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Heterogeneity of consumer preferences and trade patterns in a monopolistically competitive setting

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Abstract The paper considers a two-sector two-country trade model of monopolistic competition featuring the heterogeneity of consumer preferences and incomes within and across countries. The incorporation of heterogeneity into a monopolistic competition setting is achieved by assuming a nested Cobb–Douglas and CES utility function exhibiting both country and sector-specific consumer tastes and expenditure shares on manufacturing and traditional goods. The key question analyzed in the paper is how consumer heterogeneity affects the home bias of trade in different countries. The key finding here is that the heterogeneity in tastes and incomes of consumers can provide a substantial influence on degree of home bias in trade but only in combination with high transportation costs.

Keywords Heterogeneous consumers · Monopolistic competition · CES utility function · International trade · Markups · Wages

JEL Classification F12 · D43 · L13

1 Introduction

Until recently, most of the existing contributions on international trade, following the salient papers of Krugman (1979, 1980), have been focused on the production side of

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economy in trying to explain trade patterns and gains from trade (Eaton and Kortum 2002; Melitz 2003; Melitz and Ottaviano 2008; Eaton et al. 2011). Demand-side determinants of trade provided by preference specifics, which was put forward by Linder (1961), were not ordinarily accounted for. Indeed, the number of existing contributions, encompassing many trade papers, typically postulate identical and homothetic preferences across consumers. This assumption, which is central to the canonical models of trade (Krugman 1980; Helpman and Krugman 2000), implies that the market demand function is symmetric across varieties and countries, i.e. the same for the same varieties across different countries as well as for different varieties within the country. Although at odds with reality, this assumption allows one to greatly simplify the analysis and obtain explicit analytical results.

In the meantime though, there is an increasing list of publications where an attempt is made to take the heterogeneity and non-homotheticity of consumer preferences into account when explaining market outcomes and international trade patterns (Choi et al. 2009; Simonovska 2010; Auer 2010; Fieler 2011; Markusen 2013; Hepenstrick and Tarasov 2015; Kichko et al. 2014; Di Comite et al. 2014; Nigai 2016; Wang and Gibson 2015). Despite the fact that the heterogeneity of consumer preferences doesn't raise any doubts (Allenby and Rossi 1999; Calvet and Comon 2003; Auer 2010; Di Comite et al. 2014; Christensen 2014; Nigai 2016), the authors dealing with the models of monopolistic competition, customary avoid its consideration. There are at list two reasons explaining this fact. First is that the heterogeneity of consumer preferences entails a significant complication of the formal structure of the models, and second is that the effects of unobserved heterogeneity in tastes are very difficult to identify empirically.

The present paper builds a two-sector two-country trade model of monopolistic competition in which consumers/workers, employed in agricultural and manufacturing sectors, differ not only in their incomes, but also in their tastes and expenditure shares on manufacturing and traditional goods. Workers employed in industrial sector are assumed to be relatively richer than workers in agricultural sector, and as a consequence, tend to spend a larger share of their income on manufacturing goods compared to agricultural goods.[1] The relationship between expenditure shares of the two types of consumers/workers and relative wages of industrial workers is provided by a system of equations constituting the general equilibrium of the model. The kind of consumer heterogeneity considered in our framework is neither reflected in the canonical model of monopolistic competition (Dixit and Stiglitz 1977), nor in the canonical models of trade (Krugman 1980; Helpman and Krugman 2000), since all of these models is based on the assumption of identical consumers.

One approach which is close to ours in terms of modelling strategy is that of Di Comite et al. (2014). Here the authors also invoke the heterogeneity of consumers to explain the strong variation observed in the quantities of identical varieties sold in various countries. Nevertheless, there is a difference between the two models. While the model of Di Comite et al. (2014) is based on the restructured quadratic utility used previously by Ottaviano et al. (2002), Melitz and Ottaviano (2008), and others,

[1] Evidence in favor of this assumption can be found in the literature, suggesting that rich and poor consumers have substantially different consumption patterns (Broda et al. 2009; Faber 2012).

we prefer the modification of the nested Cobb–Douglas and CES utility function to model consumers' perception of the manufacturing goods. Similar strategy was applied in our earlier paper (Osharin et al. 2014), where an attempt was made to develop a monopolistic competition model accounting for heterogeneity in consumer preferences and incomes for a closed economy case.

