical evidence on the impact of the terms of trade on total factor productivity. Empirical literature on endogenous determinants of total factor productvity is extensive. Closely related to our work Miller and Upadhyay (2000) using macroeconomic evidence show that higher openness, more outward orientation and higher human capital have significant positive effects on total factor productivity. Similarly Alcalá and Ciccone (2004) find that international trade has an economically significant and statistically robust positive effect on productivity. More recently Mayer, Rüth, and Scharler (2016) using sign restrictions in SVAR framework show that total factor productivity responds endogenously to exogenous spending demand shocks.

The impact of the terms of trade on TFP did not raise too much attention in the literature so far. Notable exception is the paper by Kehoe and Ruhl (2008). They start with an observation that theoretically the terms of trade shocks seem to have equivalent effects to that of productivity, while from purely accounting point of view changes in the terms of trade do not affect real GDP nor TFP calculated as the residual from real output after subtracting the contribution of properly deflated inputs[1]. However, this observation is inconsistent with the empirical correlations between the terms of trade and TFP they document which

[1] The impact of terms of trade measurement on TFP growth is also a theme of Feenstra et al. (2013) who claim that once the terms of trade are overestimated, this results in higher than actual TFP growth. Since we find a negative relationship between the two, this actually strengthens our findings - when the terms of trade are overstated, if they were properly measured, TFP growth will be even lower after their improvement than what we find.

calls for a mechanism capturing any possible causal relationship between the two. Kehoe and Ruhl analyze the data for the United States and Mexico and find that sharp deteriorations in the terms of trade were accompanied by drops in real GDP and that most of these drops in real GDP were driven by drops in TFP. However, they also show that in case of Switzerland, for instance, the terms of trade improvements were associated with declines in GDP and TFP, so their evidence is inconclusive and based on pure correlations. Additional evidence can be find in Gopinath and Neiman (2014) who show how during the Argentine crisis an increase in import prices (i.e. worsening of the terms of trade) led to a significant decline in productivity. These results differ from ours since instead of focusing on correlations we analyze detrended data in the structural VAR framework and find the opposite effect that the terms of trade improvements are associated with declines in detrended TFP in the European Union countries.

Microeconomic evidence on the possible effects of the terms of trade on TFP is only indirect. Dunne, Klimek, and Schmitz (2010), Galdon-Sanchez and Schmitz (2002) Schmitz (2005) using industry-level data show how competitive pressure driving down the prices increased total factor productivity in cement and iron-ore industries. More recently Alfaro et al. (2017) analyze the effects of the real exchange rate (the relative price of foreign basket in terms of domestic baskets) and show that these effects are not uniform. In Asian emerging countries real depreciations improve TFP at the firm level, while the opposite is true for European emerging economies. They do not find significant effects in case of developed countries. Our study is the first one to analyze the effects of aggregate TOT shocks on industry level TFP.

The main finding of this paper - terms of trade improvements slowing down the TFP growth - resembles the resource curse (the Dutch disease): discovery of natural resources may have a negative impact on economic performance. This literature is reviewed in Frankel (2010) and Ploeg (2011). Recently, this issue in a different variant was studied by Benigno and Fornaro (2014) who show that similar effects (weak productivity growth) might be related to abundant access to foreign capital. Easy credit expands consumption and while additional tradable goods can be imported, the production of nontradable goods needs to increase. In the model of Benigno and Fornaro productivity growth is increasing in labor employed in tradable sector, so shifting productive resources away from this sector deteriorates productivity. In our setting similar effects are associated with the terms of trade improvement - resources are shifted away from R&D into physical goods production which slows down the productivity growth.

The rest of this paper is organized as follows. In the next section we present the empirical evidence showing how TFP reacts to changes in the terms of trade based on the data from the EU countries. Section 3 presents our theoretical model which combines open economy framework with endogenous growth models. In section 4 we calibrate and simulate the model to show its ability of replicating the empirical relationships. Section 5 concludes.

2 Empirical evidence

In this section we present our empirical evidence showing how total factor productivity responds to changes in the terms of trade. The first subsection below deals with macroeconomic evidence, the next one - with microeconomic evidence. In the third subsection we discuss some evidence on the relationship between R&D spending and the terms of trade.

2.1 Macroeconomic evidence

In this subsection we analyze how the overall country TFP responds to changes in the terms of trade. We test it using a structural bivariate VAR model with two lags. We estimate the VAR system using quadratically-detrended time series of the total factor productivity index (a residual of the change in aggregate output that cannot be accounted for by the change in combined inputs) and the terms of trade index (the ratio of the price index for exports of goods and services to the price index for imports of goods and services). The annual data used include the period 1985-2016 and come from the OECD database. We estimate the model country by country for Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden and the United Kingdom. The choice of the countries was determined by the data availability. All analyzed countries are relatively open economies and the European Union member states, hence to some extent homogeneous. The share of their trade in GDP is presented in Table A1. in the Appendix of this paper.

We identify the structural shock using the long-run restrictions (Blanchard and Quah, 1989). We impose the restriction that TFP in the long-run can only be affected by its own shocks while the terms of trade shock is assumed to have no long run effects on TFP[2]. Hence the VAR model takes the following form:

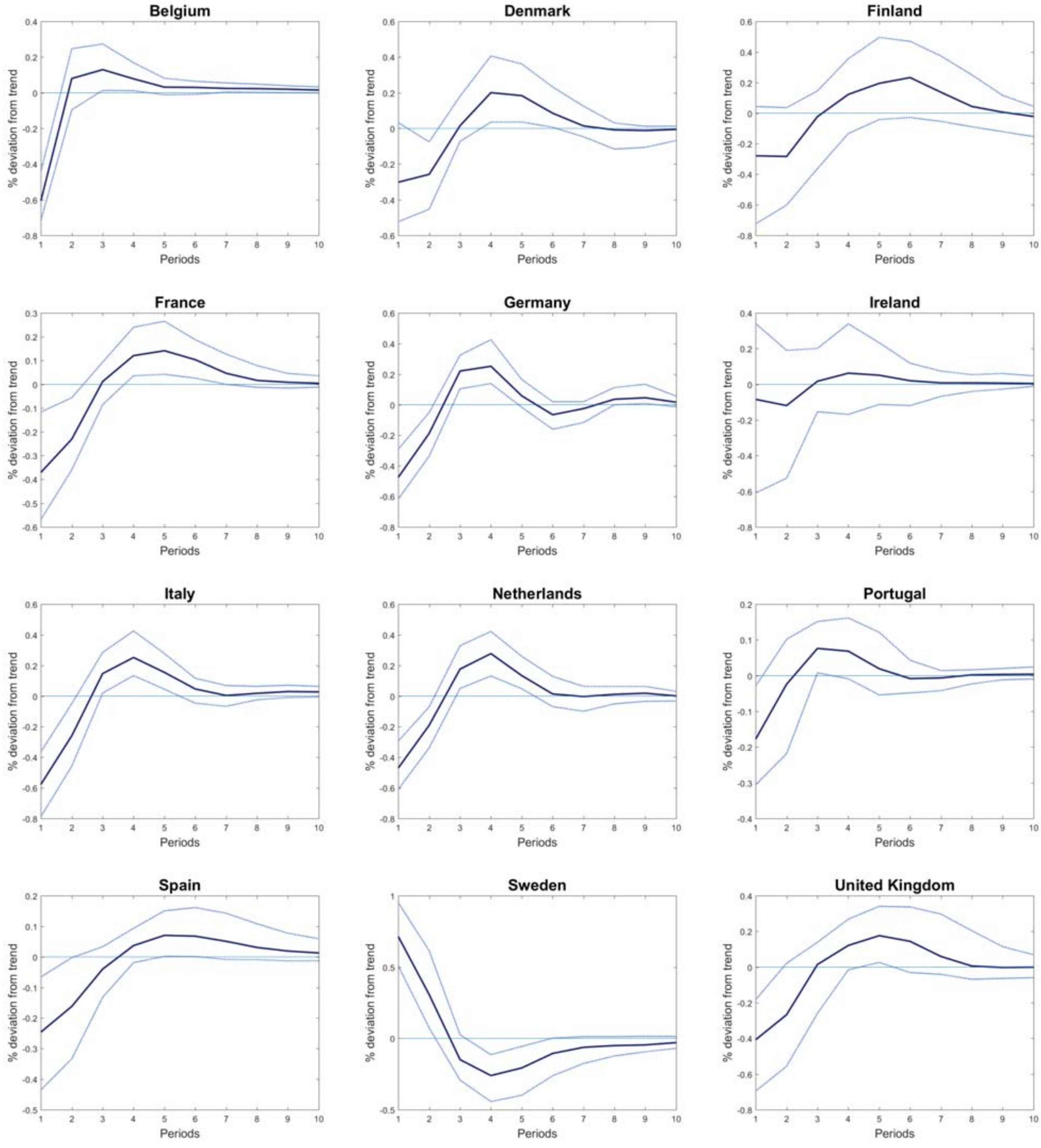
$$\begin{bmatrix} TFP_t \\ TOT_t \end{bmatrix} = \begin{bmatrix} \psi_{11}(L) & \psi_{12}(L) \\ \psi_{21}(L) & \psi_{22}(L) \end{bmatrix} \begin{bmatrix} \epsilon_t^{TFP} \\ \epsilon_t^{TOT} \end{bmatrix}$$

