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The Optimal Tariff in the Presence of Trade-Induced Productivity Gains

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Abstract

We scrutinize the impact of international productivity gains (spillovers) induced by imports and exports on optimal tariffs. First, we solve a stylized 2x2 trade model of a large open economy and show that (a) productivity gains via exports and imports both reduce the strategically optimal tariff, (b) there exists a certain strength of productivity gains such that the incentive to manipulate the terms of trade strategically vanishes, (c) the welfare gain that can be achieved via a tariff is lower in the presence of productivity gains than in their absence, and (d) these results even hold without power on international markets. Second, we apply this model to a panel data set covering 40 countries, 29 sectors and the years 1995 to 2009. We find that import-driven productivity gains are stronger than export-driven productivity gains. Third, we extend our 2x2 model to a multi-region, multi-sector model that we calibrate to the data set used in the econometric analysis and to the econometrically estimated productivity gains. Optimal tariffs are reduced by 17% for the US and China and 40% for Brazil when taking trade-induced productivity gains into account. The USA are the only model region that gains from European optimal tariff policy. Thus, trade-induced productivity gains have empirically relevant effects on optimal tariffs.

JEL Classifications: F12, F14, F17, O33, O40

Keywords: trade, optimal tariff, productivity gains, technology spillovers

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1 Introduction

Nations do not only benefit from international trade by specializing according to their competitive advantages or by exploiting economies of scale. If knowledge and ideas are embodied in traded goods, openness to trade will also provide access to knowledge stocks abroad (Grossman and Helpman, 1991). International exchange of goods and services also implicates more competition and more efficient production (Melitz, 2003). Nations enjoy spillovers boosting their productivity when they open up to trade. Embodied technology spillovers generate a positive externality of trade.

If a country exhibits power on international markets, it will be able to increase domestic welfare by erecting trade barriers and thereby manipulating terms of trade. Surprisingly, it has not yet been investigated how the incentives for strategic trade policy are altered in the presence of trade-induced productivity gains, in particular embodied technology spillovers. This paper fills this gap, both qualitatively and quantitatively. It sets up and solves a theoretical model; it estimates trade-related productivity gains based on this model econometrically; and it applies the estimates to a computable general equilibrium (CGE) model. It is a main contribution to the literature that we design these three methodological parts in a monolithic way such that all parts build on the same basic model.

The theoretical analysis highlights that setting a tariff without taking international productivity spillovers into account will fail to achieve the welfare optimum. It proves that productivity gains through imports and exports reduce the optimal tariff. If spillovers are strong enough compared to a country's market power, they can offset the incentive to abuse that power completely. Unlike in the model by Markusen (1975), power on international markets is not a prerequisite for productivity spillovers to be policy-relevant. The trade-induced productivity increasing externality occurs in the home country so that there is no need to manipulate international prices to internalize it.

Unlike the existing literature, the econometric estimations utilize the same novel data set as the computational part: the World Input-Output Database (cf. Dietzenbacher et al., 2013) providing bilateral and bisectoral production, consumption and trade data for 40 countries and 35 sectors for the years 1995 to 2009. Hence, as an improvement of the literature, all parts, theory, econometrics and numerical modeling, are built in a consistent fashion. The focus of our analysis is on the numerical modeling part.

The econometric analysis approves that import- as well as export-related productivity gains exist and shows that import-induced productivity gains are larger than export-induced ones. Implementing the theoretical and econometric findings in the numerical model application illustrates their policy-relevance. Optimal tariffs are reduced by a range between 17% for the US and China and 40% for Brazil when taking trade-induced productivity gains into account. Note that we only simulate spillovers from one year to another. Long-run productivity effects would be greater, further strengthen their importance.

We find higher optimal tariffs for China, India and the United States of America (USA) than for Europe. Productivity gains via trade are also meaningful for the competitiveness of European producers. Sectoral losses due to optimal tariffs across Europe show great diversity. Herein, the impact of trade-induced productivity gains is significant. The insights of this paper are policy-relevant, in particular in the light of real-world trade policy like the currently debated European Union - United States of America free trade agreement.

Our analysis refers to the optimal tariff literature which has a long tradition. Johnson (1954) demonstrates in a two-by-two model that under certain conditions a country will gain from imposing an strategic optimal tariff. Hamilton and Whalley (1983) highlight that in reality tariffs are "some distance from optimal tariffs" and that there is potential for making use of strategic optimal tariffs. They affirm that import price elasticities are crucial for setting optimal tariffs. Referring to the political economy literature, Mayer (1984) notes that "political decisions on tariff rates are reflections of the selfish economic interests of voters, lobbying groups, politicians, or other decision makers in trade policy matters". Gros (1987) suggests (drawing upon Krugman, 1980) that the optimal ad valorem tariff is an increasing function of the economy size and product differentiation. Kennan and Riezman (1988) claim that especially large open economies are able to manipulate the terms of trade in their favor. Brown (1987) argues that an Armington (1969) trade specification creates a strong terms-of-trade effect independent of country size so that even small countries will choose non-zero optimal tariffs. Brown (1987) shows that the terms-of-trade effect will vanish if the elasticity of substitution between imported varieties or imported varieties and the domestically produced variety becomes infinite. Kennan and Riezman (1990) exhibit that by imposing optimal tariffs, members of custom unions can become better off than under free trade. Broda et al. (2008) argue that, given power on international markets, "countries set import tariffs nine percentage points higher on inelastically supplied imports relative to those supplied elastically." Their results underline the policy relevance of optimal tariff literature.

The paper proceeds as follows: section 2 sets up and analyzes the theoretical framework. Section 3 explains the econometric strategy derived from the theoretical framework and the results. This illuminates the magnitude of the theoretical effects. Section 4 applies the theoretical framework and the estimated parameter values to a computable general equilibrium (CGE) model. This illuminates the policy relevance of the theoretical effects. Section 5 concludes with policy implications.

2 Theoretical framework

This section sets up and analyzes our theoretical framework. We draw upon Markusen's (1975) general equilibrium two-by-two trade model in the modified version by Jakob et al. (2013). This theoretical model describes trade policy in the presence of a negative transboundary, environmental externality. The home country wishes to influence foreign country's producers so that their impact on the home country via the transboundary externality is attenuated. The means to influence foreign producers' behavior is manipulating the terms of trade. When the home country imposes a higher tariff on its imports from the foreign country, foreign producers will produce less for the export market so that the externality will be mitigated.

Different to Markusen (1975) and Jakob et al. (2013), we do not implement a negative environmental externality of trade, but a positive productivity externality of trade. The positive productivity externality is associated with imports as well as exports. First, the positive externality can emerge through international technology spillovers. A broad literature stream (summarized by Saggi, 2002; Keller, 2004) has identified imports as a source of international technology spillovers. Imports embody advanced knowledge that can be exploited, and imports are often associated with international enterprises that exchange knowledge between their affiliates. Knowledge can further spill over from foreign affiliates to local firms. Second, the positive externality can emerge through increased competition and firm selection through exporting as described by Melitz (2003)[1] and the vast literature based on this seminal contribution. In particular, Felbermayr et al. (2013) analyze strategic trade policy in a Melitz model. In their model, the optimal tariff addresses a mark-up distortion, an entry distortion and a terms-of-trade externality. Our work is, however, more general by looking at export- as well as import-related productivity gains and by addressing a technology spillover externality, which creates additional effects.

[1]In the Melitz model of heterogeneous firms, trade liberalization induces the exit of low-productivity firms and the expansion of the profits and the market share of high-productivity exporting firms. This reallocation across firms raises overall productivity and welfare.

The following subsections set up and solve our basic model.

2.1 Model setup

Let us assume a *large open economy* called Home producing two tradable goods, X and Y. We further assume that goods X and Y are produced by one representative firm per sector. Each representative firm characterizes the behavior of a large number of atomistic firms in the sector. Therefore, firms cannot exploit market power in terms of price setting on national or international markets. We define $p^0 = \frac{p^Y}{p^X}$ as the domestic price for good Y relative to good X. Defining X as the numeraire with $p^X = 1$ results in $p^0 = p^Y$. We do not model the rest of the world and its behavior or reaction explicitly. We restrict the analysis to unilateral trade policy.

Home's production pattern depends upon p^0 and can be characterized by the following concave, decreasing production possibility frontier:

$$Q^X = T(Q^Y),\ T_{Q^Y} < 0,\ T_{Q^Y Q^Y} < 0 \tag{1}$$

Q denotes produced quantities. In general, quantities are measured in constant currency values throughout the paper. T determines the output of X that can be generated when producing a certain quantity of Y. One can imagine that the exogenously given quantity of production factors (resources) limits total production of X and Y.

Home's consumption pattern also depends upon p^0 and can be characterized by the following concave, increasing utility function:

$$U(C^X, C^Y),\ U_{C^X} > 0,\ U_{C^Y} > 0,\ U_{C^X C^X} < 0,\ U_{C^Y C^Y} < 0 \tag{2}$$

C^X and C^Y denote consumed quantities and hence demand.

Home's trade pattern can be described as follows. Let us without loss of generality assume that Home is a net exporter of X and a net importer of Y. We assume a balanced trade budget closure so that the following condition holds:

$$E^X = p^* M^Y \tag{3}$$

E denotes exports, whereas M denotes imports. International prices are expressed as $p^* = \frac{p^{Y*}}{p^{X*}}$. In general p^* differs from the domestic price ratio p^0. Home's terms of trade improve when p^* declines. The following expressions characterize the influence of Home's exports and imports and international prices:

$$p^*_{M^Y} > 0,\ p^*_{E^X} > 0 \tag{4}$$

A lower index represents a derivative with respect to the corresponding variable throughout the paper. Higher imports into Home raise the world market demand for Y and hence the relative price for Y, signified by p^*. Conversely, higher exports from Home raise the world market supply of X and hence again p^*.

Let us introduce a time index t that encompasses two periods $\{1; 2\}$. For the sake of simplicity, we assume that knowledge spillovers only occur in the first period $t = 1$, whereas they are realized in the second period $t = 2$. This takes into account that technology diffusion processes require time. Second-period trade and its growth effects are not relevant for this analysis and hence not taken into account. Second-period output proportionately relates to first-period output in the following fashion:

$$Q^{X2} = \left(1 + \gamma^0 + \gamma^E \tfrac{E^{X1}}{Q^{X1}}\right) Q^{X1} \tag{5}$$

$$Q^{Y2} = \left(1 + \gamma^0 + \gamma^M \tfrac{M^{Y1}}{Q^{Y1}}\right) Q^{Y1} \tag{6}$$

γ^0 captures exogenous growth, raising the efficiency of production equally for both X and Y. This corresponds to an proportionate outward shift of the production possibility frontier by the factor γ^0 without sector bias. The focus of our analysis is on trade-related productivity growth. We assume that trade-related growth adds to exogenous growth and is strictly separable from exogenous growth. This assumption implies that the choice of the production point (the shares of X and Y production in total production) in the second period equal those of the first period, while total quantities are multiplied by γ^0.