In contrast to trade models based on identical consumers, an assumption of preference heterogeneity makes it possible to obtain different demands for the same variety across destination countries when consumers within these countries have nonidentical joint distributions of tastes and expenditure shares. Since there is no reason to assume *a priory* that the taste and income (expenditure share) distributions of consumers in different countries are the same (Calvet and Comon 2003; Fernandez-Blanco et al. 2009; Atkin 2013; Di Comite et al. 2014; Christensen 2014), we may expect that the consumer-specific preferences used in the present model will provide a richer set of predictions compared to that of Krugman (1980) and Helpman and Krugman (2000).

The main objective of the paper is the assessing of the role of within country taste and income heterogeneity in resolving "home bias in trade puzzle".[2] The "home bias in trade" is defined as the excessive consumption or absorption of domestically produced goods compared with what the traditional models of trade predict. The first illustration of this phenomenon is McCallum's finding that trade between two Canadian provinces is twenty times greater than trade between individual Canadian provinces and individual U.S. states (McCallum 1995). Nitsch (2000) has come to a similar conclusion on home bias by estimating that on average EU countries internal trade is seven to ten times larger than trade with partner countries. Using gravity specification and inspecting trade within U.S. states, Wolf (2000) showed that home bias is present even on the subnational level, although its magnitude is substantially lower than the home bias found for Canada versus the United States and for intra-versus international trade of OECD countries. Taken together, the most of the literature comes to a conclusion that countries do exhibit a sufficiently high degree of home bias in consumption, but its magnitude is not as large as McCallum's original estimation.

Traditional explanation of home bias is the presence of formal and informal trade barriers. Moreover, Obstfeld and Rogoff (2001, henceforth OR) argue that trade costs in goods markets can be the unified explanation of the most of the existing trade puzzles, including the home bias in trade. To prove their proposition they used a highly simplified two-country trade model which was calibrated to an observed ratio of home to foreign consumption spending and showed that trade costs and appropriately chosen common elasticity of substitution between home and foreign goods can explain a large observed home bias in trade. Recently Eaton et al. (2016, henceforth EKN) took a multi-country dynamic model of trade to data from nineteen countries and obtained results in favor of OR conclusions.

While there is quite a consensus about the role of trade costs in explaining the home bias in consumption, less is known about the influence of consumer taste heterogeneity on home bias (Markusen 2013; Balta and Delgado 2009; Bahles 2014; Morey 2016). Our paper contributes to the related literature and shows that prefer-

[2] "Home bias in trade puzzle" is the one of the "trade puzzles" encompassing the empirical regularities currently unexplained by the leading models of international economics.

ence and income heterogeneity in combination with trade costs can be an essential ingredient in resolving home bias in trade puzzle. By taking a few simple illustrative examples, we show that the growing taste differential between skilled and unskilled workers within the countries may provide divergence in the price elasticities of the market demand for home and foreign goods, making market demand for importables less elastic. This leads to an increase in the price of imported goods compared to local goods. As a consequence, the local goods' becoming relatively cheaper strengthens the home bias in trade. This observation is in line with OR early prediction that the "…home bias in demand for goods can work similarly to trade costs, at list for the trade and portfolio-bias puzzles" (OR, p. 348).

What is interesting is that our model demonstrates an ambiguous prediction towards the direction of trade bias depending on the sign of the correlation coefficient between tastes and expenditure shares of the two groups of consumers/workers. While positive correlation between tastes and expenditure shares provides a substantial increase in home bias in response to the rising taste differential between agricultural and industrial workers, the negative correlation acts in the opposite direction, providing a noticeable reduction in home bias in trade.

Alongside with the difference in tastes of consumers, our paper reveals also an additional channel through which the structure of an economy may exert influence on home bias in trade. This is the inhomogeneity of within country income distribution arising due to difference in wages across production sectors. The larger the wage difference between the two groups of consumers/workers in our model of trade the more the consumption spending is skewed in favor of domestic goods. This finding seems to be in line with the data, provided by EKN for nineteen economies over the period of 2000–2014, and contributes to the existing literature on trade and income inequality linkages (Mitra and Trindade 2005; Waugh 2010; Kurokawa 2014; Eppinger and Felbermayr 2015; Martinez-Zarzoso and Vollmer 2016).

The rest of the paper is organized as follows. Section 2 describes the model and obtains short-run and long-run equilibrium outcomes. In Sect. 3 we carry out the comparative static analysis of the model (both analytically and numerically) and present our main results. Section 4 discusses the perspectives of the model. Section 5 concludes.