where TFP_t is total factor productivity, TOT_t are the terms of trade, $\psi_{ii}(L)$ are polynomials of the lag operator, ϵ_t^{TFP} is a structural TFP shock and ϵ_t^{TOT} is a structural terms-of-trade shock. We make the usual assumption that these shocks are orthogonal and serially uncorrelated. Our restriction corresponds to $\psi_{12}(1) = 0$[3].

[2] Alternative approach would be to use the short run restrictions. However, this is not suitable in our case given the annual frequency of our data and the fact that in order to identify the structural shocks this requires to assume that depending on the ordering one of the variables (either TFP or the terms of trade) is not affected by the other one (the terms of trade or TFP, respectively) contemporaneously – the assumption we are not willing to make.

[3] We have also tried a trivariate VAR by including GDP in the system. This did not affect significantly the impulse responses of TFP. Given the limited number of observations we have (31) including more variables in the system quickly results in running out of the degrees of freedom.

Figure 1: Impulse responses of TFP to TOT shocks



Note: Solid line - impulse response. Dotted line - 68% confidence intervals.

Source: Author's calculations.

The impulse response functions of TFP to structural terms of trade shocks are presented in Figure 1. We can see from the graphs that for 9 out of 12 countries considered we find a negative and significant[4] response of TFP to a positive structural shock to the terms of trade on impact. Hence, improvements in the terms of trade have a negative impact on detrended TFP. In the next subsection we present microeconomic evidence capturing the same pattern.

2.2 Microeconomic evidence

In this subsection we analyze how the industry level TFP responds to changes in the terms of trade. In our empirical investigation we use the data from the Competitiveness Research Network (CompNet) database (4th Round) which is a European Union firm-level based dataset and provides some moments of the distribution of available variables[5]. As a dependent variable we use a change in mean TFP in particular industries. TFP in the dataset is computed as Solow residual in production function of the real value added after subtracting the inputs of labor, materials and capital in real terms. Our dataset contains 22 manufacturing industries[6] for 10 countries: Austria, Belgium, Estonia, Finland, Germany, Italy, Lithuania, Portugal, Slovenia and Spain in the period 1996-2012. Again, the choice of the countries was constrained by the data availability. All analyzed countries are open economies and the European Union member states, hence to some extent homogeneous. The share of their trade in GDP are presented in Table A1. in the Appendix of this paper.

The estimated regression takes the following form

$$\Delta TFP_{sct} = \alpha + \beta \Delta TOT_{ct} + \eta_s + \nu_c + \gamma_t + \varepsilon_{sct}$$

where TFP_{sct} is the total factor productivity in time t, sector s and country c, TOT_{ct} are the terms of trade in time t and country c, η_s captures the sector fixed effect, ν_c captures the country fixed effect, γ_t captures the time fixed effect and ε_{sct} is the error term.

The data on the terms of trade - the ratio of the price index for exports of goods and services to the price index for imports of goods and services - are taken from the OECD database as before. As we can see, for all sectors at time t and country c face the same level of the terms of trade - there is more variation in the total factor productivity than in the terms of trade series. The regression is performed under the assumption that particular industries are unlikely to affect the overall country terms of trade index. Under this assumption there is no endogeneity problem and the terms of trade shocks can be treated as exogenous shocks to particular industries[7].

[4]At the 68% confidence level which is common in the literature as suggested by Sims and Zha (1999).

[5]The data provider indicates that data collection rules and procedures across countries are different, and out of CompNet's control. Hence, despite all efforts made to improve sample comparability across countries some country samples might still suffer from biases. For a more detailed account of raw data characteristics and sample biases, please refer to the ECB Working Paper 1764 (Lopez-Garcia and Di Mauro, 2015)

[6]The list of industries in available in Table A2. in the Appendix of this paper.

[7]Unfortunately the data on the industry-specific terms of trade indexes are not available and calculating them is out of the

The regression results are presented in Table 1. As we can see the regression results suggest that improvements in the terms of trade are associated with a reduction in changes of TFP. This result is robust under different specifications, including various control variables - sector, countries and year dummies as well as their combinations. We can also interpret the results in the following way. Sectoral TFP improves when relative prices of goods a given country sells (exports) go down and when relative price of goods a given country buys (imports) go up. This is consistent with previous economic evidence suggesting that foreign competition driving down domestic tradable goods prices induces improvements in productivity.

Table 1: Microeconomic evidence - regression results

Model	(1) ΔTFP	(2) ΔTFP	(3) ΔTFP	(4) ΔTFP	(5) ΔTFP	(6) ΔTFP	(7) ΔTFP	(8) ΔTFP
ΔTOT	-.4923***	-.4935***	-.4958***	-.3179***	-.4956***	-.3198***	-.2857***	-.2866***
	(.0550)	(.0543)	(.0579)	(.0718)	(.0576)	(.0708)	(. 0783)	(.0770)
Sector dummies	NO	YES	NO	NO	YES	YES	NO	YES
Country dummies	NO	NO	YES	NO	YES	NO	YES	YES
Year dummies	NO	NO	NO	YES	NO	YES	YES	YES
Mean TFP	62.0282	62.0282	62.0282	62.0282	62.0282	62.0282	62.0282	62.0282
Number of obs.	2591	2591	2591	2591	2591	2591	2591	2591
R^2	0.0296	0.0599	0.0482	0.0808	0.0802	0.1127	0.0989	0.0766

Standard deviation in parenthesis. Legend: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Source: Author's calculations.

Table 2. presents the results of robustness checks of the empirical analysis of the microeconomic data. The second column repeats the result from the last column of Table 1. for convenience. In the third column of Table 2. we can see that improvements in TOT reduce changes in TFP even after including non-manufacturing sectors in the sample[8]. However, this result does not hold when non-manufacturing sectors are considered separately.

In column (11) and (12) we test the importance of trade openness by using the exporters share in the industry as an explanatory variable in the regression. The share of exporting firms in the industry is taken from the Eurostat database. As we can see in specification (11), the higher the share of exporters in the industry, the greater are changes in the productivity. Once we interact changes in the terms of trade index with the share of exporters in (12), we can see that the greater is the share, the more TFP worsens once the terms of trade improve, while the non-interacted coefficient is no longer significant. As one would

scope of this paper. Still, such a measure would clearly suffer from the endogeneity problem.