Trade-induced productivity gains add to this second-period production unexpectedly in the second step without affecting the production point of the production possibility frontier. This implies, producers do not internalize the productivity gains from trade. Hence, producers' choice of relative X and Y production in any period is not affected by trade-induced productivity gains without policy intervention. To model the unanticipated externality, we assume that productivity gains in period 2 depend on Home's export and import intensity (measured relative to production) in period 1. We assume that the externality is sector-specific so that a higher export intensity in the X sector expands second-period X production. γ^E governs the strength of export-induced productivity gains, which are supposed to capture Melitz-type firm selection effects, productivity gains from competition on export markets and possibly technology spillovers through contact with trading partners, although technology spillovers are mainly expected from importing.

A higher import intensity expands second-period Y production in the analog way. γ^M governs the strength of import-induced productivity gains, which are supposed to capture technology spillovers and productivity gains from competition on import markets. In this stylized typical two-by-two trade model with homogeneous products, though, each sector is either a net exporter (here X) or a net importer (here Y). This simplification will again be relaxed in the econometric estimation and in the numerical model calibration in order to fit theory to real-world data. Formally, we write sectoral second-period production Q^{X2} and Q^{Y2} as a function of first-period export intensity $\frac{E^{X1}}{Q^{X1}}$ and import intensity $\frac{M^{Y1}}{Q^{Y1}}$. We employ the intensity form to make spillovers independent of sector size.

2.2 Closed-form solution

We are now able to phrase and solve Home's two-period utility maximization problem:

$$\max_{\{Q^{Y1},Q^{Y2},M^{Y1},M^{Y2},E^{X1},E^{X2}\}} W, \quad W = U^1 + U^2 \tag{7}$$

We insert Equations (1) to (6). Moreover, we assume that there is no change in consumer preferences so that the second-period utility function equals the first-period function. We impose a balanced budget condition given by (3) on first-period trade. The total output of each good is fully absorbed. We drop the time index, assuming that all variables refer to period 1. Using (3), we can write the international price ratio p^* as a function of M^Y. Note that we only look at first-period trade like in a static one-period trade-model. By assumption, no induced spillovers occur in the second period. Therefore, the second period reverts to the standard case of the optimal tariff model. We refrain from displaying Home's optimal trade pattern in the second period to focus our analysis on the spillover-related effects in the first period. We recall that the exogenous part of technical progress governed by γ^0 shifts the production possibility frontier $T(Q^Y)$ outward so that X and Y production expand by the same factor γ^0. Trade-induced productivity gains, on the contrary, are sector-specific and add to the exogenous expansion of the production possibility frontier independently. We recall that firms do not anticipate trade-induced spillovers, or in other words productivity gains, and thus do not take them into account in their calculus. The second-period distribution of production to the X- and the Y-sector is therefore unaffected by the existence of the trade-induced spillovers. Since all production is absorbed by the consumer of the home country and we do not look at second-period trade, both, the exogenously and the endogenously created additional second-period production directly add to consumption. Since the utility function does not change across periods and everything else stays constant across periods, we can subsume first- and second-period consumption within one consumption function with the arguments X and Y consumption. For the sake of brevity, we do not discount utility. Based on these considerations, we obtain the following maximization problem with first-period Y production and first-period imports M as the only control variables:[2]

$$\max_{\{Q^Y,M^Y\}} W, \quad W = U\left[T(Q^Y) - M^Y \cdot p^*(M^Y),\ Q^Y + M^Y\right]$$
$$+U\left[(1+\gamma^0)T(Q^Y) + \gamma^E M^Y \cdot p^*(M^Y), (1+\gamma^0)Q^Y + \gamma^M M^Y\right] \tag{8}$$

By executing $\frac{\partial W}{\partial Q^Y} = 0$ and $\frac{\partial W}{\partial M^Y} = 0$, we obtain the first-order conditions:

$$(2+\gamma^0)U_{C^Y} + (2+\gamma^0)T_{Q^Y}U_{C^X} = 0 \tag{9}$$

$$(1+\gamma^M)U_{C^Y} - (1-\gamma^E)(p^* + M^Y \cdot p^*_{M^Y})U_{C^X} = 0 \tag{10}$$

A lower index indicates a first derivative with respect to this variable. We recall from basic micro-economic theory that a consumer achieves maximum utility when the ratio of marginal utilities (the marginal rate of substitution) equals the corresponding consumer price ratio q^0:

$$q^0 = \frac{q^Y}{q^X} = \frac{U_{C_Y}}{U_{C_X}} \tag{11}$$

We also recall that producers earn maximum profits when the ratio of marginal productivities (the technical rate of substitution) equals the corresponding producer price ratio with inverse sign:

$$p^0 = -T_{Q^Y} \tag{12}$$

[2]Note that the trade- induced productivity gains, $\gamma^E M^Y \cdot p^*(M^Y)$ in the X-sector and $\gamma^M M^Y$ in the Y-sector, are independent of first-period production quantities Q. (Q cancels out in the trade-induced terms in Equations 5 and 6.) They solely depend on first-period import and export quantities and the related strengths of productivity gains (spillovers).

Rearranging (9) and (10) and inserting (11) and (12) yields:

$$q^0 = p^0 \tag{13}$$

$$q^0 = (p^* + \underbrace{M^Y \cdot p^*_{M^Y}}_{\theta^{strat}}) \cdot \underbrace{\frac{1-\gamma^E}{1+\gamma^M}}_{\theta^{prod}} \tag{14}$$

The first equation simply affirms that in the optimum, Home's consumer price equals the producer price. This means, production is unaffected by the existence of trade-induced productivity gains as specified in Equation (5) and (6). The second equation affirms that the optimal tariff drives a wedge between the international price and Home's consumer price. θ^{strat} is the well-known strategic term: by imposing a tariff at the rate $\theta^{strat} = M^Y \cdot p^*_{M^Y}$ in addition to the international price, Home optimally exploits its power on international markets.[3] A higher $p^*_{M^Y}$ implies a stronger reaction of the world market price to changes in Home's imports (and exports). As a consequence, Home's optimal tariff rises in order to exploit the market power increasing in $p^*_{M^Y}$.

Proposition 1. *In the presence of trade-induced productivity gains, there is an incentive to expand trade even without market power on international markets (when the home country is a small open economy). The potential for expanding trade with the aim to exploit trade-induced productivity gains increases in international market power.*

Proof. Consider Equation (14) for a small open economy. Without market power on international markets, $p^*_{M^Y}$ is zero. Hence, the possibility to manipulate the terms of trade (θ^{strat}) vanishes. The incentive to internalize the productivity effect of trade is nevertheless present, represented by the last term (θ^{prod}). Home attempts to export and import more in order to exploit the trade-induced productivity gains (technology spillovers) that occur within its boundaries. If international prices stay constant and cannot be influenced by Home, Home can nevertheless influence domestic prices relative to the constant international prices. This mechanism differs from Markusen (1975), where the environmental externality occurs abroad and Home requires market power to mitigate the environmental externality in the foreign country by influencing international prices. Hence, in Markusen's model, it is necessary that the home country is a large open economy. In our model, on the contrary, the externality occurs within the home country so that the ability to internalize it does not depend on power on international markets. This result also

[3] The import-dependency of the international price creates a term that is typical for a maximization problem with monopoly power, in this case $M^Y \cdot p^*(M^Y)$ in equation (8).

differs from Brown (1987), where no externality is taken into account so that the terms-of-trade effect will vanish, when traded commodities become perfectly substitutable, i.e. when market power disappears.

Nevertheless, the potential for expanding the externality in absolute terms increases in power on international markets. This can easily be seen in Equation (14). The productivity-related term (θ^{strat}) reduces any given price wedge in relative terms, i.e. by a factor $\theta^{prod} < 1$. In absolute terms, the effect depends upon the magnitude of $p^* + \underbrace{M^Y \cdot p^*_{M^Y}}_{\theta^{strat}}$. Since $p^*_{M^Y}$ rises in Home's market power, θ^{prod}'s absolute effect also rises in Home's market power. The intuition is that with higher market power, Home has a higher potential for boosting trade by manipulating international prices so that foreign producers intend to enhance trade with Home.

Proposition 2. *Productivity gains through imports and exports reduce the optimal tariff that manipulates the terms of trade in favor of a large open economy.*

Proof. In Equation (14), θ^{strat} attenuates the price for Y imports and elevates the price for X exports relative to each other. This improves the terms of trade in Home's favor but hampers trade in absolute volumes. Stronger productivity gains via exports, expressed by γ^E, or stronger productivity gains via imports, expressed by γ^M, both contradict the effect of θ^{strat}. This converse effect of productivity gains from trade on the terms of trade is summarized by θ^{prod}. $\theta^{prod} < 1$ has the form of an ad-valorem subsidy that multiplies the world market price plus the strategic tariff by a factor smaller than one. The intuition is simple: the strategic term improves the international price in Home's favor, but diminishes import and export volumes. Home, on the contrary, attempts to expand import and export volumes in the presence of productivity gains in order to better exploit them.

Proposition 3. *For every world market price, there exists a certain strength of productivity gains through imports and exports such that the incentive to manipulate the terms of trade vanishes.*

Proof. Solving Equation (14) in the form $p^* = q^0 = (p^* + M^Y \cdot p^*_{M^Y}) \cdot \frac{1-\gamma^E}{1+\gamma^M}$ yields:

$$p^* \cdot (\gamma^M - \gamma^E) = M^Y \cdot p^*_{M^Y} \cdot (1 - \gamma^E) \tag{15}$$

If this condition is fulfilled, there will be no difference between the original world market price p^* and the one manipulated via Home's optimal tariff. The incentive for beggarthy-neighbor policies is perfectly offset by the incentive to internalize the productivity spillovers.

Proposition 4. *The welfare gain for a large open economy achieved via a given tariff rate is lower in the presence of productivity gains through imports and exports than in their absence.*

Proof. More potent market power expressed by a higher $p^*_{M^Y}$, i.e. a stronger impact of Home's imports on international prices, magnifies the potential for welfare gains through the manipulation of international prices. In Equation (8), a reduction in imports M^Y reduces consumption C^Y, which is detrimental for Home, and simultaneously reduces exports valued by international prices $M^Y \cdot p^*(M^Y)$, which raises consumption C^X, which is beneficial. The more potent Home's market power is, the stronger the latter beneficial effect is. As a consequence, the welfare gain that can be achieved by compressing imports is higher under more potent market power. It is obvious in Equation (14) that the productivity gain factor θ^{prod} reduces $p^*_{M^Y}$ and hence the effective market power and thus counteracts the use of strategic tariffs. This in turn attenuates the welfare gain generated by a tariff (the optimal tariff or any other tariff).