2 Model

There are two countries in the world, home and foreign, indexed by r ($r = H, F$) and populated by L_r consumers. Let $L = L_H + L_F$ denote the world population, and let $\theta = L_H/L$ denote the population share of domestic consumers. The economy of each country is made up of the two sectors, agricultural (traditional) and industrial (manufacturing), and uses the single factor of production, labor, which is domestically and internationally immobile. Agricultural sector produces a homogeneous good under constant returns to scale, which is sold in a perfectly competitive market. Manufacturing sector supplies a differentiated good, produced under increasing returns in a monopolistically competitive setting.

Labor is assumed to be heterogeneous and specific to each sector. We will use index s ($s = a, m$) to distinguish between the two types of consumers/workers, depending on the sector they reside. Those employed in the agricultural sector are assumed to be unskilled workers of a type-a in contrast to a type-m skilled workers employed in the manufacturing sector. There are L_H^a workers in the agricultural sector and L_H^m workers in the manufacturing sector of Home country, so that the share of domestic unskilled labor involved in production of agricultural goods in the total population of Home country is $\theta_H^a = L_H^a/L_H$, while $\theta_H^m = L_H^m/L_H$ is the corresponding share of unskilled labor involved in production of manufactured goods.

The difference in the character of competition between the two sectors together with the difference in skills endowments of consumers/workers provides the difference in income between the two types of employees—the wage w_H^m of skilled workers typically differs from the wage w_H^a of unskilled ones (Dixit and Stiglitz 1977). Throughout the paper we will consider consumers/workers employed in industrial sector as being relatively richer than those employed in agricultural sector by assuming $w_r^m > w_r^a$.[3]

2.1 Preferences, budget constraints and demand functions

Taking the existing difference in wages between agricultural and manufacturing workers into account, we connect this difference with the differences in consumers'/workers' tastes and expenditure shares. This is done by using the following Cobb–Douglas utility function of a country-r consumer employed in the sector s of national economy:

$$U_r^s = \left(X_{Mr}^s\right)^{\mu_r^s} \left(X_{Ar}^s\right)^{1-\mu_r^s}, \tag{1}$$

where X_{Ar}^s is an individual consumption of the agricultural good by a type-s consumer, X_{Mr}^s is the corresponding consumption of the manufacturing composite, μ_r^s is the expenditure share of a type-s consumer on manufacturing goods.

The agricultural composite X_{Ar}^s consists of the two components. The first one is the consumption of the traditional good, produced at home; the second is the consumption of the traditional good, produced abroad ($X_{Ar}^s = X_{Arr}^s + X_{Atr}^s$). The manufacturing composite in (1) is of a CES-type:

$$X_{Mr}^s = \left(\sum_{t=H,S} \int_{j \in N_t} \left(x_{tr}^s(j)\right)^{(\sigma_r^s - 1)/\sigma_r^s} dj \right)^{\sigma_r^s/(\sigma_r^s - 1)}, \tag{2}$$

where $x_{tr}(j)$ stands for the individual consumption of variety $j \in [0, N_t]$, produced in country t and sold in country r, N_t is the mass of varieties produced in country t, $\sigma_r^s > 1$ is both the price elasticity of a type-s consumer demand and the elasticity of substitution between any two varieties within an industry.

[3] This kind of inequality between manufacturing and agricultural wages is achieved by an appropriately given relationship between expenditure shares of industrial and agricultural workers (see below for details).

Our assumption here is that consumers' willingness to pay for a particular variety depends on how much they care about this variety. Formally this means that the price elasticity of an individual demand for a particular variety may differ across consumers, becoming consumer-specific. An alternative modeling strategy was proposed by Sa (2015), who suggested that sigma parameter can be influenced by firms, capable to regulate the degree of products differentiation by investing in either advertising or research activities.

Assuming expenditure share μ of a consumer can correlate with σ-parameter appearing in the CES composite, we capture consumer heterogeneity in both tastes and incomes, since the expenditure shares determine the wage ratio w_r^m/w_r^a of the two types of workers through the general equilibrium of the model (see below). In such a case, consumers/workers having different expenditure shares (incomes), will have different tastes and will perceive the same variety differently. As a result, this will make the aggregate price elasticities of the market demands both country- and variety-specific and varying with joint taste and expenditure share distribution.