[8]The list of non-manufacturing industries is available in Table A3. in the Appendix of this paper.

expect, it is the engagement in international trade that drives TFP growth slowdown after the terms of trade improvements. Finally, we also include the lagged changes in the terms of trade in the regression but only the second lag is significant.

Table 2: Microeconomic evidence - robustness checks

Sample	Manufact	All	Non-manufact	Manufact	Manufact	Manufact	Manufact	Manufact
Model	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP
ΔTOT	-.2866***	-.1019*	.0193	-.2924***	.1562	-.3059***	-.3697***	-.4180***
	(.0770)	(.0509)	(.0671)	(.0772)	(.1307)	(.0822)	(.0859)	(.0989)
Share of exporters				7.0555***	6.8286***			
				(1.5989)	(1.5944)			
Share of exporters x ΔTOT					-1.2193***			
					(.2870)			
Lagged ΔTOT (t-1)						.0469	.0560	.0797
						(.0797)	(.0836)	(.0932)
Lagged ΔTOT (t-2)							-.1792*	-.1888*
							(.0840)	(.0903)
Lagged ΔTOT (t-3)								.0692
								(.1043)
Sector dummies	YES	YES	YES	YES	YES	YES	YES	YES
Country dummies	YES	YES	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES	YES	YES
Mean TFP	62.0282	55.8045	51.4509	62.3931	62.3931	62.0282	62.0282	62.0282
Number of obs.	2591	6295	3704	2563	2563	2591	2591	2591
R^2	0.0766	0.0678	0.0340	0.1390	0.1452	0.1387	0.1278	0.1182

Standard deviation in parenthesis. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Source: Author's calculations.

It might be also the case that when the terms of trade improve more less-productive firms with higher prices are able to sell their goods abroad. Since they are less productive overall TFP in the industry might fall because of these new entrants. We test this possibility in Table 3 above using the World Bank Exporter Dynamics database. Unfortunately the data corresponding with our sample are available only for Germany (2011-2012), Portugal (2008-2012) and Spain (2007-2012) which decreases the number of observations. The results suggest that the number of new entrants and the change of new entrants are not significant factors affecting the total factor productivity.

Table 3: Microeconomic evidence - new entrants

Model	(16) ΔTFP	(17) ΔTFP	(18) ΔTFP
ΔTOT	-1.2218*	-1.1935*	-1.3117*
	(.6020)	(.6028)	(.6391)
New entrants		.0001428	
		(.0001499)	
Δ New entrants			-.0005477
			(.0006245)
Sector dummies	YES	YES	YES
Country dummies	YES	YES	YES
Year dummies	YES	YES	YES
Mean TFP	62.2994	62.2994	62.2994
Number of obs.	260	260	260
R^2	0.2564	0.2596	0.1870

Standard deviation in parenthesis. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Source: Author's calculations.

To summarize, we can see that both macroeconomic evidence based on SVAR analysis and microeconomic evidence based on industry level data suggests that the terms of trade improvements are associated with a slowdown in the total factor productivity growth[9]. In the next section we describe the model which aims at explaining this phenomenon. First, however, we discuss the relationship between R&D spending and the terms of trade in the next subsection below.

2.3 Evidence on the relationship between R&D and terms of trade

Since our channel of the terms of trade shock propagation to TFP is research and development activity, in this subsection we provide some evidence on how R&D correlates with the terms of trade. We use quadratically detrended data on R&D spending, i.e., the total expenditure on R&D carried out by all resident companies, research institutes, university and government laboratories and the terms of trade series from the OECD database. The results of the regression of R&D spending on the terms of trade are presented

[9] Unfortunately our microeconomic sample is too short to repeat the SVAR analysis separately for manufacturing and non-manufacturing industries based on microeconomic data and obtain meaningful results.

in Table 4.

Table 4: R&D on TOT regression

Country	Regression coefficient	Standard error	R^2	Sample period
Belgium	0.1729	1.2130	0.0009	1993-2016
Denmark	-0.8980	1.0650	0.0483	2001-2016
Finland	-1.6031**	0.5321	0.2323	1985-2016
France	0.5047	0.2476	0.1217	1985-2016
Germany	-0.2844	0.2231	0.0514	1985-2016
Ireland	-0.8496	0.5512	0.0734	1985-2016
Italy	0.3336	0.2688	0.0488	1985-2016
Netherlands	-0.1765	0.4769	0.0045	1985-2016
Portugal	-1.7011	0.8601	0.1154	1985-2016
Spain	0.9430*	0.4534	0.1260	1985-2016
Sweden	-0.9075	1.3203	0.0379	2003-2016
United Kingdom	0.2211	0.4163	0.0093	1985-2016

Source: Author's calculations.

As we can see there is a negative relationship between the detrended R&D spending and the terms of trade in the majority of cases. However, in general it is not statistically significant. Clearly, there are many determinants of the R&D spending other than the terms of trade developments, which is also suggested by very low R^2 in some cases. Another caveat is the fact that the sample size for some countries (Belgium, Denmark and Sweden) is quite small. Unfortunately our microeconomic dataset (CompNet) does not include the data on R&D spending for individual firms.

3 Model

In this section we describe our model which combines open economy framework featuring importable (M), exportable (X) and non-tradable (N) goods with the endogenous growth theory. Importable goods are defined as goods that are domestically consumed, produced and imported, but not exported. Exportable goods are defined as goods that are domestically consumed, produced and exported, but not imported. Nontradable goods are defined as goods that are domestically consumed and produced, but neither imported nor exported[10].

[10]Clearly those sectors cannot be easily mapped to the actual industries. However, this classification is a useful modelling device and is common in the literature.

Our model is a small open economy (SOE) model - a country takes export and import prices as well as world interest rate as given and faces perfectly elastic demand for goods it exports[11]. We start with a description of households problem, exportable goods producer profit maximization and technology producer (R&D sector) profit maximization. The latter endogenously determines the technology level[12]. Optimality conditions of these three agents allow us to describe our main mechanism in which the terms of trade improvements slow down the TFP growth.

In the subsequent subsections we describe the remaining elements of the model. We start with the maximization problems of the importable and non-tradable goods producers which are standard perfectly competitive firms. The introduction of the former is necessary to have relative prices of export goods to import goods, i.e., the terms of trade in the model. The introduction of the latter is needed to soften the effects of the terms of trade which otherwise would be implausibly large. In next subsections we describe the evolution of the debt interest rate and the terms of trade process, market clearing and the definition of competitive equilibrium. In the model importable good is treated as numeraire with its price $P_t^m = 1$.

3.1 Households

The model features a large number of identical households. At time t households choose consumption c_t labor supply to importables l_t^m, exportables l_t^x and nontradables l_t^n production sector, labor supply to technology production sector h_t, capital supply to importables k_{t+1}^m, exportables k_{t+1}^x and nontradables k_{t+1}^n production sector, and the level of future debt d_{t+1} to maximize expected discounted lifetime utility

$$\max_{\{c_t, l_t^m, l_t^x, l_t^n, h_t, k_{t+1}^m, k_{t+1}^x, k_{t+1}^n, d_{t+1},\}} E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t^m, l_t^x, l_t^n, h_t)$$

where E_0 is the expectations operator, $\beta \in (0,1)$ is the subjective discount factor and $U(.)$ is twice continuously differentiable utility function which is increasing and concave in consumption $(U_1 > 0, U_{11} < 0)$ and decreasing and concave in labor supply $(U_2 < 0, U_{22} < 0, U_3 < 0, U_{33} < 0, U_4 < 0, U_{44} < 0, U_5 < 0, U_{55} < 0)$, subject to the sequential budget constraint (expressed in terms of importable goods)

$$p_t^f c_t + p_t^\tau d_t + p_t^f \left[k_{t+1}^m + k_{t+1}^x + k_{t+1}^n\right]$$

$$= p_t^\tau \frac{d_{t+1}}{1+r_t} + (1-\tau_t) w_t^m l_t^m + (1-\tau_t) w_t^x l_t^x + (1-\tau_t) w_t^n l_t^n + s_t h_t + r_t^{km} k_t^m + r_t^{kx} k_t^x + r_t^{kn} k_t^n + p_t^f (1-\delta)(k_t^m + k_t^x + k_t^n)$$

where p_t^f is the relative price of the final composite good, p_t^τ is the relative price of the composite tradable good, τ_t is the tax rate on wages in physical good production, w_t^m, w_t^x, w_t^n are wages earned for work in importables, exportables and nontradables production sector, respectively, s_t are salaries earned in technology production sector, $r_t^{km}, r_t^{kx}, r_t^{kn}$ are the rental income for capital services to importables, exportables and

[11]Hence, when the terms of trade improve foreign demand for domestic goods does not fall.