The following Section 3 finds evidence for the existence of the productivity gains driving the propositions. Section 4 validates these propositions in a more complex numerical model.

3 Econometric estimation

This section estimates the coefficients governing the strength of import- and export-driven productivity gains. Our econometric analysis builds upon a vast literature stream on trade-related international productivity (technology) spillovers as summarized by Saggi (2002), Keller (2004) and Havranek and Irsova (2011) (cf. Coe and Helpman, 1995, and Coe et al., 1997, for seminal papers on North-South productivity spillovers). Although the results of this literature are diverse and ambiguous, the bottom-line is that trade-induced (and more significantly foreign direct investment-induced) international productivity gains do exist. Other than to these studies, we contrast import-induced with export-induced productivity gains. The latter endeavor follows the literature that seeks for Melitz (2003) type of productivity gains from firm selection. Girma et al. (2004), for example, find for manufacturing firms in the United Kingdom that exporters are more productive than other firms and become even more productive through exporting. The contribution of our econometric analysis is to compare import- and export-related productivity gains at the country and sector level within a large global data set. Our econometric analysis itself is, however, mainly an intermediate step that proves the validity of the theoretical model (of section 2) and provides the parameter values for the numerical implementation (in section 4). We abstain from including control variables (besides fixed-effects) because we make the estimations as consistent as possible with the numerical model implementation described in the following section. The numerical implementation does not allow us to include control variables since they are not implemented in the model. As a consequence, it is less detailed than fully-fledged econometric analyzes that infer their implications solely from the econometric results based on various tests, regressions and robustness checks. Such a detailed econometric analysis is beyond the scope of this model analysis. Consequently, direct policy inference from our econometric analysis requires some caution and an interpretation in the context of the existing literature. The following subsections derive the econometric estimation from the theoretical model and interpret the estimation results.

3.1 Model setup

This subsection derives the econometric model from the framework set up in the previous section. Equations (5) and (6) implicitly assume that output expands while total input stays constant. Let now input Z, which captures all inputs of production factors as well as intermediate goods, enter the equation explicitly. Furthermore, let us generalize the model to s sectors. In order to fit the model to real-world data, the assumption that each sector produces a homogeneous good which is either imported or exported is dropped. Instead, we take into account that in reality products of sector s can both be imported and exported. This requires the existence of varieties of each good produced in different countries. For this purpose, we also introduce a region index r describing a number of countries. Each sector in each region exports and imports one good (one commodity). Imports to one region and sector are aggregated over all other exporting regions. Likewise, exports of a country and sector are imported by any other region. In addition, let t denote time, or more specifically, a number of years. Then, the generalized combination of Equations (5) and (6) results in the following equation for each sector:

$$\frac{Q^{rst+1}}{Z^{rst+1}} = \left(1 + \gamma^{0r} + \gamma^M \frac{M^{rst}}{Q^{rst}} + \gamma^E \frac{E^{rst}}{Q^{rst}}\right) \cdot \frac{Q^{rst}}{Z^{rst}} \tag{16}$$

The exogenous growth factor γ^{0r} is region-specific. The trade-related growth factors γ^M and γ^E are assumed to be identical in all sectors and regions. $\frac{Q^{rst}}{Z^{rst}}$ can be interpreted as total factor productivity (TFP).[4] This means, the above equation describes total factor productivity growth. It describes the growth rate of $\frac{Q^{rst+1}}{Z^{rst+1}}$ and can therefore be rewritten in *dlog* form. γ^{0r} can be interpreted as country fixed-effects. Adding an error term ϵ^{rst} that captures deviations not explained by the model yields:

$$d\log\left(\frac{Q^{rst+1}}{Z^{rst+1}}\right) = \gamma^{0r} + \gamma^M \frac{M^{rst}}{Q^{rst}} + \gamma^E \frac{E^{rst}}{Q^{rst}} + \epsilon^{rst} \tag{17}$$

We estimate this equation using the novel World Input Output Database (WIOD)[5] panel data for 40 countries[6], 29 sectors[7] and the years 1995 to 2009. It is to our knowledge the first database providing bilateral and bisectoral input-output relations and various socio-economic and environmental indicators for a sequence of years within one consistent data set.

The growth of total factor productivity is computed with the help of the production function defined by Equation (19). The equation depicts the constant elasticity of substitution (CES) nesting structure that will be used in the numerical model. It is assumed that technical progress only affects total factor productivity, while optimal input shares of factors remain constant. Inputs of labor and energy, measured in physical units (million hours worked, Terajoule), are also taken from the WIOD database. All quantities

[4]Setting $Z^{rst+1} = Z^{rst}$ and multiplying by Z^{rst} on both sides leads back to Equations (5) and (6).

[5]The WIOD project has been funded by the European Commission, Directorate General Research, as part of the 7^{th} Framework Programme, Theme 8: Socio-Economic Sciences and Humanities. WIOD has been available for the public since April 2012. See Timmer, M.P. (2012, ed.), The World Input-Output Database (WIOD): Contents, Sources and Methods. `http://www.wiod.org/database/`.

[6]Australia (ROW), Austria (EUR), Belgium (EUR), Canada (ROW), Czech Republic (EUR), Denmark (EUR), Estonia (EUR), Finland (EUR), France (EUR), Germany (EUR), Greece (EUR), Hungary (EUR), Ireland (EUR), Italy (EUR), Japan (EAS), Luxembourg (EUR), Mexico (ROW), Netherlands (EUR), Poland (EUR), Portugal, Slovak Republic (EUR), South Korea (EAS), Spain (EUR), Sweden (EUR), Turkey (ROW), United Kingdom (EUR), United States of America (USA), Bulgaria (EUR), Brazil (BRA), China (CHN), Cypress (EUR), India (IND), Indonesia (ROW), Latvia (EUR), Lithuania (EUR), Malta (EUR), Romania (EUR), Russia (RUS), Slovenia (EUR), Taiwan (EAS) (for region codes like ROW and explanations see section 3.2 and Table 2).

[7]Agriculture, Hunting, Forestry and Fishing; Mining and Quarrying; Food, Beverages and Tobacco; Textiles and Textile Products; Wood and Products of Wood and Cork; Pulp, Paper, Printing and Publishing; Chemicals and Chemical Products; Rubber and Plastics; Other Non-Metallic Mineral; Basic Metals and Fabricated Metal; Machinery, Nec; Electrical and Optical Equipment; Transport Equipment; Manufacturing, Nec, Recycling; Electricity, Gas and Water Supply; Construction; Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles; Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods; Hotels and Restaurants; Inland Transport; Water Transport; Air Transport; Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies; Post and Telecommunications; Financial Intermediation; Real Estate Activities; Renting of M&Eq and Other Business Activities; Health and Social Work; Other Community, Social and Personal Services. 6 WIOD sectors with missing data are left out.

appearing in the estimation are measured in 1995 US-$. Elasticities of substitution are taken from Koesler and Schymura (2012). They estimate the elasticities with the help of the WIOD data in a non-linear fashion. Hence, we utilize consistent data and parameter values throughout the econometric and numerical modeling analysis.

3.2 Estimation results

This subsection discusses the estimation results reported in Table 1. We always report heteroscedasticity robust standard errors. The estimated import-related coefficient γ^M can be economically interpreted in the following way: suppose the exogenous growth rate of a country is 0.02 per year and the import intensity of a specific sector in this country rises from 0.3 to 0.4, i.e. by 0.1. As a result, the annual productivity growth rate will increase from 0.02 to 0.02359. The same interpretation applies to the export-related coefficient, albeit the magnitude of this effect is less than half the import-related effect.

The regressions include country-specific fixed effects. Anticipating the regional structure of our modeling exercise in the following section, we aggregate the 40 countries to eight countries and regions. We aggregate country-specific growth rates by computing GDP-weighted averages (for the country-region matching see footnote 5). Table 2 depicts the eight model regions and their resulting estimated aggregate, *exogenous* annual total factor productivity growth rates. The results highlight two aspects:

	Annual growth rate of total factor productivity $d\log\left(\frac{Q^{rst+1}}{Z^{rst+1}}\right)$	
Import intensity $\frac{M^{rst}}{Q^{rst}}$	$\gamma^M = 0.0359^{***}$	(0.01370)
Export intensity $\frac{E^{rst}}{Q^{rst}}$	$\gamma^E = 0.0160^{**}$	(0.00777)
F	19.44	(0.0000)
R^2	0.0380	
Number of observ.	15,678	

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 1: Panel estimation for 40 countries, 29 sectors and 15 years including country-specific fixed-effects.

Result 1. *The existence of import- and export-driven productivity gains (technology*

Region-specific exogenous annual growth rate of total factor productivity γ^{0r}		
European Union	EUR	0.005
United States of America	USA	0.008
Russia	RUS	0.014
Brazil	BRA	0.000
India	IND	0.017
China	CHN	0.030
East Asia	EAS	0.009
Rest of the World	ROW	0.009

Table 2: Aggregated country-specific fixed-effects taken from the panel estimation.

spillovers) presumed in our theoretical framework is confirmed by the data.

Both, the coefficients of import intensity and export intensity, are statistically significant and positive. This implies that importing and exporting are associated with a positive externality that raises total factor productivity.

Result 2. *The strength of trade-related productivity gains is asymmetric: imports entail higher productivity gains than exports.*

This result is in accordance with the econometric literature (referred to in the introduction to this section) which in most cases focuses on import- (or FDI-) induced technology spillovers. Consequently, fostering imports will entail higher productivity gains than fostering exports.

Result 3. *Taking endogenous trade-induced productivity gains into account, diminishes the strategically optimal international price ratio by about 5 per cent.*

According to (14), the productivity gain factor that diminishes the the strategically optimal international price ratio can be expressed as $\theta^{prod} = \frac{1-\gamma^E}{1+\gamma^M}$. Inserting the estimations of γ^E and γ^M reported in Table 1, yields the factor $\theta^{prod} \approx 0.95$.