Following the logic of the canonical model of trade (Combes et al. 2008), based on the Dixit and Stiglitz two-sector model of monopolistic competition (Dixit and Stiglitz 1977), we assume that traditional sectors of Home and Foreign countries are identical in every respect as regards their economic structure. Both sectors produce homogeneous good which is freely traded around the world. The perfect competition in the traditional sectors of both countries makes the price of homogeneous good equal to the marginal cost of agricultural firms, which are the same in each of the two countries, and is equal to the marginal labor requirements (c_r^a) times the agricultural wage (w_r^a). Assuming that one worker, employed in the traditional sector, produces one unite of agricultural good (which means that $c_r^a = 1$), we will have the same prices of the homogeneous good across the world (irrespective of the location where it is produced and sold). Taking this good as the numeraire, we will measure nominal parameters of the model in units of agricultural wage and will set $p_{Ar} \equiv p_A = w_r^a = 1$ $(r = H, F)$ in the final expressions.

Assuming that resale or third-party arbitrage in international trade is rather costly, so that manufacturing firms are able to price discriminate between destinations, the budget constraint for a type-s consumer residing in country r can be written as

$$p_A X_{Ar}^s + \sum_{t=H,\,F} \int_{j\in N_t} p_{tr}(j) x_{tr}^s(j) dj = w_r^s, \tag{3}$$

where w_r^s is the wage of consumer, p_A is the common price of the agricultural good, $p_{tr}(j)$ is the price of variety j produced in country t and sold in country r.

The same budget constraint can be written alternatively by using the notion of the country and consumer specific price index P_r^s of the manufactured good (which will be defined below):

$$p_A X_{Ar}^s + P_r^s X_{Mr}^s = w_r^s. \tag{4}$$

Combining (1)–(4) and using the standard two-stage budgeting procedure (Combes et al. 2008), we find that each individual consumes the domestic and foreign agricultural goods in equal volumes $X^s_{Arr} = X^s_{Atr} = (1/2)\, X^s_{Ar}$ and generates the following demand functions for composites

$$\begin{cases} X^s_{Ar} = (1-\mu^s_r)\dfrac{w^s_r}{p_A} \\ X^s_{Mr} = \mu^s_r \dfrac{w^s_r}{P^s_r} \end{cases}, \tag{5}$$

and for varieties

$$x^s_{tr}(j) = \frac{(p_{tr}(j))^{-\sigma^s_r}}{\left(P^s_r\right)^{1-\sigma^s_r}} \mu^s_r w^s_r. \tag{6}$$

In both cases the manufactured price index in country r common to the consumers sharing the same preference parameter equals to

$$P^s_r = \left(\sum_{t=H,\ F} \int_{j\in N_t} (p_{tr}(j))^{1-\sigma^s_r} dj \right)^{1/(1-\sigma^s_r)}. \tag{7}$$

Note that this price index is dependent on the prices of varieties produced both in home and foreign countries. Note also that $\mu^s_r = \left(P^s_r X^s_{Mr}\right)/w^s_r$ represents an expenditure share of a type-s consumer for the manufacturing goods, and $1-\mu^s_r = \left(p_A X^s_{Ar}\right)/w^s_r$ represents an expenditure share of a type-s consumer for the agricultural goods.

2.2 Technology and production

Technology in the manufacturing sectors of the model is represented through the cost function, which is of the unique-factor type. Manufacturing firms produce under increasing returns and share identical technology in both countries with $f > 0$ and $c > 0$ being the fixed and the marginal type-m labor requirements needed to produce $q_{rr}(i)$ units of variety i in country r for domestic consumption and $q_{rt}(i)$ units of the same variety for consumption abroad. So the total cost needed to produce variety i in country r is given by

$$C_r(i) = \left(c \sum_{t=H,F} \tau_{rt} q_{rt}(i) + f \right) w^m_r, \tag{8}$$

where $\tau_{rt} \geq 1$ is the iceberg-type transportation costs, satisfying the following condition: $\tau_{rt} = \begin{cases} 1, & r = t \\ \tau, & r \neq t \end{cases}$. Taking (8) into account, the profit of firm i in country r can be written as

$$\pi_r(i) = \sum_{t=H,\ F} \left(p_{rt}(i) - cw^m_r \tau_{rt}\right) q_{rt}(i) - f w^m_r, \tag{9}$$

where the market demand functions $q_{rt}(i)$ are obtained by aggregating individual demands (6) over the two types ($s = a,\ m$) of consumers/workers. Assuming a one-to-one correspondence between tastes and expenditure shares of consumers for simplicity (see "Appendix" for details), we have

$$q_{rt}(i) = \sum_{s=a,m} x_{rt}^s(i) L_t^s = \sum_{s=a,m} \frac{(p_{rt}(i))^{-\sigma_t^s}}{\left(P_t^s\right)^{1-\sigma_t^s}} \mu_t^s w_t^s L_t^s. \tag{10}$$