[12]In the model setting we use the term technology and knowledge interchangeably.

nontradables production sector, respectively and r_t is the interest rate on external debt, and the non-Ponzi scheme condition

$$\lim_{T\to\infty}\left(\prod_{i=0}^{T-1}(1+r_i)^{-1}\right)\frac{d_{T+1}}{1+r_T}=0$$

The first order conditions of the households problem are given by

$$[c_t:]\quad U_1(c_t,l_t^m,l_t^x,l_t^n,h_t)=\lambda_t p^f \tag{1}$$

$$[l_t^m:]\quad -U_2(c_t,l_t^m,l_t^x,l_t^n,h_t)=\lambda_t(1-\tau_t)w_t^m \tag{2}$$

$$[l_t^x:]\quad -U_3(c_t,l_t^m,l_t^x,l_t^n,h_t)=\lambda_t(1-\tau_t)w_t^x \tag{3}$$

$$[l_t^n:]\quad -U_4(c_t,l_t^m,l_t^x,l_t^n,h_t)=\lambda_t(1-\tau_t)w_t^n \tag{4}$$

$$[h_t:]\quad -U_5(c_t,l_t^m,l_t^x,l_t^n,h_t)=\lambda_t s_t \tag{5}$$

$$[k_{t+1}^m:]\quad \lambda_t p_t^f=\beta E_t\lambda_{t+1}[r_{t+1}^{km}+(1-\delta)p_{t+1}^f] \tag{6}$$

$$[k_{t+1}^x:]\quad \lambda_t p_t^f=\beta E_t\lambda_{t+1}[r_{t+1}^{kx}+(1-\delta)p_{t+1}^f] \tag{7}$$

$$[k_{t+1}^n:]\quad \lambda_t p_t^f=\beta E_t\lambda_{t+1}[r_{t+1}^{kn}+(1-\delta)p_{t+1}^f] \tag{8}$$

$$[d_{t+1}:]\quad \lambda_t p_t^\tau=\beta(1+r_t)E_t\lambda_{t+1}p_{t+1}^\tau \tag{9}$$

where λ_t is the Lagrange multiplier on the budget constraint. Condition (1) equates the marginal utility of consumption to its price multiplied by the Lagrange multiplier which reflects marginal utility of income. Conditions (2) to (5) equate the marginal disutility of labor to the marginal utility gain due to higher consumption. Conditions (6) to (8) reflect the Euler equations for different types of capital equating the marginal utility of forgoing one unit of consumption today with the marginal benefit - the expected discounted return on capital expressed in tomorrow's utility units. Finally, condition (9) is the Euler equation for external debt and equates the marginal utility of obtaining one more unit of consumption today with the marginal cost - the expected discounted payment of debt expressed in tomorrow's utility units.

3.2 Exportable goods producer

Firms producing exportable goods are perfectly competitive and maximize profits:

$$\max_{\{l_t^x,k_t^x\}} tot_t y_t^x - w_t^x l_t^x - r_t^{kx}k_t^x$$

subject to

$$y_t^x = A_t z_t F^x(k_t^x,l_t^x) \tag{10}$$

where tot_t are the terms of trade - the relative price of exportable goods in terms of importable goods, y_t^x is exportable goods production, l_t^x is labor employed in exportable goods production, k_t^x is capital employed in exportable goods production, w_t^x is wage rate in exportable goods production and r_t^{kx} is capital rental rate in exportable goods production, z_t is a technology shock and A_t is endogenously determined technology level. Function $F^x(k^x, l^x)$ is assumed to be twice continuously differentiable, constant returns to scale with positive and decreasing marginal products of the inputs.

First order conditions of exportable goods producer are given by

$$[l_t^x :] \quad tot_t A_t z_t F_2^x(k_t^x, l_t^x) = w_t^x \tag{11}$$

$$[k_t^x :] \quad tot_t A_t z_t F_1^x(k_t^x, l_t^x) = r_t^{kx} \tag{12}$$

At the optimum the prices of factors of production are equal to the market value of their marginal products.

3.3 Technology producer

The producer of technology is assumed to solve the following intertemporal maximization problem:

$$\max_{\{A_{t+1}, h_t\}} \left\{ \quad E_0 \sum_{t=0}^{\infty} \prod_{i=0}^{t-1} \frac{1}{1+r_i} (A_{t+1} - s_t h_t) \quad \right\}$$

subject to the law of motion of the technology

$$A_{t+1} - A_t = B A_t z_t h_t^{\gamma} \tag{13}$$

where A_t is the current level of technology (endogenously determined in $t-1$), z_t is a technology shock, s_t is a salary in knowledge production, h_t is labor employed in knowledge production, while B and γ are parameters of the knowledge production function[13].

The first order condition of the problem is given by:

$$[h_t :] \quad B A_t z_t \gamma {h_t}^{\gamma-1} = s_t \tag{14}$$

The marginal product of labor employed in knowledge production is equated to the salary in the sector.

[13]In order for the technology growth rate to be stable, we need to assume that along the balance growth path labor employed in the knowledge production h_t (hours worked) does not grow over time - see section A2. in the Appendix.

3.4 The main mechanism

Having derived the optimality conditions for households, exportable goods producer and technology producer we are ready to discuss our main mechanism. By (3) and (11) we have that

$$\lambda_t = -\frac{U_3(c_t, l_t^m, l_t^x, l_t^n, h_t)}{(1-\tau_t)w_t^x} = -\frac{U_3(c_t, l_t^m, l_t^x, l_t^n, h_t)}{(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)}$$

By (5) and (14) we have that

$$\lambda_t = -\frac{U_5(c_t, l_t^m, l_t^x, l_t^n, h_t)}{s_t} = -\frac{U_5(c_t, l_t^m, l_t^x, l_t^n, h_t)}{BA_t z_t \gamma {h_t}^{\gamma-1}}$$

This implies that

$$-\frac{U_3(c_t, l_t^m, l_t^x, l_t^n, h_t)}{(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)} = -\frac{U_5(c_t, l_t^m, l_t^x, l_t^n, h_t)}{BA_t z_t \gamma {h_t}^{\gamma-1}}$$

When the terms of trade improve the left-hand side of the above expression goes down. In order for the equality to be satisfied, the right-hand side needs to go down as well. Since it is increasing in h_t (denominator corresponds to labor supply and hence is increasing in h_t[14], while numerator is marginal product of labor and thus is decreasing in h_t), h_t needs to fall after the terms of trade improve. A fall in h_t has a negative impact on TFP growth. This can be also seen in the following way. Equations (3), (5) and (11) imply that:

$$s_t = \frac{U_5(c_t, l_t^m, l_t^x, l_t^n, h_t)}{U_3(c_t, l_t^m, l_t^x, l_t^n, h_t)}(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)$$