In accordance with the literature, our results confirm the existence of positive trade-induced technology spillovers, however, without detecting tremendous effects. Whereas the literature on technology spillovers focuses on imports, we also take exports into account in terms of firm selection and increased competition and find a positive significant effect. More specifically, Hübler and Keller (2009) regress energy intensities of 60 developing countries between 1975 and 2004 in *dlog* form on import intensity as in our specification. They find a negative, yet insignificant coefficient of -0.017 for import *intensity* (in regression B1, which is most similar to our estimation). This result comes close to the coefficient of 0.016 for total factor *productivity* (the inverse of factor intensity) that we find for export intensity. The coefficient for import intensity is more than twice the coefficient for export intensity in our results. Hübler and Keller (2009), however, utilize energy instead of labor intensity, they do not use sectoral data, they include further regressors – and their results are neither robust across specifications nor significant.

4 Numerical simulation

This section implements the growth mechanism that has been theoretically and econometrically studied in the previous sections in the WIOD computable general equilibrium (CGE) model. It particularly addresses the propositions derived in section 2. The results underline the policy-relevance of trade-induced productivity spillovers.

Our trade analysis is related to numerical analyses of trade liberalization as critically reviewed by Ackerman and Gallagher (2008). The authors conclude that the gains from free trade have a small magnitude, which is in line with our results. Ackerman and Gallagher highlight the crucial role of Armington (1969) elasticities, which we will also address in our robustness checks. This literature strand does not take international productivity spillovers into account, though. International productivity spillovers are considered by some studies in the field of development economics. Diao et al. (2005), for example, build a general equilibrium model in which trade-related international technology spillovers enhance economic growth. They calibrate this model to the Thai economy. They demonstrate that protectionism slows down economic growth. Nonetheless, shock liberalization creates a strong short-run stimulus, but a smaller long-run stimulus. More recently, the model-based assessment of international climate policy emphasizes the possible role of international technology spillovers for reducing carbon mitigation costs (e.g. Bosetti et al., 2008; Leimbach and Baumstark, 2010; Hübler, 2011). This literature overall finds a significant, but small influence of international technology spillovers on climate policy costs. Yet, this literature strand does not specifically deal with trade policy as our analysis does. Notably, a single distinct approach implements the Melitz (2003) mechanism in a numerical general equilibrium model (Balistreri et al., 2011; Balistreri and Rutherford, 2012). This approach captures productivity gains through trade and firm selection, but not technology spillovers through exporting and importing as our approach does. Balistreri et al. (2011) find gains from trade liberalization that are four times larger with the Melitz approach than with the standard Armington approach. Balistreri and Rutherford (2012) and Böringer et al. (2012) underline that the Melitz mechanism accentuates the impacts of trade measures (in this case, tariffs based on carbon intensities of products known as border carbon adjustment). Like Balistreri et al. (2011), we build our numerical implementation on theory and an econometric estimation of the parameter values that we require for parameterizing our theoretical approach.

Whereas benchmark year data for the static calibration are available from sources like GTAP[8], parameter values for the dynamic calibration including the international spillover mechanism are not directly available. It is a shortcoming of this literature to apply guesstimated parameter values for the mechanisms of endogenous growth and international technology spillovers. Thus, the main advancement of our implementation compared to the literature is the use of the same mathematical formulation and the same dataset for the model implementation as for the econometric estimation of the model parameter values. This guarantees a high precision of the parameterization. The following subsections explain the extended general equilibrium framework and discuss the simulation results.

4.1 Model setup

This subsection explains the extended model framework. In particular, we implement Equation (16) of the econometric estimation in a WIOD-data-based CGE model:

$$\frac{Q^{rs2}}{Z^{rs2}} = \left(1 + \gamma^{0r} + \gamma^{M}\frac{M^{rs1}}{Q^{rs1}} + \gamma^{E}\frac{E^{rs1}}{Q^{rs1}}\right) \cdot \frac{Q^{rs1}}{Z^{rs1}} \tag{18}$$

This implies that each sector imports and exports a variety of each good so that we can calibrate the model to the same real-world data as in the econometric analysis.[9] In each sector, imports and exports create sector-specific productivity gains. For computational reasons and for a better regional focus, we aggregate the WIOD data set to eight regions r: Europe, USA, China, India, Brazil, Russia, East Asia (without China) and Rest of the World. In addition, we aggregate the original 35 WIOD sectors to 18 sectors[10] denoted

[8] Global Trade Analysis Project, `https://www.gtap.agecon.purdue.edu/default.asp`.

[9] In the theoretical model, we followed the classical trade model type and assumed only two sectors which can either be a net importer or a net exporter.

[10] Agriculture/forestry/fishing, chemicals, construction, coke/petroleum/nuclear, electrical/optical equipment, electricity/gas/water supply, food/beverages/tobacco, machinery, metals, mining/quarrying,

by s. We choose 2007 as the benchmark year representing period 1. This means, we calibrate our model to the global WIOD input-output table for the year 2007.[11] Period 2 is generated by expanding each region and sector according to the above equation. Output Q, imports M, exports E, and inputs Z are endogenous variables resulting from the general equilibrium of period 1. Notably, the γ-parameter values are taken from the econometric estimation in the previous section.

The general equilibrium model ist written in price or marginal-cost form as a mixed complementarity problem (MCP). It consists of the following elements:

1. Zero-profit conditions:

First, the main production function, defined over all regions and sectors, generates (final) goods by using production factors and (intermediate) goods as inputs:

$$0 \geq \pi^{Q}_{rst} = p^{Q}_{rst} - CES^{\sigma^{klem}}_{rst}\{p^{m}_{rst}, CES^{\sigma^{kle}}_{rst}[CES^{\sigma^{kl}}_{rt}(p^{l}_{rt}, p^{k}_{rt}), CES^{\sigma^{e}}_{rst}(p^{e}_{rst})]\} \tag{19}$$

where π denotes profits, p a price (not a price ratio) and CES a constant elasticity of substitution function with the arguments in parentheses and the elasticity of substitution σ in the upper index. As before, r denotes regions, s sectors and t time (years). Q denotes a produced quantity. k signifies capital, l labor, e energy and m non-energy (intermediate) goods, all used as inputs and written in small letters. This condition implies perfect competition on goods markets. Goods are traded between regions, whereas the production factors capital and labor are region-specific. Like in the econometric analysis, the elasticities of substitution are again taken from Koesler and Schymura (2012) who estimate them with the help of the same WIOD data set. We will apply alternative upper and lower bound Armington elasticities in a robustness check.

Second, the Armington (1969) trade structure, indicated by a and defined over source and recipient regions and sectors, aggregates a good produced in various foreign regions to a bundle and combines it with the corresponding domestically produced good thereafter.

$$0 \geq \pi^{a}_{rst} = p^{a}_{rst} - CES^{\sigma^{a'}_{s}}_{rst}[p^{q}_{rst}, CES^{\sigma^{a}_{s}}_{r^{*}st}(p^{q}_{r^{*}st} - \tau_{r})] \tag{20}$$

where r^{*} signifies source regions, whereas r denotes recipient regions. The index em denotes that both, non-energy and energy goods, are included. This condition implies that

other non-metallic minerals, other manufacturing/recycling, paper/printing/publishing, services, transport equipment, textiles, transportation, wood.

[11] We choose 2007 as a compromise between using the newest data and using data that are not affected by the economic crisis. Other benchmark years will be discussed in a robustness check.

no profits exist within the Armington trade domain. Nonetheless, goods produced in different regions are not perfect substitutes; they are distinct varieties. The preference for each variety is determined by its share in total imports given by the benchmark data. The sensitivity of this share with respect to (price) shocks is determined by the Armington elasticity of substitution which is sector-specific. σ_s^a symbolizes the elasticity of substitution between imported varieties from different regions, whereas $\sigma_s^{a'}$ symbolizes the elasticity of substitution between the bundle of imported varieties and the domestically produced variety. As a consequence of the Armington specification, each region has some extent of (monopolistic) market power on international goods markets. Since the WIOD data do not contain parameter values for the Armington elasticities, we borrow them from the GTAP[12] 7 data. Armington trade has implications for optimal trade policy. Most notably, product differentiation by country of origin implies some degree of market power for all regions (cf. Brown, 1987).

Importantly, τ is the *ad valorem import tariff rate* that we will exogenously vary in our numerical simulations. For the sake of consistency with the theoretical model and of analytical clarity, we assume the same tariff rate for all goods imported to country r.

Third, the consumption function, defined over regions, aggregates non-energy goods to a bundle and energy goods to another bundle and combines them thereafter:

$$0 \geq \pi_{rt}^c = p_{rt}^c - CES_{rt}^{\sigma^{cme}}[CES_{rst}^{\sigma^{cm}}(p_{rst}^m), CES_{rst}^{\sigma^{ce}}(p_{rst}^e)] \tag{21}$$

This function defines the representative consumer of each region.

2. Market clearance conditions:

First, domestic production ought to satisfy domestic input demand, Armington export demand and domestic consumption so that all goods markets clear:

$$Q_{rst} \geq \sum_{s'} \frac{\partial \pi_{rs't}^q}{\partial p_{rst}^q} Q_{rs't} + \sum_{r^*} \frac{\partial \pi_{r^*st}^{em}}{\partial p_{rst}^q} M_{r^*st} + \frac{\partial \pi_{rt}^c}{\partial p_{rst}^q} C_{rt} \tag{22}$$

where Q denotes the output value, M the import value and C consumption as before. s' signifies sectors that demand good s as an intermediate input (s' and s cover the same set of sectors so that a specific sector can also receive intermediate inputs from itself), and r^* again foreign regions.

[12]Global Trade Analysis Project, `https://www.gtap.agecon.purdue.edu/`

Second, domestic import demand for each good ought to absorb the supply of this good by all foreign regions so that all international goods markets clear:

$$M_{rst} \geq \sum_{r^*} \frac{\partial \pi^{em}_{r^*st}}{\partial p^{em}_{rst}} Q_{r^*st} \tag{23}$$

Third, an intratemporal condition ensures that the representative consumer of each region spends his budget fully on consumption:

$$C_{rt} \geq \frac{B_{rt}}{p^c_{rt}} \tag{24}$$

where B denotes the value of the consumer's budget.

3. Budget condition:

The model is closed by imposing a balanced budget condition on each representative consumer:

$$B_{rt} = p^l_{rt}\bar{L}_{rt} + p^k_r\bar{K}_r + \bar{p}^d\bar{D}_r \tag{25}$$

where $\bar{L}$ and $\bar{K}$ characterize the consumer's endowments with labor and capital. $\bar{D}$ indicates a fixed current account deficit (given by the data) associated with the numeraire price $\bar{p}^d = 1$.

4.2 Numerical solution

This section first and foremost illustrates our theoretical findings for the European economy. It then examines how these results vary across different regions, different benchmark years, different Armington elasticities and thus different degrees of market power, and different European production sectors. It ends with a short resume.