Unlike the individual demands, the market demands in our model are not isoelastic because parameter σ_r^s in either country varies across the two types of consumers. This results in the aggregate price elasticities depending on consumers' joint taste and expenditure share distribution. Indeed, applying the first-order condition to profits (9), one can get the following short-run equilibrium prices:

$$p_{rt}(i) = \frac{\varepsilon_{rt}(i)}{\varepsilon_{rt}(i) - 1} c w_r^m \tau_{rt}, \tag{11}$$

where $\varepsilon_{rt}(i) \equiv -\frac{p_{rt}(i)}{q_{rt}(i)} \frac{\partial q_{rt}(i)}{\partial p_{rt}(i)}$ is the price elasticities of the domestic and foreign consumers' market demands for variety i, produced in country r:

$$\varepsilon_{rt}(i) = \left(\sum_{s=a,m} \frac{\sigma_r^s (p_{rt}(i))^{1-\sigma_r^s}}{\left(P_r^s\right)^{1-\sigma_r^s}} \mu_t^s w_t^s \theta_t^s \right) \bigg/ \left(\sum_{s=a,m} \frac{(p_{rt}(i))^{1-\sigma_r^s}}{\left(P_r^s\right)^{1-\sigma_r^s}} \mu_t^s w_t^s \theta_t^s \right). \tag{12}$$

The latter depends on the joint distribution of tastes and expenditure shares ($\theta_r^s \equiv L_r^s / L_r$). To see this more clearly, assume identical preference parameters for consumers in both of the two countries, i.e. set $\sigma_r^s = \sigma$ irrespective of the consumer type in (12). It is easily verified that in such a case we get $\varepsilon_{rt}(i) = \sigma$ and, hence, the system of price Eq. (11) simplifies to

$$p_{rt} = \frac{\sigma}{\sigma - 1} c w_r^m \tau_{rt}.$$

First, note that this is exactly what we have in Krugman's model with identical consumers (Krugman 1980). Second, and more importantly, it means that the potential dependence of prices $p_{rt}(i)$ upon the joint taste and expenditure share distribution and other parameters, which is present in (11), immediately drops out of the model once we get rid of the heterogeneity in consumer preferences. This clearly highlights the role played by preference heterogeneity in the trade model of monopolistic competition. Third, the same observation holds true for the markups

$$m_{rt}(i) \equiv \frac{p_{rt}(i) - c w_r^m \tau_{rt}}{p_{rt}(i)} = \frac{1}{\varepsilon_{rt}(i)}, \tag{13}$$

which turn out to be equal the inverse sigma in the Krugman framework, $m_{rt}(i) = 1/\sigma$, pointing out that notwithstanding of the trade interaction between the two countries, everything looks like these countries are in autarky, which is strange. Contrarily, it would be natural to expect that any model purposefully developed to reflect specifics of trade interaction should contain corresponding effects in markups. Nevertheless, the models of trade based on identical consumer preferences lack such an opportunity. In our point of view, this could be due to the homogeneity assumption which is central to these models. In trying to dispense with consumer heterogeneity, the models of trade lose a number of important elements. Fortunately, the aforementioned shortcoming can be circumvented by applying the modified utility function incorporating consumer heterogeneity.

2.3 Symmetric price equilibrium

Following common practice in monopolistic competition literature, we focus on the symmetric price equilibrium by letting $p_{rt}(i) = p_{rt}$ in (11) and (12) for any variety. In such a case we have the following price equations in home and foreign countries (see "Appendix"):

$$p_{HH} = \frac{\varepsilon_{HH}}{\varepsilon_{HH} - 1} c w_H^m, \quad p_{HF} = \frac{\varepsilon_{HF}}{\varepsilon_{HF} - 1} c w_H^m \tau \tag{14}$$

$$p_{FF} = \frac{\varepsilon_{FF}}{\varepsilon_{FF} - 1} c w_F^m, \quad p_{FH} = \frac{\varepsilon_{FH}}{\varepsilon_{FH} - 1} c w_F^m \tau. \tag{15}$$