This and (14) yields:

$$h_t = \left(\frac{s_t}{BA_t z_t \gamma}\right)^{\frac{1}{\gamma-1}} = \left(\frac{\frac{U_5(c_t, l_t^m, l_t^x, l_t^n, h_t)}{U_3(c_t, l_t^m, l_t^x, l_t^n, h_t)}(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)}{BA_t z_t \gamma}\right)^{\frac{1}{\gamma-1}}$$

We can apply the implicit function theorem to the above expression (we skip the arguments of the utility function) which yields:

$$\frac{dh_t}{dtot_t} = \frac{-\frac{1}{\gamma-1}\left(\frac{\frac{U_5(.)}{U_3(.)}(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)}{BA_t z_t \gamma}\right)^{\frac{1}{\gamma-1}-1} \frac{\frac{U_5(.)}{U_3(.)}(1-\tau_t)A_t z_t F_2^x(k_t^x, l_t^x)}{BA_t z_t \gamma}}{\frac{1}{\gamma-1}\left(\frac{\frac{U_5(.)}{U_3(.)}(1-\tau_t)tot_t A_t z_t F_2^x(k_t^x, l_t^x)}{BA_t z_t \gamma}\right)^{\frac{1}{\gamma-1}-1} \frac{(1-\tau_t)A_t z_t F_2^x(k_t^x, l_t^x)}{BA_t z_t \gamma} \frac{U_{55}(.)U_3(.)-U_5(.)U_{35}(.)}{(U_3(.))^2} - 1} < 0$$

[14]We assume that the substitution effect dominate over the income effect.

Since $\gamma < 1$ the denominator is positive, while the numerator is negative[15], the whole expression is negative. Then, by (13) implying $\frac{dA_{t+1}}{dh_t} > 0$ we have that

$$\frac{dA_{t+1}}{dtot_t} = \frac{dA_{t+1}}{dh_t}\frac{dh_t}{dtot_t} < 0$$

so that the terms of trade improvements are associated with a slowdown in the TFP growth. Clearly this analysis is keeping other variables unchanged, while in general equilibrium they would also be affected. However, the negative impact of the terms of trade improvements on technology is also illustrated in our numerical simulation in section 4.

The result that increasing terms of trade have a negative impact on future productivity is in line with empirical facts described in section 2. What is the intuition behind it? The terms of trade improvements encourage to put more resources into physical exportable good production at the expense of knowledge production. Demand for labor employed in physical goods production increases, which increases wages and employment in the sector. Wages in all sectors are connected by the household's optimality conditions. When the terms of trade drive up wages in exportable production sector they also increase salaries in R&D production. Since the marginal product of labor in this sector is unchanged, the labor demand in this sector is lower under these higher wages. The employment in technology production sector decreases which leads to a deterioration in an endogenously determined component of the TFP level.

Alternative technology production function

In the current version of the technology production function described by (13) growth of the technology increases in the employment in the R&D sector. Since the terms of trade improvements increase employment in exportable sector and drive up wages in this sector, by (imperfect) wage equalization employment in R&D sector decreases and TFP growth slows down. One could, however, imagine a different technology production function where technology would be increasing in the amount of labor employed in exportable sector capturing learning-by-doing effects (for example as in Benigno and Fornaro, 2014). In our setting it would take the following form:

$$A_{t+1} - A_t = BA_t z_t (l_t^x)^\gamma$$

In such a case terms of trade improvement would be associated with an acceleration of the TFP growth.

[15] As long as $U_{55}(.)U_3(.) > U_5(.)U_{35}(.)$ which we assume holds. This condition can be equivalently written as $\frac{U_{55}(.)}{U_5(.)} > \frac{U_{35}(.)}{U_3(.)}$ or $\frac{U_{55}(.)}{U_5(.)}h_t > \frac{U_{35}(.)}{U_3(.)}h_t$ which means that the elasticity of the marginal disutility of working in R&D sector with respect to labor supply to R&D sector is higher than the elasticity of the marginal disutility of working in exportable sector with respect to labor supply to R&D sector.

3.5 Remaining elements of the model

3.5.1 Importable goods producer

Firms producing importable goods are perfectly competitive and maximize profits:

$$\max_{\{l_t^m, k_t^m\}} y_t^m - w_t^m l_t^m - r_t^{km} k_t^m$$

subject to

$$y_t^m = A_t z_t F^m(k_t^m, l_t^m) \tag{15}$$

where y_t^m is importable goods production, l_t^m is labor employed in importable goods production, k_t^m is capital employed in importable goods production, w_t^m is wage rate in importable goods production, r_t^{km} is capital rental rate in importable goods production, z_t is a technology shock and A_t is endogenously determined technology level. Function $F^m(k^m, l^m)$ is assumed to be twice continuously differentiable, constant returns to scale with positive and decreasing marginal products of the inputs.
First order conditions of importable goods producer are given by

$$[l_t^m :] \quad A_t z_t F_2^m(k_t^m, l_t^m) = w_t^m \tag{16}$$

$$[k_t^m :] \quad A_t z_t F_1^m(k_t^m, l_t^m) = r_t^{km} \tag{17}$$

At the optimum the prices of factors of production are equal to the market value of their marginal products.

3.5.2 Non-tradable goods producer

Firms producing non-tradable goods are perfectly competitive and maximize profits:

$$\max_{\{l_t^n, k_t^n\}} p_t^n y_t^n - w_t^n l_t^n - r_t^{kn} k_t^n$$

subject to

$$y_t^n = A_t z_t F^n(k_t^n, l_t^n) \tag{18}$$

where p_t^n is the relative price of non-tradable goods in terms of importable goods, y_t^n is non-tradable goods production, l_t^n is labor employed in non-tradable goods production, k_t^n is capital employed in non-tradable goods production, w_t^n is wage rate in non-tradable goods production r_t^{kn} is capital rental rate in non-tradable goods production, z_t is a technology shock and A_t is endogenously determined technology level. Function $F^n(k^n, l^n)$ is assumed to be twice continuously differentiable, constant returns to scale with positive and decreasing marginal products of the inputs.

First order conditions of non-tradable goods producer are given by

$$[l_t^n :] \quad p_t^n A_t z_t F_2^n(k_t^n, l_t^n) = w_t^n \tag{19}$$

$$[k_t^n :] \quad p_t^n A_t z_t F_1^n(k_t^n, l_t^n) = r_t^{kn} \tag{20}$$

At the optimum the prices of factors of production are equal to the market value of their marginal products.

3.5.3 Composite tradable goods

The composite tradable good is produced using an increasing, concave and linearly homogeneous aggregator function:

$$a_t^\tau = G(a_t^m, a_t^x) \tag{21}$$

where a_t^m is the domestic absorption of importable goods and a_t^x is the domestic absorption of exportable goods. The maximization problem takes the following form

$$\max_{a_t^m, a_t^x} p_t^\tau G(a_t^m, a_t^x) - a_t^m - tot_t a_t^x$$

where p_t^τ is the relative price of the composite tradable goods in terms of importables. Assuming perfect competition in the composite tradable goods production process, the first order conditions are given by

$$p_t^\tau G_1(a_t^m, a_t^x) = 1 \tag{22}$$

$$p_t^\tau G_2(a_t^m, a_t^x) = tot_t \tag{23}$$

3.5.4 Composite final goods

The composite final good is produced using an increasing, concave and homogeneous of degree one aggregator function:

$$H(a_t^\tau, a_t^n)$$

where a_t^τ is the tradable composite good and a_t^n is the domestic absorption of nontradable goods. The maximization problem takes the following form

$$\max_{a_t^\tau, a_t^n} p_t^f H(a_t^\tau, a_t^n) - p^\tau a_t^\tau - p_t^n a_t^n$$

where p_t^f is the relative price of the final goods in terms of importables. Assuming perfect competition in the composite final goods production process, the first order conditions are given by

$$p_t^f H_1(a_t^\tau, a_t^n) = p_t^\tau \tag{24}$$

$$p_t^f H_2(a_t^\tau, a_t^n) = p_t^n \tag{25}$$

3.5.5 Financing the externality

The technology developed by the knowledge production sector is freely used by the physical goods production sectors. Since they do not pay for it, there is an externality in the model. This externality whose cost is equal to the wage bill in the technological sector $s_t h_t$ is financed by taxes levied on other type of labor:

$$s_t h_t = \tau_t (w_t^m l_t^m + w_t^x l_t^x + w_t^n l_t^n) \tag{26}$$

The tax rate τ_t adjusts so that the feasibility constraint of the economy is not violated.