4.2.1 European trade policy

In our numerical experiment, we first choose Europe (EUR) in the year 2007 as the exemplary region r in the spotlight. This means, we exogenously vary the tariff τ imposed on Europe's imports. We examine the effect of varying the import tariff on Europe's welfare and identify the optimal tariff with endogenous in comparison to exogenous trade-related technology spillovers to Europe. We also investigate how the other model regions are affected by the European tariff.

We first solve a benchmark run without trade policy intervention. Then, we impose tariffs at various rates on European imports. In the exogenous spillover scenario, denoted by *ExoSpill*, productivity gains are fixed at their benchmark run values independent of changes in imports and exports. In the endogenous spillover scenario, denoted by *EndoSpill*, productivity gains are a function of the import and export intensity following our theoretical and empirical model. Importantly, without policy intervention and thus without deviations of the trade pattern, both scenarios generate the same benchmark growth rate between periods one and two. When trade patterns change due to policy intervention, productivity growth will be unaffected in scenario *ExoSpill*, but will react in scenario *EndoSpill*. The propositions formulated in the theoretical part basically compare a situation where productivity gains depend on imports and exports with a situation in which they do not. Consequently, the theoretical outcomes can be evaluated by comparing the scenario *EndoSpill* with *ExoSpill*.

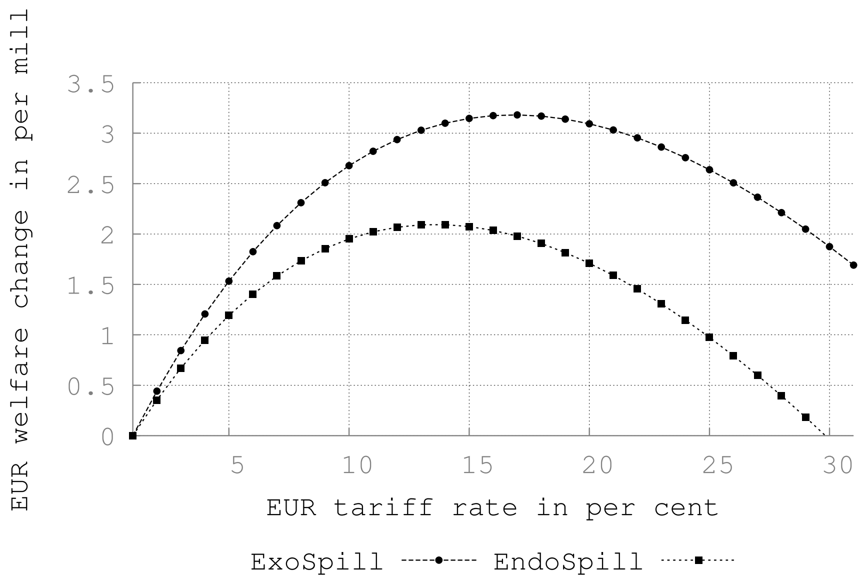

Figure 1: Europe's per mill welfare change in *EndoSpill* and *ExoSpill* relative to the benchmark run without a tariff measured within period 2 over various tariff rates.

Figure 1 illustrates Europe's per mill welfare change in *EndoSpill* and in *ExoSpill* relative to the benchmark run without a tariff, always measured within period 2 and plotted over various tariff rates. The curve has an inverted U-shape which is typical for optimal tariff analysis.

We recall Proposition 2 stating that productivity gains through imports and exports reduce the optimal tariff manipulating the terms of trade in favor of a large open economy. Figure 1 shows that the optimal, i.e. the welfare-maximizing, tariff rate under *EndoSpill* is about 13 percent, whereas the optimal tariff rate under *ExoSpill* is about 16 percent, which corroborates the proposition.

We recall Proposition 3 stating that there exists a certain strength of productivity gains from trade such that the incentive to manipulate the terms of trade vanishes. In our simulations, the spillover strength of exports and imports is given by the econometric estimates of the previous section based on real-world data. Apparently, the estimated spillover strength is by far too low to completely enervate the incentive to use a tariff for strategic (terms of trade) reasons.

We recall Proposition 4 stating that the welfare gain for a large open economy achieved via a given tariff rate is lower in the presence of productivity gains through imports and exports than in their absence. Figure 1 illustrates that the welfare change curve for *EndoSpill* always lies below the welfare curve for *ExoSpill* in accordance with Proposition 2. The maximum welfare gain reached by the optimal tariff is about 3.2 per mill under *ExoSpill* and only about 2.1 under *EndoSpill*. This leads us to conclude:

Result 4. *The numerical simulations corroborate the relevance and significance of Propositions 2 and 4. Optimal tariffs are always lower when accounting for endogenous productivity growth. For all tariffs welfare is lower if endogenous productivity gains are neglected.*

How does the optimal European tariff affect the other regions' welfare? Table 3 answers this question by setting the European tariff to the optimal rate within scenario *ExoSpill* (16 per cent) and thereafter to the optimal rate within scenario *EndoSpill* (13 per cent) as depicted by Figure 1. Table 3 reveals the following surprising outcome: the USA gain from Europe's optimal tariff by more than one per mill, whereas the other regions lose to different extents. The USA obviously absorb part of the imports which, previous to the introduction of the optimal tariff, went to Europe and benefit from this inverse trade diversion effect (Lower European imports attenuate world market prices so that the USA can import at lower prices). Russia as an energy exporter loses up to 15 per mill, and China up to 9 per mill of welfare due to Europe's tariff. India, on the contrary, is hardly affected by Europe's trade policy. In all cases, the *ExoSpill* effects with fixed regional productivity growth on the other regions are larger than the *EndoSpill* effects with endogenous trade-dependent regional growth. The first reason is that the optimal tariff under *EndoSpill* is lower than under *ExoSpill* so that the trade impacts are smaller. The second theoretical reason is that Europe can achieve higher productivity growth under *EndoSpill*. Consequently, it will demand more imports and produce more (or cheaper) exports, which is beneficial for the other regions. Yet, it is not beneficial for the USA because they benefit from higher, not from lower European trade barriers due to inverse trade diversion.

Welfare effects of EU trade policy W^{r2}			
		ExoSpill	*EndoSpill*
European Union	EUR	3.2	2.1
United States of America	USA	1.5	1.1
Russia	RUS	-15.1	-12.8
Brazil	BRA	-3.6	-3.2
India	IND	-0.4	-0.6
China	CHN	-9.2	-7.7
East Asia	EAS	-2.6	-2.1
Rest of the World	ROW	-6.8	-6.2

Table 3: Regional welfare effects of Europe's optimal tariffs under the scenarios *ExoSpill* and *EndoSpill* in period 2 in per mill (compared to the benchmark without tariffs).

With respect to the magnitude of the effects under scrutiny, it turns out, though, that the welfare changes have a magnitude of some per mill. This means, the effects under scrutiny have a limited economic meaning with regard to real-world data. Notably, our model has only a two-period scope. Some per mill of global GDP accumulated over a number of years nonetheless generate a substantial welfare effect. The optimal tariff rates themselves are within a realistic range. For comparison: Europe's unweighed average tariff rate on products from the USA was 7.3 per cent in 2007;[13] it reached 9.1 per cent in 1990 and 12.0 per cent in 1995; it declined to 4.6 in 2010. Thus, Europe's computed optimal tariff rates of 13 or 16 per cent are not much above these historical rates.

4.2.2 Region-specific trade policy

We carry out the same tariff analysis for the other main model regions, i.e. the United States and the BRIC countries (Brazil, Russia, India and China). Figure 2 in the Appendix puts the European result depicted by Figure 1 in perspective to the corresponding results for the other model regions. Table 4 summarizes the optimal tariffs τ^r_{opt} and corresponding welfare effects W^{r2} for the main model regions. The results are reported for each scenario, *ExoSpill* and *EndoSpill* (compared to the benchmark without tariffs), and as relative

[13]UNCTAD, TRAINS data, accessed 07/2013.

changes of *EndoSpill* relative to *ExoSpill* in parentheses.

Region-specific optimal tariffs and welfare effects τ^r_{opt}, W^{r2}					
		ExoSpill		*EndoSpill*	
		τ^r_{opt}	W^{r2}	τ^r_{opt}	W^{r2}
European Union	*EUR*	16	3.2	13 (-19%)	2.1 (-34%)
United States of America	*USA*	24	4.8	20 (-17%)	3.6 (-25%)
Russia	*RUS*	17	3.6	13 (-24%)	2.3 (-36%)
Brazil	*BRA*	10	1.3	6 (-40%)	0.4 (-69%)
India	*IND*	15	4.0	11 (-27%)	2.4 (-40%)
China	*CHN*	18	12.1	15 (-17%)	8.8 (-27%)

Table 4: Optimal tariffs τ^r_{opt} of the main model regions in per cent and the corresponding welfare affects W^{r2} in period 2 in per mill under the scenarios *ExoSpill* and *EndoSpill* (compared to the benchmark without tariffs); relative changes of *Endospill* relative to *ExoSpill* in per cent in parentheses.

All optimal tariffs are significantly greater than zero. This outcome is in line with Brown (1987) who argues that in an Armington specification strong terms-of-trade effects exist independent of the size model regions. In our results, the United States' optimal tariffs and welfare gains are higher than Europe's, but their relative changes between *ExoSpill* and *EndoSpill* is smaller than for Europe. Russia's optimal values and their changes are slightly higher than Europe's. Brazil's values are relatively small, but the relative change in welfare and the optimal tariff between the scenarios is highest among all regions. India's optimal tariffs are lower than Europe's, yet its welfare gains compared to the baseline are higher; and the relative change in welfare and the optimal tariff between the scenarios is second highest among the regions. Finally, China's optimal tariffs are the highest among the regions, whereas the changes in the optimal tariff and in welfare between *ExoSpill* and *EndoSpill* is similar to those of the USA and thus relatively low. Thus, in summary the importance of the optimal tariff with and without productivity spillovers for Europe is lower than in the BRIC countries.

The regional diversity of the results is surprising when considering that we assume the same strength of trade-induced productivity spillovers for all regions (applying the estimated coefficients in Table 1). Thus, country-specific characteristics affect the potential of endogenous trade-induced productivity gains. They are determined by the input-output structure including existing productivity levels, the sectoral composition and trade patterns, and by the exogenous part of the country-specific growth rate as reported by Table 2.