Aggregate price elasticities in (14)–(15) can be represented as the weighted sums of the preference parameters of unskilled (agricultural) and skilled (industrial) workers (see "Appendix" for details):

$$\varepsilon_{HH} = (1 - \alpha_{HH}) \cdot \sigma_H^a + \alpha_{HH} \cdot \sigma_H^m, \quad \varepsilon_{HF} = (1 - \alpha_{HF}) \cdot \sigma_F^a + \alpha_{HF} \cdot \sigma_F^m \tag{16}$$

$$\varepsilon_{FF} = (1 - \alpha_{FF}) \cdot \sigma_F^a + \alpha_{FF} \cdot \sigma_F^m, \quad \varepsilon_{FH} = (1 - \alpha_{FH}) \cdot \sigma_H^a + \alpha_{FH} \cdot \sigma_H^m, \tag{17}$$

where α_{rt} are the functions of the twelve exogenously given parameters θ_H^a, θ_H^m, θ_F^a, θ_F^m, μ_H^a, μ_F^a, μ_H^m, μ_F^m, σ_H^a, σ_H^m, σ_F^a, σ_F^m, and the five endogenous parameters $\xi_H = p_{FH}/p_{HH}, \xi_F = p_{HF}/p_{FF}, \nu = N_H/N_F, w_H^m, w_F^m$:

$$\alpha_{HH} = \left(\frac{\mu_H^m w_H^m \theta_H^m}{1 + \nu^{-1} \xi_H^{-(\sigma_H^m - 1)}} \right) \Bigg/ \left(\frac{\mu_H^a w_H^a \theta_H^a}{1 + \nu^{-1} \xi_H^{-(\sigma_H^a - 1)}} + \frac{\mu_H^m w_H^m \theta_H^m}{1 + \nu^{-1} \xi_H^{-(\sigma_H^m - 1)}} \right)$$

$$\alpha_{HF} = \left(\frac{\mu_F^m w_F^m \theta_F^m}{1 + \nu^{-1} \xi_F^{\sigma_F^m - 1}} \right) \Bigg/ \left(\frac{\mu_F^a w_F^a \theta_F^a}{1 + \nu^{-1} \xi_F^{\sigma_F^a - 1}} + \frac{\mu_F^m w_F^m \theta_F^m}{1 + \nu^{-1} \xi_F^{\sigma_F^m - 1}} \right). \tag{18}$$

$$\alpha_{FF} = \left(\frac{\mu_F^m w_F^m \theta_F^m}{1 + \nu \xi_F^{-(\sigma_F^m - 1)}} \right) \Bigg/ \left(\frac{\mu_F^a w_F^a \theta_F^a}{1 + \nu \xi_F^{-(\sigma_F^a - 1)}} + \frac{\mu_F^m w_F^m \theta_F^m}{1 + \nu \xi_F^{-(\sigma_F^m - 1)}} \right)$$

$$\alpha_{FH} = \left(\frac{\mu_H^m w_H^m \theta_H^m}{1 + \nu \xi_H^{\sigma_H^m - 1}} \right) \Bigg/ \left(\frac{\mu_H^a w_H^a \theta_H^a}{1 + \nu \xi_H^{\sigma_H^a - 1}} + \frac{\mu_H^m w_H^m \theta_H^m}{1 + \nu \xi_H^{\sigma_H^m - 1}} \right) \tag{19}$$

Inspection of (18)–(19) shows that α_{rt} represents the country-level expenditure shares of industrial workers on domestic and foreign varieties. Particularly, α_{rr} is the expenditure share of country r industrial workers on domestically produced variety in the total country spending on this variety, α_{rt} is the share of total spending of country t industrial workers on the imported variety in the total country t spending on this variety. In accordance with (16)–(17), the larger the share of spending of industrial workers on manufacturing good the more pronounced is their tastes contribution into the price elasticity of the corresponding market demand.