3.5.6 Debt-elastic interest rate premium

The interest rate on debt is assumed to evolve according to

$$r_t = r^* + p(d_{t+1}) \tag{27}$$

where r^* is the world interest rate and the function $p(.)$ is assumed to be increasing and takes the form

$$p(d) = \psi(e^{d-\bar{d}})$$

where $\bar{d}$ is the steady state level of debt. This debt-elastic interest rate premium is necessary to ensure a stationary equilibrium process for external debt.

3.5.7 Market clearing, import and export

In equilibrium the demand for final goods must equal their supply:

$$c_t + k_{t+1}^m + k_{t+1}^x + k_{t+1}^n - (1-\delta)(k_t^m + k_t^x + k_t^n) = H(a_t^\tau, a_t^n) \tag{28}$$

Since non-tradable goods by definition are consumed only domestically, their market has to clear so that demand for nontradables is equal to their production:

$$a_t^n = y_t^n \tag{29}$$

In our setting import is given by

$$m_t = a_t^m - y_t^m \tag{30}$$

and export is given by:

$$x_t = tot_t (y_t^x - a_t^x) \tag{31}$$

Then from households' budget constraint and by producers making zero profits and by (26):

$$m_t - x_t + p_t^\tau d_t = p_t^\tau \frac{d_{t+1}}{1+r_t} \tag{32}$$

which is the economy-wide resource constraint.

3.5.8 Exogenous processes

We assume that the terms of trade follow a univariate first-order autoregressive (AR(1)) process of the form

$$\ln \frac{tot_t}{\overline{tot}} = \rho_{tot} \ln \frac{tot_{t-1}}{\overline{tot}} + \sigma^{tot} \varepsilon_t^{tot} \tag{33}$$

where $\overline{tot} > 0$ is the deterministic level of the terms of trade, $\rho_{tot} \in (-1,1)$ is the serial correlation of the process and $\sigma^{tot} > 0$ is the standard deviation of the innovation to the terms of trade.

We also assume that the technology shock follows a univariate first-order autoregressive (AR(1)) process of the form

$$\ln \frac{z_t}{\overline{z}} = \rho_z \ln \frac{z_{t-1}}{\overline{z}} + \sigma^z \varepsilon_t^z \tag{34}$$

where $\overline{z} > 0$ is the deterministic level of the technology shock normalized to one, $\rho_z \in (-1,1)$ is the serial correlation of the process and $\sigma^z > 0$ is the standard deviation of the innovation to the technology shock.

3.5.9 Competitive equilibrium definition

A competitive equilibrium is a set of prices $\{r_t^{km}, r_t^{kx}, r_t^{kn}, w_t^m, w_t^x, w_t^n, s_t, p_t^f, p_t^\tau, p_t^n, r_t\}_{t=0}^\infty$, an allocation $\{k_{t+1}^m, k_{t+1}^x, k_{t+1}^n, l_t^m, l_t^x, l_t^n, h_t, A_{t+1}, y_t^m, y_t^x, y_t^n, c_t, a_t^m, a_t^x, a_t^n, a_t^\tau, m_t, x_t, d_{t+1}\}_{t=0}^\infty$, a sequence of multipliers $\{\lambda_t\}_{t=0}^\infty$, and a tax system $\{\tau_t\}_{t=0}^\infty$ which satisfy equations (1) to (32) such that households' and firms' optimality conditions are satisfied and markets clear given the stochastic processes $\{tot_t, z_t\}_{t=0}^\infty$ described by (33) and (34) and the initial conditions $k_0^m, k_0^x, k_0^n, d_0, A_0, tot_{-1}, z_{-1}$.

4 Quantitative model evaluation

In this section we perform a quantitative evaluation of the theoretical model presented in the previous section. As TFP is non-stationary the trending variables in the model are normalized by the one-period lagged TFP level for the purpose of this quantitative evaluation. The model has a stationary equilibrium in terms of the normalized variables. The model is solved using a second-order perturbation method.

4.1 Functional forms

We assume that the utility function is of constant relative risk aversion (CRRA) in a quasilinear composite of consumption and labor:

$$U(c, l^m, l^x, l^n, h) = \frac{[c - L(l^m, l^x, l^n, h)]^{1-\sigma} - 1}{1-\sigma}$$

where

$$L(l^m, l^x, l^n, h) = \frac{(l^m)^{\omega_m}}{\omega_m} + \frac{(l^x)^{\omega_x}}{\omega_x} + \frac{(l^n)^{\omega_n}}{\omega_n} + \frac{(h)^{\omega_h}}{\omega_h}$$

with parameters $\sigma, \omega_m, \omega_x, \omega_n, \omega_h > 0$. This specification ensures that sectoral labor supplies are wealth inelastic[16]. The wage elasticities of labor supply are given by $\frac{1}{1-\omega}$.

The production technologies in importable, exportable and nontradable sectors are assumed to be Cobb-Douglas

$$F^m(k^m, l^m) = (k^m)^{\alpha_m}(l^m)^{1-\alpha_m}$$

$$F^x(k^x, l^x) = (k^x)^{\alpha_x}(l^x)^{1-\alpha_x}$$

$$F^n(k^n, l^n) = (k^n)^{\alpha_n}(l^n)^{1-\alpha_n}$$

with parameters $\alpha_m, \alpha_x, \alpha_n \in (0, 1)$. The aggregators used in the production of composite tradable and final goods take the constant elasticity of substitution form

$$G(a_t^m, a_t^x) = \left[\chi_m (a_t^m)^{1-\frac{1}{\nu_{mx}}} + (1-\chi_m)(a_t^x)^{1-\frac{1}{\nu_{mx}}}\right]^{\frac{1}{1-\frac{1}{\nu_{mx}}}}$$

$$H(a_t^\tau, a_t^n) = \left[\chi_\tau (a_t^\tau)^{1-\frac{1}{\nu_{\tau n}}} + (1-\chi_\tau)(a_t^n)^{1-\frac{1}{\nu_{\tau n}}}\right]^{\frac{1}{1-\frac{1}{\nu_{\tau n}}}}$$

with parameters $\chi_m, \chi_\tau \in (0, 1)$ and $\nu_{mx}, \nu_{\tau n} > 0$.

4.2 Calibration

The calibration of the model is summarized in Table 5. The time unit is a year. We follow a standard calibration of the MXN model (see Schmitt-Grohé and Uribe, 2018). The coefficient of the relative risk aversion σ is set at 2 which is a usual value used in business cycle literature. The subjective discount factor β takes value of 0.95. The parameter ω is set at 1.455 so that labor supply elasticity $\frac{1}{\omega-1}$ equals 2.2 as in Mendoza (1991) and is the same in all sectors. Parameters of the production function (capital share in production) are given by $\alpha_m = 0.33$, $\alpha_x = 0.33$, $\alpha_n = 0.25$. The latter reflects higher labor share in production of nontradable goods sector comparing to importable and exportable sectors.

[16]Imperfect substitutability of labor in different sectors was chosen for computational reasons (this gives us separate labor supply schedules for each sector) and is not necessary for our results - the mechanism is preserved also under perfect substitutes. Similarly allowing for income effects does not affect the results as long as the substitution effect dominates over the wealth effect.