4.2.3 Variation of the benchmark year

It is a strength of WIOD to offer benchmark data for the years 1995 to 2009. We exploit this strength by calibrating the model to other benchmark years for comparison. Figure 3 in the Appendix shows the outcome for Europe (EUR). Besides the year 2007 (which is also available in the GTAP[14] 8 data), we report results for the year 2004 (which is also available in the GTAP 7 data) and for the most recent available years 2008 and 2009, which goes beyond GTAP. We report the results in parentheses in the form (optimal tariff in per cent/welfare change with respect to benchmark in per mill under *ExoSpill* — optimal tariff in per cent/welfare change with respect to benchmark in per mill under *EndoSpill*). In 2004, the optimal tariffs and the corresponding welfare gains for Europe under *ExoSpill* and *EndoSpill* (14/2.3 — 11/1.5) are significantly smaller than for 2007 (16/3.2 — 13/2.1). In 2008, the optimal tariffs are the same as in 2007, whereas the welfare gains are slightly higher (16/3.6 — 13/2.4). In 2009, the values are again smaller (15/2.5 — 11/1.6), similar to the result for 2004. This robustness check demonstrates that the choice of the benchmark year *can* play a role, i.e. for some years the results are very similar, whereas they differ for some other years. This applies in particular to deviations measured relative to benchmark data, wherein the absolute values of the benchmark data do hardly matter. Nonetheless, different production and trade patterns across benchmark years do matter for the results. We conclude that in general, the sensitivity of the results to the choice of the benchmark year is limited and does not affect the qualitative interpretation of the results. A clear time trend in the benchmark year data is not evident.

4.2.4 Variation of Armington elasticities

In another robustness check, we vary the Armington elasticities (the elasticity of substitution between foreign varieties as well as between the import bundle and domestic production taken from GTAP). We refer to Europe calibrated to 2007 data. Higher Armington elasticities make varieties from different countries more similar and reduce market power. Hence, the optimal tariffs and the resulting welfare gains decline in higher Armington elasticities. Figure 2 (e) poses the results for all Armington elasticities set to a high value of 8, whereas Figure 2 (f) poses the results for all Armington elasticitites set

[14]Global Trade analysis Project, `https://www.gtap.agecon.purdue.edu/databases/v8/`

to a low value of 2. In the high Armington case, the optimal tariffs and welfare gains decline substantially to (10/2.6 — 7/1.3). In the low Armington case, the values soar to (63/17.6 —59/15.9). We conclude that the sensitivity of our results to the choice of Armington elasticities is high. Moreover, a lower (higher) Armington elasticity represents lower (higher) substitutability between varieties and thus higher (lower) market power and vice versa. Against this background, the optimal tariffs and corresponding welfare effects rise in market power in accordance with Proposition 1.

Furthermore, we set the Armington elasticities of Europe to a very high value of 25.[15] This mimics the situation with almost no power on international markets marked by Proposition 1. In accordance with the proposition, we find a negative optimal tariff, i.e. an import subsidy under *EndoSpill*. The subsidy deteriorates Europe's terms of trade. This result deviates from Brown (1987) who does not take trade-induced productivity gains into account.

Result 5. *The numerical simulations corroborate Propositions 1 stating that trade-induced productivity gains can also be exploited without power on international markets to raise welfare, resulting in a negative optimal tariff.*

Yet, the import subsidy induces productivity gains that overcompensate the deterioration of the terms of trade. The subsidy rate is with a value of 1 per cent quantitatively small, though. Likewise, the welfare gain achieved through this optimal subsidy is very small and hence probably negligible by practical trade policy. In accordance with Proposition 1, in this scenario with almost no market power, an export subsidy is detrimental for Europe.

4.2.5 European sector-specific results

Finally, we strive for deeper insights into the drivers of the economy-wide effects at the sector level and for insights into competitiveness effects for European sectors. For this purpose, Figure 4 in the Appendix plots forgone total factor productivity (total factor productivity loss) compared to the benchmark run due to reduced European exports and imports. We run scenario *EndoSpill* twice: once by setting the tariff to its optimal level as before, and once by setting the tariff to the optimal level given by the *ExoSpill* scenario. We signify the latter setup by $EndoSpill - ExoTariff$. In $EndoSpill - ExoTariff$, the tariff is set to a rate above the optimal level. Thus, it generates higher forgone total factor

[15] Perfect substitutes and perfect competition on international markets would require an infinite Armington elasticity, which is not feasible for this type of model.

productivity than *EndoSpill* in all sectors as illustrated in Figure 4. These forgone productivity is solely driven by the trade-induced productivity *spillover channel* since the tariff rate and all other model parameters are kept constant. Note that the difference in forgone productivity between the two scenarios represents the forgone welfare through trade policy when not taking into account that trade induces productivity gains. The figure illustrates that services, construction and electricity/gas/water supply suffer the highest forgone total factor productivity in both scenarios, whereas agriculture/forestry/fishing, mining/quarrying and other non-metallic minerals suffer to the smallest extent. Notably, the economy-wide welfare effect of the trade policies under scrutiny is positive as examined in the previous analysis, because the government collects the revenues from the tariffs and redistributes them to the representative consumer in a lump-sum way and because the tariffs shift demand from imports to domestic supply, which is beneficial for domestic producers. These positive effects overcompensate the forgone sectoral factor productivity (total factor productivity loss) and are not visible in Figure 4.

We relax the assumption of an identical tariff on all goods τ^r to explore the sectoral dimension in greater detail. A tariff τ^{rs} specific to sector s is introduced instead. For each sector s, we calculate the optimal tariffs τ_{opt}^{EURs} that maximizes Europe's welfare W^{EUR2}. Tariffs on all goods except for s are fixed to zero when determining τ_{opt}^{EURs}.

The results of these simulations are shown in Table 5. The first column lists the 18 sectors. Columns 2 to 5 display the sectoral optimal tariff τ_{opt}^{EURs} in per cent and the corresponding European welfare effects W^{EUR2} in per mill, both in the *ExoSpill* and *EndoSpill* scenario. The percentage changes in parentheses (6^{th} and 7^{th} column) show the differences between the two scenarios in per cent. All further columns display parameters potentially explaining the results. The Armington elasticity between foreign and domestic varieties $\sigma_s^{a'}$, the import and export intensities ($\frac{M^{s1}}{Q^{s1}}$, $\frac{E^{s1}}{Q^{s1}}$) in per cent, the sectoral size $\frac{Q^{s1}}{Q^1}$ measured as the share of Europe's total output in per cent, and the share of good s consumed by final demand $\frac{C_{EURs1}}{C_{EURs1}+Q_{EURs'1}}$ in per cent as a measure for the position in the value chain (higher final demand share means more downstreamness).

Sectoral optimal tariffs τ_{opt}^{EURs} are generally lower than the economy-wide one, which is $\tau_{opt}^{EUR} = 16$ per cent in the *ExoSpill* scenario and $\tau_{opt}^{EUR} = 13$ per cent in the *EndoSpill* scenario. Only the optimal tariff on textiles is is greater than τ_{opt}^{EUR} in the *ExoSpill* scenario, while three sectors exhibit optimal tariffs above τ_{opt}^{EUR} per cent in the *EndoSpill* scenario: food, transport equipment and textiles. The largest welfare gain W^{EUR2} of 0.7 per mill is achieved by the optimal tariff on mining goods. Despite having a high

Sector	*ExoSpill* tariff & welf. τ_{opt}^{EURs}	*ExoSpill* tariff & welf. W^{EUR2}	*EndoSpill* tariff & welf. τ_{opt}^{EURs}		*EndoSpill* tariff & welf. W^{EUR2}		Arm. elas. $\sigma_s^{a'}$	Trade intensity $\frac{M^{EURs1}}{Q^{EURs1}}$	Trade intensity $\frac{E^{EURs1}}{Q^{EURs1}}$	Sector share $\frac{Q^{EURs1}}{Q^{EUR1}}$	Demand share $\frac{C_{EURst}}{C_{EURst}+Q_{EURs't}}$
Agriculture	14	0.09	13	(-7%)	0.07	(-22%)	2.93	9.6	4.4	1.9	40.2
Mining	15	0.71	12	(-20%)	0.47	(-35%)	8.48	150.1	6.6	0.7	5.9
Minerals	11	0.01	8	(-27%)	0.01	(-47%)	1.90	4.8	10.0	1.0	13.5
Food	16	0.15	15	(-6%)	0.14	(-9%)	2.91	7.2	8.7	3.8	62.8
Wood	13	0.02	10	(-23%)	0.01	(-41%)	3.40	6.8	9.3	0.6	15.5
Paper	11	0.03	8	(-27%)	0.01	(-47%)	2.95	4.4	11.3	1.8	27.6
Coke	14	0.08	11	(-21%)	0.06	(-31%)	2.10	17.1	16.5	1.6	39.0
Chemicals	15	0.29	12	(-20%)	0.19	(-33%)	3.30	15.0	23.7	4.0	29.5
Metals	13	0.22	10	(-23%)	0.12	(-48%)	3.63	13.0	14.2	3.9	12.6
Trans. equip.	16	0.29	15	(-6%)	0.24	(-18%)	3.55	11.5	22.9	4.0	55.6
Elec. equip.	13	0.32	10	(-23%)	0.20	(-37%)	4.40	28.3	28.0	3.0	40.4
Textiles	17	0.22	17	(0%)	0.20	(-8%)	3.83	35.1	21.7	1.1	66.5
Transport	12	0.08	10	(-17%)	0.05	(-39%)	1.90	7.0	12.8	5.4	28.7
Machinery	12	0.15	11	(-8%)	0.12	(-22%)	4.05	11.7	30.7	2.8	52.1
Other manu.	14	0.08	13	(-7%)	0.07	(-9%)	3.75	14.4	15.2	1.0	63.0
Electricity	15	0.02	13	(-13%)	0.01	(-32%)	2.80	1.2	1.3	2.8	34.3
Construction	8	0.00	6	(-25%)	0.00	(-33%)	1.90	0.3	0.5	7.7	67.3
Services	5	0.06	2	(-60%)	0.02	(-75%)	1.90	2.5	2.9	53.0	56.2

Sector-specific optimal tariffs and welfare effects τ_{opt}^{EURs}, W^{EUR2}

Table 5: Optimal sectoral tariffs τ_{opt}^{EURs} in EUR in per cent and the corresponding welfare affects W^{EUR2} in period 2 in per mill under the scenarios *ExoSpill* and *EndoSpill* (compared to the benchmark without tariffs); changes of *Endospill* relative to *ExoSpill* in per cent in parentheses; sectoral import shares $\frac{M^{EURs1}}{Q^{EURs1}}$ and export shares $\frac{E^{EURs1}}{Q^{EURs1}}$ for the EU in per cent as well as sectoral output share $\frac{Q^{EURs1}}{Q^{EUR1}}$ in the EU economy in per cent; commodity share consumed by final demand $\frac{C_{EURst}}{C_{EURst}+Q_{EURs't}}$ in total demand (including intermediate goods demand) in per cent; sector names in short form, for more details see Figure 4 and footnote 8.

Armington elasticity of about $\sigma_s^{a'} = 8.5$, the mining sector's huge import intensity of 150 per cent allows Europe to exert market power.

The comparison of the chemicals and metals sectors is illuminating. Both account for about 4 per cent of European production. Chemicals, however, exhibit a higher import intensity than metals, 15 per cent compared to 13 per cent, and a lower Armington elasticity, 3.3 compared to 3.6. Consequently, sectoral optimal tariffs are higher for chemicals, 15 per cent compared to 13 per cent in the *ExoSpill* and 12 per cent compared to 10 per cent in the *EndoSpill* scenario. Welfare effects are stronger as well. In the *EndoSpill* scenario, the welfare gain is 0.19 per mill for chemicals and 0.12 per mill for metals. Without trade-induced productivity gains, expressed by *ExoSpill*, the welfare gain is 0.29 per mill for chemicals and 0.22 for metals.

Accounting for 53 per cent of total production, the services sector is the largest sector in the European economy. Its Armington elasticity is low ($\sigma_s^{a'} = 1.9$). Import intensities are low, too ($\frac{M^{s1}}{Q^{s1}} = 2.5$ per cent). Sectoral optimal tariffs (5 per cent under *ExoSpill* and 2 per cent under *EndoSpill*) as well as the corresponding welfare effects (0.06 per mill in the *ExoSpill* and 0.02 per mill in the *EndoSpill* scenario) are small. Notwithstanding, services is the sector for which neglecting trade-induced productivity gains is most detrimental to Europe's welfare. According to Table 5, considering endogenous trade-induced productivity gains reduces the sectoral optimal tariff by 60 per cent and the welfare gains by 75 per cent. The economic intuition is that a higher sector size implies that any trade-induced productivity gain affects a larger part of the economy and thus has a stronger overall impact on the economy.

In general, optimal tariffs and welfare gains are always smaller in the presence of trade-induced productivity gains.[16] This confirms both the theoretical results and the numerical findings for economy-wide optimal tariffs τ_{opt}^r.

When comparing the sectoral optimal tariffs τ_{opt}^{EURs} with and without trade-induced productivity gains, two groups of sectors can be distinguished. One group contains industries whose optimal tariffs are reduced by less than 20 per cent. The other one includes all sectors for which optimal tariffs fall by 20 per cent or more if productivity spillovers are taken into account. Differences in Armington elasticities, import and export intensities, or sector size provide no obvious explanation for the differences between sectoral optimal tariffs in both scenarios.

Hence, we apply the share of commodity s absorbed $\frac{C_{EURs1}}{C_{EURs1}+Q_{EURs1}}$ by final demand as

[16]The only exception it the optimal tariff on textiles which is identical in both scenarios.

a measure of the sector's downstreamness. Most sectors for which the difference between sectoral optimal tariffs in the *ExoSpill* and *EndoSpill* scenario is 20 per cent or more exhibit a consumption share of less than 50 per cent. Sectors whose commodities are absorbed by more than 50 per cent by final demand mostly exhibit optimal tariffs falling by less than 20 per cent if productivity spillovers are considered. The economic intuition is that more upstreamness implies that any trade-induced productivity gain affects a larger part of the economy through intermediated goods flows in the production chain and thus has a stronger overall impact on the economy. The absorption by final demand, on the contrary, stops the transmission of productivity gains embodied in intermediate goods through the economy.

We conclude that trade-induced productivity gains affect optimal tariffs on upstream sectors more strongly. Downstream industries benefit from increased productivity of intermediate suppliers. Restricting trade with intermediate inputs hampers productivity growth and reduces the productivity of upstream firms, too. Analyzing trade-induced productivity spillovers along the value chain in detail with more sophisticated measures of industries' position in production chains (Antras et al., 2012) is beyond the scope of this paper. It appears to be a fruitful area for future research.

4.2.6 Resume of the numerical analysis

We can summarize the numerical results in general form as follows:

Result 6. *A constant given magnitude of trade-induced productivity gains exhibits regionally and sectorally diverse optimal tariffs and induced welfare effects.*

This heterogeneity across regions and sectors computed within a complex multi-region, multi-sector general equilibrium framework extends the pure trade-induced effect found in our simplified theoretical model in Equation (14) and Result (3). Trade policy that aims at welfare maximization needs to take this heterogeneity into account. For example, productivity gains have a stronger impact in larger or more upstream sectors.

The variation of the benchmark year as a small impact on the results (at least when measuring deviations between the policy scenario and the benchmark scenario in relative from), whereas the choice of Armington elasticities has a strong impact.

In relation to the literature, our results are in line with studies that examine the influence of international technology spillovers on climate policy costs (e.g. Bosetti et al., 2008; Leimbach and Baumstark, 2010; Hübler, 2011). These studies find a significant, but small influence. Like in Balistreri et al. (2011), the welfare effects of tariff variations appear small in our analysis. The endogeneity of trade-induced productivity gains does, however, not as strongly affect the results as in Balistreri et al.'s explicit Melitz implementation. Though, their analysis is not directly comparable since it does not examine optimal tariffs imposed by one region. Importantly, we use a stylized two-period setup so that we merely capture the trade-induced productivity gains within one period. Running the model over a long time horizon would result in a much higher cumulated welfare gain. In this respect, Rutherford and Tarr (2002) simulate a 54-year time horizon. Consequently, they find an average welfare gain of ten per cent induced by a ten per cent tariff cut, which appears huge compared to the trade-induced welfare gains of some per mill found in our analysis.

5 Conclusion

Our research explores how endogenous productivity gains from trade affect tariff instruments imposed by a large open economy. It builds on a threefold methodological base and has direct policy implications. It evidences that trade-induced productivity gains exist which counteract strategic trade policy and which are policy relevant. Our results caution against the strategic use of tariffs in order to manipulate the terms of trade. Instead, they opt for reducing trade barriers, for example in a European Union- United States free trade agreement, to exploit productivity growth induced by the international exchange of goods and services.

Markusen (1975) models an environmental externality occurring in the foreign country. The home country requires market power in order to influence international prices and thus to have an impact on the externality abroad. This means, the model requires the large open economy assumption. This is different in our model. The productivity (technology) spillover externality occurs in the home country. Therefore, the home country has an incentive to enhance trade in order to magnify the externality even in the absence of power on international markets. Trade-induced productivity spillovers also differ from the terms-of-trade effect, which disappears in the absence of market power. The mechanism scrutinized in our model works under the large open economy as well as the small open economy assumption.

We estimate the parameters governing the strength of trade-induced productivity spillovers by applying panel data econometrics. We employ the same dataset that we use to calibrate the general equilibrium model in the subsequent step. The results show that imports imply higher productivity gains than exports. The parameter relating import intensity to productivity growth is more than twice as big as the parameter for export intensity. Based on our stylized theoretical model, the optimal tariff is reduced by 5 per cent when taking the endogeneity of trade-induced productivity gains into account.

Our numerical simulations embed the stylized theoretical approach into a more complex and realistic computable general equilibrium (CGE) model. Whereas all qualitative results from the theoretical model are confirmed by the simulations, quantitative effects differ strongly between regions and sectors.

Trade-induced productivity gains are more important for trade policies of the BRIC countries, especially Brazil and India, than of Europe or the USA. Notably, the European optimal tariff implies welfare gains for the USA, presumably through trade diversion effects. This finding counteracts expected benefits from a European Union - United States free trade agreement to some extent. Neglecting the endogeneity of trade-induced productivity gains creates welfare losses. The welfare effects, however, have a small magnitude at the macroeconomic level. Welfare gains from enhanced trade become particularly small when the home country's power on international markets is negligible. Trade-induced productivity gains increase in existing market power. Note that our study has a two-period view. When accumulating the growth effects over a longer time horizon, the trade-induced productivity effects will become larger.

Sectoral optimal tariffs and their sensitivity with respect to trade-induced productivity gains are diverse and sometimes have high magnitudes. Trade policy aiming at enhancing productivity gains may focus on sectors that potentially generate stronger productivity spillovers. In larger sectors, productivity gains basically generate a stronger effect on the overall economy than in smaller sectors. Additionally, our results suggest that upstream sectors are more sensitive to neglecting trade-induced productivity gains, because foregone productivity spillovers imply cost increases for intermediate inputs by downstream sectors in addition to cost increases from trade restrictions. Consequently, welfare is reduced more strongly than when restricting imports of downstream sectors whose goods are mostly consumed.

Our robustness checks reveal a limited impact of choosing different benchmark years for the model calibration on the results. The reason is that policy impacts are commonly measured as relative deviations from the benchmark year so that the size of the benchmark year economy is of limited importance. Elasticities of substitution between foreign varieties as well as foreign and domestic varieties (Armington elasticities) have a strong impact on the results because they determine the degree of market power a country exhibits. Every trade policy analysis carried out with the standard Armington mechanism hinges upon these elasticities.

Future research could extent the number of simulation steps over time and the time frame of the simulations in order to scrutinize scenarios of long-run growth. Exploring the sectoral dimension of trade-induced productivity gains in more detail is another promising strand of future research.