The intratemporal elasticity of substitution between exportable and importable absorption ν_{mx} is set at 1. Available quarterly estimates are usually below one (see e.g. Corsetti, Dedola, and Leduc (2008)), while those based on 5-10 years data averages find it to be above one. Setting it to unity is reasonable for annual frequency model. The parameter χ_m reflecting the share of importables in tradable goods aggregator is set at 0.9 to match the average share of import in total trade for the analyzed countries over the sample period (49.01%). The intratemporal elasticity of substitution between tradable and nontradable absorption $\nu_{\tau n}$ is set at 0.5 which is based on Akinci (2011). The parameter χ_τ reflecting the share of tradables in composite goods aggregator is set at 0.36 to match the average trade share of nontradables (proxied by services) in GDP for the analyzed countries over the sample period (62.71%).

The capital depreciation rate δ is set at 0.1 which is standard. The world interest rate r^* is set at 0.04. The parameter governing the debt elasticity of the country premium ψ takes value of 0.08. The steady state debt $\bar{d}$ is set at 4.9. These two parameters are set to match the average trade balance share in GDP for the analyzed countries over the sample period (2.03%).

The steady state level of the terms of trade $\overline{tot}$ takes value of 1. The autocorrelation of the terms of trade process is set at 0.46 which is the median of the estimates for the countries in our macroeconomic sample. The standard deviation of the terms of trade innovation σ_{tot} is set at 0.0166 which is the median of the estimates of the countries in our macroeconomic sample. The autocorrelation of the technology shock process is set at 0.72 which is the median of the estimates for the countries in our macroeconomic sample. The standard deviation of the terms of trade innovation σ_{tot} is set at 0.0114 which is the median of the estimates of the countries in our macroeconomic sample.

Besides the MXN model parameters additionally we need to set the parameters of the knowledge production function. We set $B = 1$. Porter and Stern (2000) estimate equation (11) and find that $\gamma \in (0.2, 0.48)$ for different sets of controls. Here following these estimates we set γ at 0.4.

Table 5: Calibration

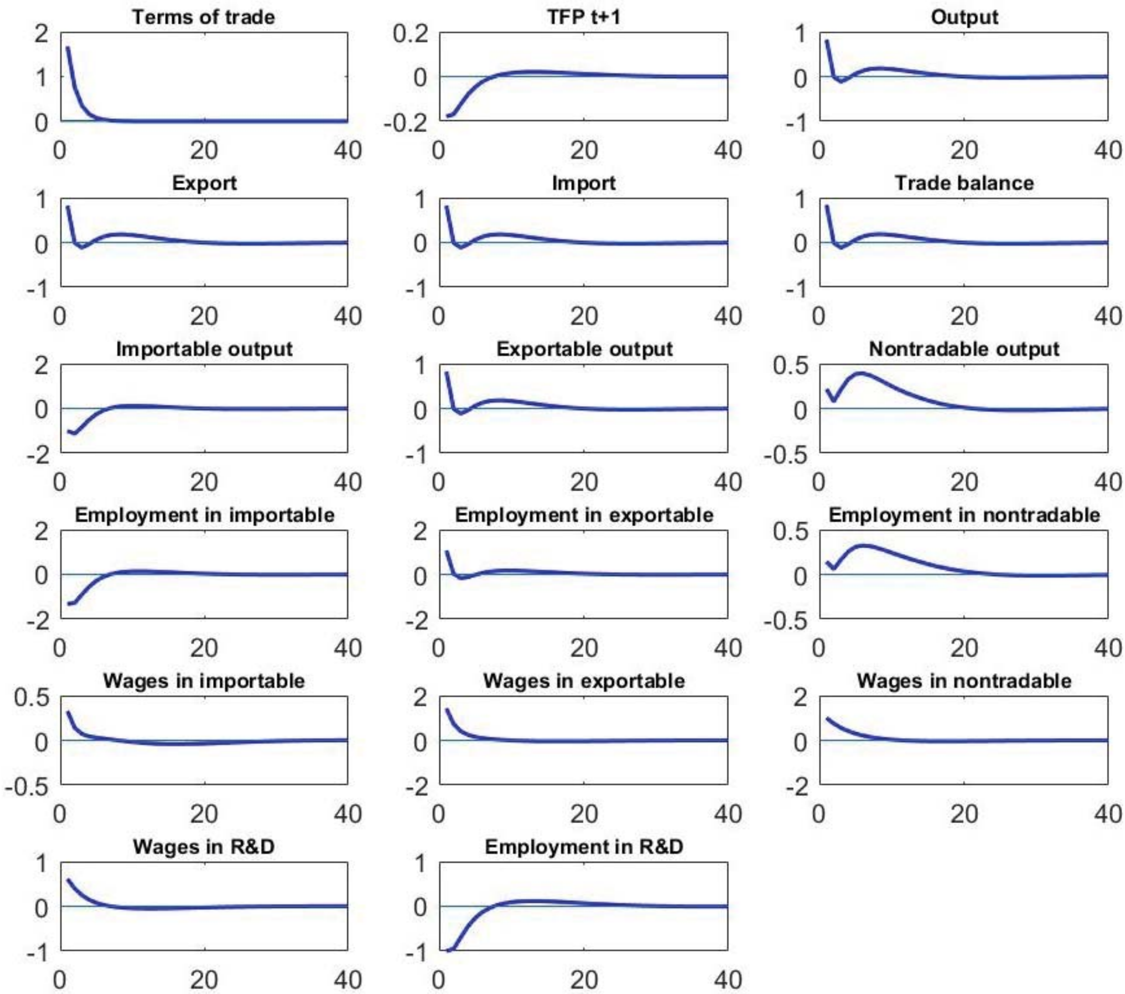
Parameter	Description	Value
σ	Coefficient of the relative risk aversion	2
β	Subjective discount factor	0.95
ω^m	$\frac{1}{\omega^m - 1}$ = Importable goods labor supply elasticity	1.455
ω^x	$\frac{1}{\omega^x - 1}$ = Exportable goods labor supply elasticity	1.455
ω^n	$\frac{1}{\omega^n - 1}$ = Nontradables goods labor supply elasticity	1.455
ω^h	$\frac{1}{\omega^h - 1}$ = Technology sector labor supply elasticity	1.455
α_m	Capital share in importable goods sector	0.33
α_x	Capital share in exportable goods sector	0.33
α_n	Capital share in nontradable goods sector	0.25
ν_{mx}	The elasticity of substitution between exportable and importable absorption	1
χ_m	The importables share parameter	0.9
$\nu_{\tau n}$	The elasticity of substitution between tradable and nontradable absorption	0.5
χ_τ	The tradables share parameter	0.36
δ	Capital depreciation rate	0.1
ψ	Parameter governing the debt elasticity of the country premium	0.08
r^*	World interest rate	0.04
$\bar{d}$	Steady state debt	20.47
$\overline{tot}$	Steady state TOT	1
ρ_{tot}	TOT autocorrelation coefficient	0.46
σ_{tot}	Standard deviation of TOT process innovation	0.0166
ρ_z	Autocorrelation coefficient of technology shock	0.72
σ_z	Standard deviation of technology shock innovation	0.0114
B	Shift parameter of the knowledge production function	1
γ	Parameter of the knowledge production function	0.4

4.3 Model responses

Figure 2 shows the impulse response functions of selected model variables in terms of the percentage deviations from the steady state to the positive terms of trade shock conditional on the technology shock being switched off. As we can see, as a result of the shock (future) TFP drops, while output increases. There is an increase in exports and exportable output. Imports increase both because they are relatively cheaper and due to positive economy-wide income effect of the terms of trade improvement. This increase is smaller than an increase in exports (in absolute terms) so that the trade balance improves. This is in line with the Harberger-Laursen-Metzler effect which predicts trade balance improvements after positive terms of trade shocks. It deteriorates slightly afterwards due to positive income shock related to the terms of trade improvement.