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8 Supplementary Appendix

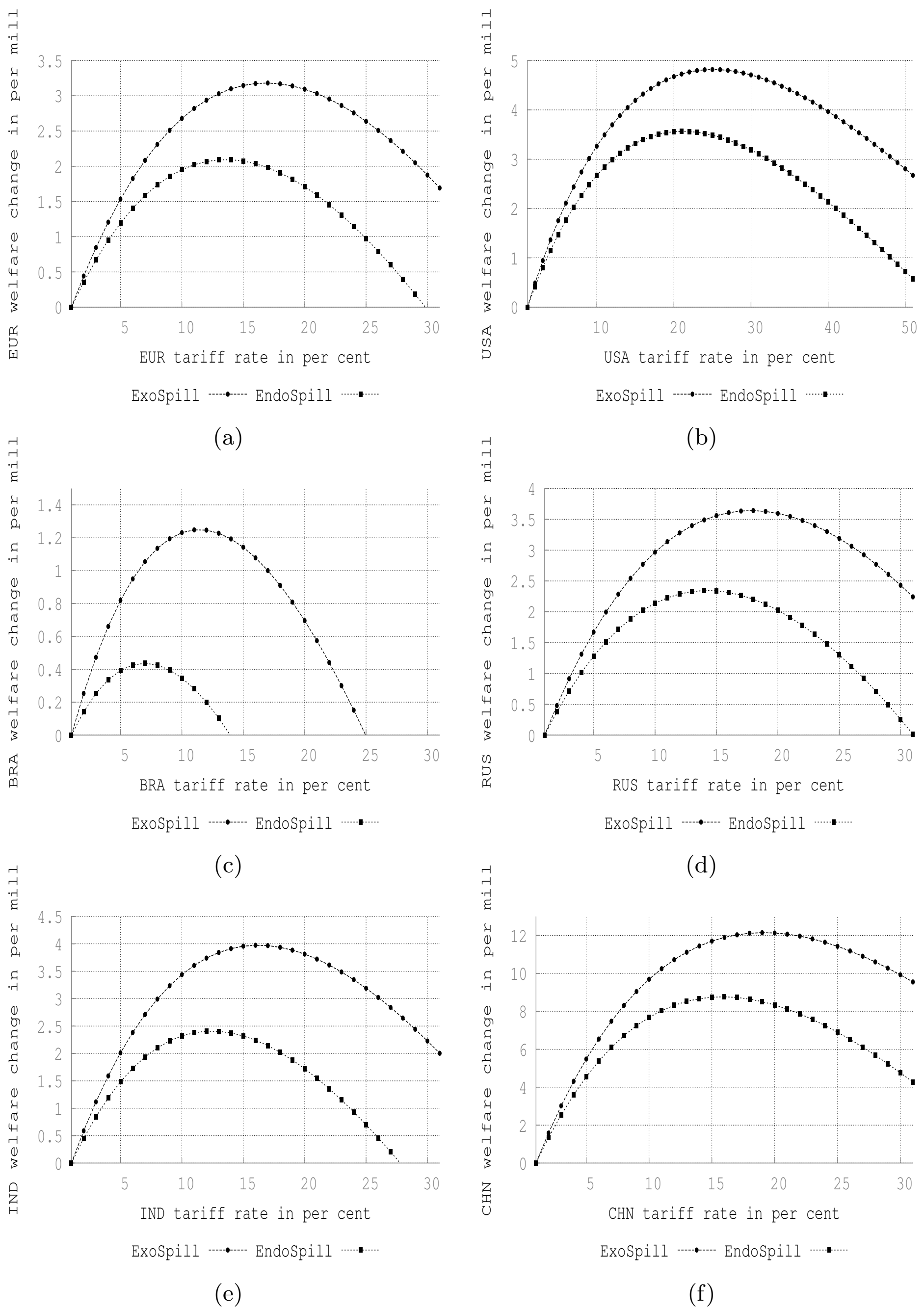

Figure 2: Regional per mill welfare changes in *EndoSpill* and *ExoSpill* relative to the benchmark run without a tariff measured within period 2 over various tariff rates; note different scales of the vertical axes and for the USA the scale of the horizontal axis; the depicted regions are (a) Europe, (b) USA, (c) Brazil, (d) Russia, (e) India, (f) China; the benchmark year is always 2007.

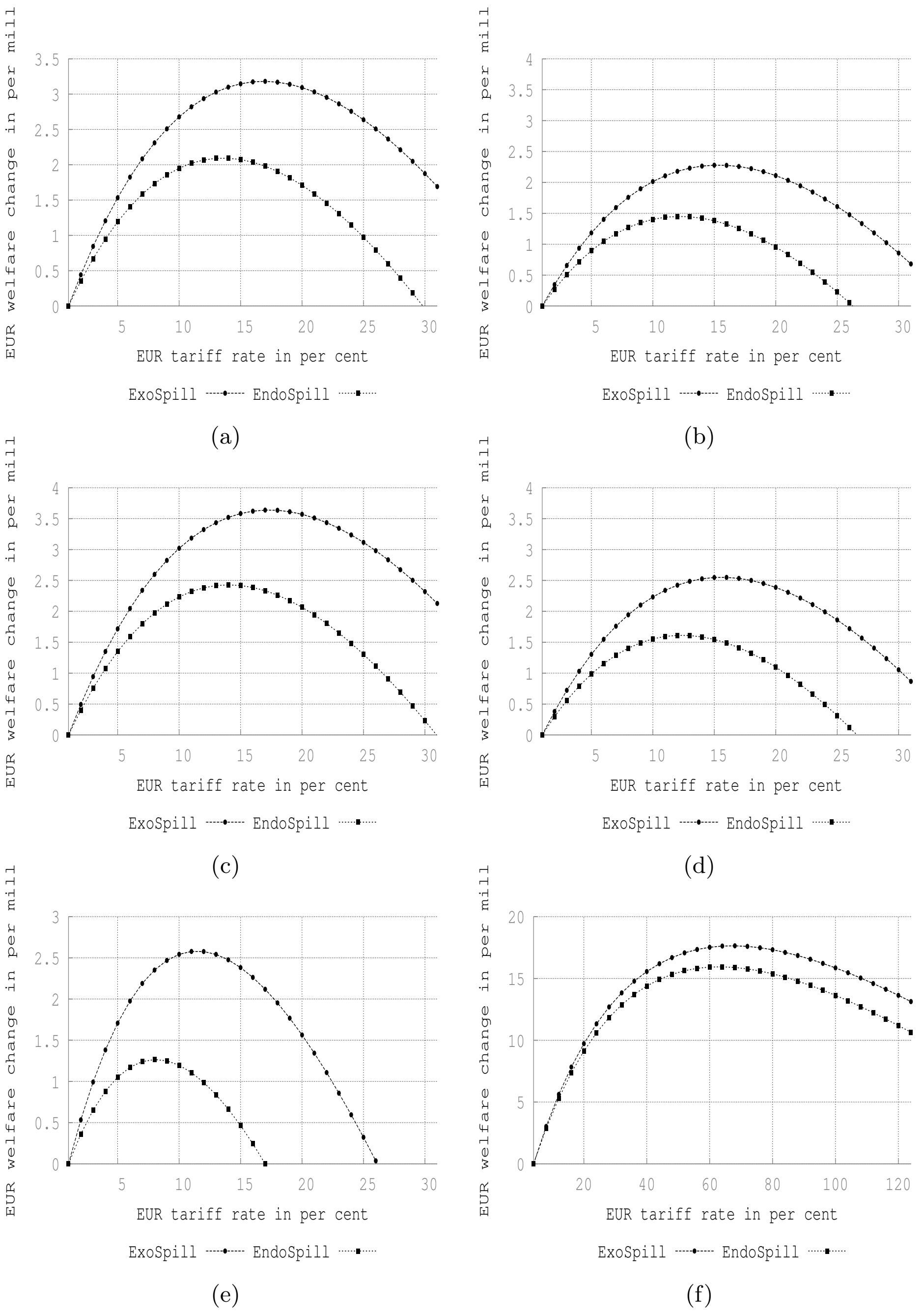

Figure 3: European per mill welfare change in *EndoSpill* and *ExoSpill* relative to the benchmark run without a tariff measured within period 2 over various tariff rates; the different benchmark years are (a) 2007, (b) 2004, (c) 2008, (d) 2009, (e) 2007 with all Armington elasticities set to 8, (f) 2007 with all Armington elasticities set to 2.

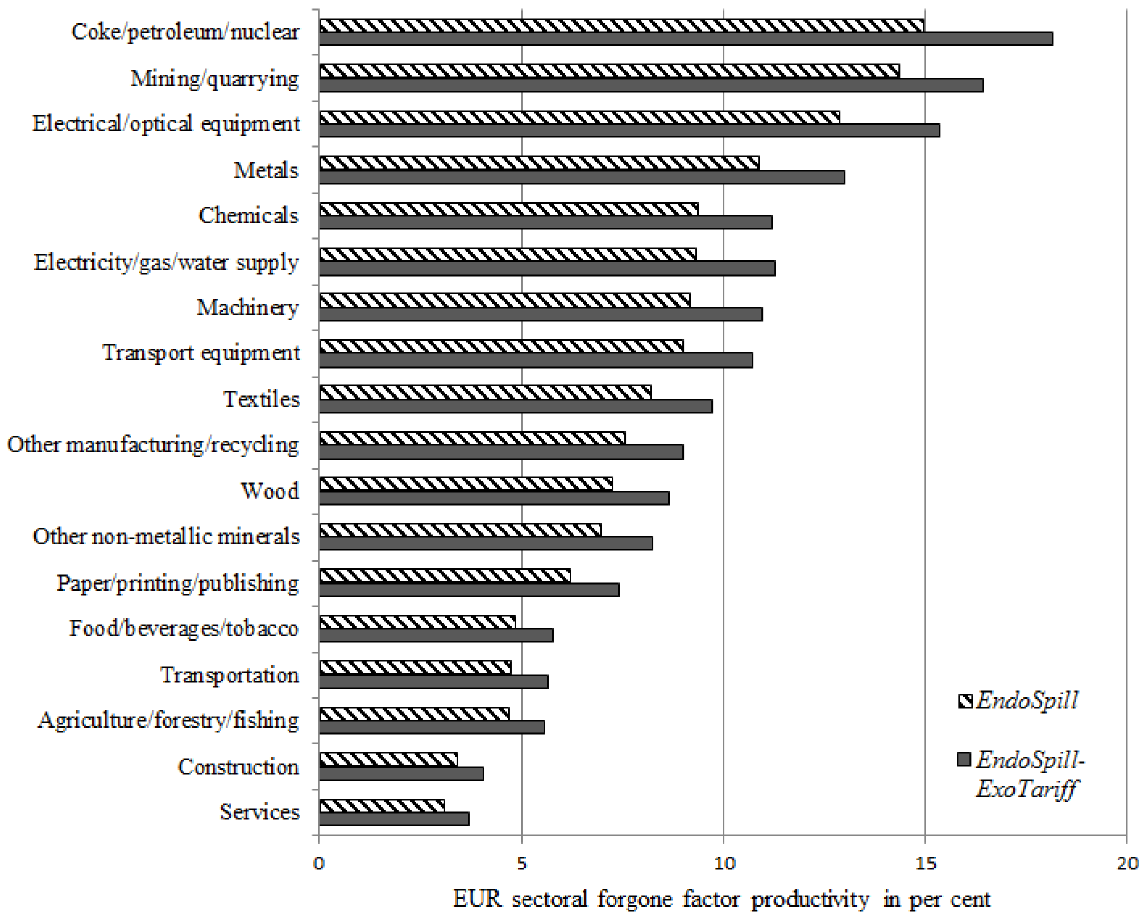

Figure 4: Forgone total factor productivity through tariffs in European sectors in per cent under *EndoSpill* and $EndoSpill - ExoTariff$ relative to the benchmark run without a tariff measured within period 2. *EndoSpill* applies the optimal tariff in the presence of endogenous spillovers, whereas $EndoSpill - ExoTariff$ applies the optimal tariff of the *ExoSpill* scenario to the *EndoSpill* scenario.