Domestic production of importable goods decreases as it is relatively less profitable. Non-tradable output increases due to the positive income effect of the terms of trade improvement. Consistently with output in each sector employment in exportables and non-tradable production increases and employment in importables production decreases. Relative (to the price of importables) wages increase in all sectors.

Figure 2: Impulse responses of selected model variables to the terms of trade shock



Note: Vertical axis - percentage deviations from the steady state. Horizontal axis - time periods (years).

Finally, we can see that wages in R&D sector increase, while employment in R&D decreases. The terms of trade improvement increases demand for labor employed in physical goods production and drives up wages in this sector. However, since all wages are connected by households' optimality conditions wages in R&D also increase. Since the marginal product of labor in R&D is unchanged, the labor demand in this sector corresponding with these higher wages is lower. Hence, we observe a drop in demand for this kind of labor and shifting resources from R&D towards physical exportable goods production. As a result, next period TFP decreases. Thus, consistently with empirical evidence, the model predicts a decrease in TFP after the terms of trade improvement[17].

The terms of trade shock increases output and at the same time decreases TFP in the model. Because of that TFP and R&D spending - which is our channel of shock propagation - are countercyclical. It is at odds with the data where TFP and R&D spending are procyclical[18]. This result capturing (data-consistent) negative relationship between the terms of trade and TFP holds only for a model which does not feature other shocks. With technology shocks z_t in force, output increases after a positive productivity shock which results in positive correlation between the two, even though positive terms of trade shocks have a negative impact on TFP.

Below in Table 6 we present the moments generated by the model with both technology and terms of trade shocks operating.

Table 6: Targeted and non-targeted moments

Statistic	**Data**	**Model**
Targeted moments		
Average share of import in total trade	49.01%	48.54%
Average trade share of nontradables in GDP	62.71%	62.83%
Average trade balance share in GDP	2.38%	2.33%
Non-targeted moments		
Standard deviation output	2.71%	3.70%
Autocorrelation output	0.76	0.79
Standard deviation TFP	1.57%	0.99%
Autocorrelation TFP	0.72	0.73
Standard deviation R&D spending	3.70%	3.06%
Autocorrelation R&D spending	0.70	0.82
Correlation output vs. TFP	0.71	0.79
Correlation output vs. R&D	0.31	0.83

Source: Author's calculations.

[17]Since all sectors share the same TFP the effects of the terms of trade shock on TFP are the same across sectors. However, the microeconomic evidence we presented suggests that these effects are heterogeneous depending on the level of tradability of goods produced. In the model this could be achieved by fixing the endogenous part of the TFP in nontradable sector at the steady state level so that TFP fluctuations only in tradable industries (and as a result the overall country-wide TFP fluctuations) would be affected by the terms of trade shocks.

[18]Indeed the average correlation between TFP and output per capita in analyzed countries for the analyzed period is 0.71 while the average correlation between R&D spending and output per capita in analyzed countries for the analyzed period is 0.31 for quadratically detrended series.

As mentioned above, the average share of import in total trade, the average trade share of nontradables in GDP and the average trade balance share in GDP were targeted in setting parameters χ^M, χ^τ and $\bar{d}$. We can see that the model is doing quite well in capturing the autocorrelation of TFP, R&D spending (proxied in the model by the wage bill in the technology production sector) and output, as well as the standard deviation of TFP. The standard deviation of output is slightly higher in the model comparing to the data, while standard deviation of TFP is slightly lower. Finally, the positive correlation between TFP and output, as well as R&D and output is achieved in the model once technology shocks are operating.

5 Conclusions

In this paper we have analyzed how the terms of trade affect total factor productivity. Using the data for the European Union countries we have shown that macroeconomic evidence based on times series SVAR analysis suggests that the structural terms of trade shocks have a negative impact on total factor productivity. Consistently, empirical microeconomic evidence based on industry level data suggests that improvements in terms of trade are associated with a slowdown of the total factor productivity growth at the sectoral level.

Next, we have built a theoretical model which combines open economy framework with the endogenous growth theory. In the model the terms of trade improvements lead to a shift of resources from R&D production towards physical exportable goods. Employment in exportables sector increases, while the opposite happens in knowledge production sector due to a drop in labor demand. As a result, total factor productivity decreases. We have also shown that under a plausible calibration the model is able to produce this mechanism and thus replicate the observed empirical pattern.

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Appendix

A1 Tables

Table A1: Trade shares of the countries used in empirical investigation

Country	Average share of exports+imports in GDP over 1985-2016
Austria	83.46
Belgium	134.73
Denmark	81.97
Estonia	143.01*
Finland	66.54
France	49.93
Germany	61.41
Ireland	150.78
Italy	46.73
Lithuania	117.08*
Netherlands	121.25
Portugal	65.32
Slovenia	118.99*
Spain	49.81
Sweden	74.66
United Kingdom	52.18

* over the period 1995-2016

Table A2: Manufacturing industries in the microeconomic dataset

Manufacture of food products
Manufacture of beverages
Manufacture of tobacco products
Manufacture of textiles
Manufacture of wearing apparel
Manufacture of leather and related products
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Manufacture of paper and paper products
Printing and reproduction of recorded media
Manufacture of chemicals and chemical products
Manufacture of basic pharmaceutical products and pharmaceutical preparations
Manufacture of rubber and plastic products
Manufacture of other nonmetallic mineral products
Manufacture of basic metals
Manufacture of fabricated metal products, except machinery and equipment
Manufacture of computer, electronic and optical products
Manufacture of electrical equipment
Manufacture of machinery and equipment
Manufacture of motor vehicles, trailers and semitrailers
Manufacture of other transport equipment
Manufacture of furniture
Other manufacturing

Table A3: Non-manufacturing industries in the microeconomic dataset

Repair and installation of machinery and equipment
Construction of buildings
Civil engineering
Specialised construction activities
Wholesale and retail trade and repair of motor vehicles and motorcycles
Wholesale trade, except of motor vehicles and motorcycles
Retail trade, except of motor vehicles and motorcycles
Land transport and transport via pipelines
Water transport
Air transport
Warehousing and support activities for transportation
Postal and courier activities
Accommodation
Food and beverage service activities
Publishing activities
Motion picture, video and television programme production, sound recording and music publishing activities
Programming and broadcasting activities
Telecommunications
Computer programming, consultancy and related activities
Information service activities
Real estate activities
Legal and accounting activities
Activities of head offices; management consultancy activities
Architectural and engineering activities; technical testing and analysis
Scientific research and development
Advertising and market research
Other professional, scientific and technical activities
Veterinary activities
Rental and leasing activities
Employment activities
Travel agency, tour operator and other reservation service and related activities
Security and investigation activities
Services to buildings and landscape activities
Office administrative, office support and other business support activities

A2 Growth of the technology

In a general case (13) would be given by

$$A_{t+1} - A_t = BA_t^{\theta} z_t {h_t}^{\gamma}$$

Then the growth rate of the technology is given by

$$g_t^A = \frac{A_{t+1} - A_t}{A_t} = BA_t^{\theta-1} z_t {h_t}^{\gamma}$$

Itself grows at

$$\frac{g_{t+1}^A - g_t^A}{g_t^A} = \gamma n + (\theta - 1) g_t^A$$

where $n = \frac{h_{t+1} - h_t}{h_t}$. To have a stable growth path, i.e., $\frac{g_{t+1}^A - g_t^A}{g_t^A} = 0$ which is positive we need either $n = 0$ and $\theta = 1$ or $\theta < 1$ for $n > 0$. In the latter case

$$g_t^A = \frac{\gamma n}{1 - \theta}$$

For simplicity we assume the former.

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