2.4 General equilibrium

We define a general equilibrium of the model as a bundle $\left(X_{Ar}, X_{Mr}, \left\{x_{tr}^{s}\right\}, \left\{p_{rt}\right\}, N_r, w_r^s,\ r, t = H, F,\ s = a, m\right)$ which (1) solves consumers' utility maximization problem, (2) solves firms' profit maximization problem, (3) ensures that all firms earn zero profit, (4) clears the labor markets, and (5) balances trade flows. Using symmetric price equilibrium, described previously, makes it possible to convert the above conditions into the following set of five nonlinear algebraic equations for five unknown ratios $\xi_H = p_{FH}/p_{HH}$, $\xi_F = p_{HF}/p_{FF}$, $\nu = N_H/N_F$, $\omega_H = w_H^m/w_H^a$, $\omega_F = w_F^m/w_F^a$ (see "Appendix" for proof):

$$\left\{\begin{array}{c}
\frac{\varepsilon_{FH}}{\varepsilon_{FH}-1}\,\frac{\varepsilon_{HH}-1}{\varepsilon_{HH}}\,\frac{\omega_F}{\omega_H}\,\tau = \xi_H \\
\frac{\varepsilon_{HF}}{\varepsilon_{HF}-1}\,\frac{\varepsilon_{FF}-1}{\varepsilon_{FF}}\,\frac{\omega_H}{\omega_F}\,\tau = \xi_F \\
\dfrac{\left(\frac{1}{\varepsilon_{HH}}\right)\left(\frac{\mu_H^a\theta_H^a}{1+\nu^{-1}\xi_H^{-(\sigma_H^a-1)}}+\frac{\mu_H^m\omega_H\theta_H^m}{1+\nu^{-1}\xi_H^{-(\sigma_H^m-1)}}\right)+\left(\frac{1}{\varepsilon_{HF}}\right)\left(\frac{\mu_F^a\theta_F^a}{1+\nu^{-1}\xi_F^{\sigma_F^a-1}}+\frac{\mu_F^m\omega_F\theta_F^m}{1+\nu^{-1}\xi_F^{\sigma_F^m-1}}\right)}{\left(\frac{1}{\varepsilon_{FF}}\right)\left(\frac{\mu_F^a\theta_F^a}{1+\nu\xi_F^{-(\sigma_F^a-1)}}+\frac{\mu_F^m\omega_F\theta_F^m}{1+\nu\xi_F^{-(\sigma_F^m-1)}}\right)+\left(\frac{1}{\varepsilon_{FH}}\right)\left(\frac{\mu_H^a\theta_H^a}{1+\nu\xi_H^{\sigma_H^a-1}}+\frac{\mu_H^m\omega_H\theta_H^m}{1+\nu\xi_H^{\sigma_H^m-1}}\right)} = \frac{\omega_H}{\omega_F}\nu \\
\left(\frac{1}{2}(1-\mu_H^m)\omega_H\theta_H^m+\frac{\mu_H^a\theta_H^a}{1+\nu\xi_H^{\sigma_H^a-1}}+\frac{\omega_H\mu_H^m\theta_H^m}{1+\nu\xi_H^{\sigma_H^m-1}}\right)\theta = \left(\frac{1}{2}(1-\mu_F^m)\omega_F\theta_F^m+\frac{\mu_F^a\theta_F^a}{1+\nu^{-1}\xi_F^{\sigma_F^a-1}}+\frac{\omega_F\mu_F^m\theta_F^m}{1+\nu^{-1}\xi_F^{\sigma_F^m-1}}\right)(1-\theta) \\
(1-\mu_H^m)\omega_H\frac{\theta_H^m}{\theta_H^a}+(1-\mu_F^m)\omega_F\frac{\theta_F^m}{\theta_F^a} = \mu_H^a+\mu_F^a
\end{array}\right. \tag{20}$$

The first and the second equations in (20) result from the pricing rules (11) by dividing equation for p_{rt} by the corresponding equation for p_{rr}. The third equation stems from the zero profit conditions for firms in countries H and F. The forth equation reflects the balance of trade between the two countries and, finally, the fifth equation is the labor clearing condition in the traditional sector, where the total production of one unite of the agricultural good requires one unite of unskilled labor (see "Appendix" for details).

The system of Eq. (20) is highly non-linear and does not provide an explicit solution. This sufficiently complicates the comparative static analysis of the model. Nevertheless, by resolving (20) numerically and using the equilibrium outputs for ξ_H, ξ_F, ν, ω_H, ω_F, one can calculate all other equilibrium parameters of the model in each of the two countries.

3 Some applications of the model: resolving the home bias in trade puzzle

In this section we demonstrate some applications of the model. Our main focus is on the role of the heterogeneity of consumer preferences and incomes in resolving the home bias in consumption puzzle. The key parameters in examining effects of home bias are the share of domestic spending on home-produced goods in the gross domestic product (GDP) and the share of imports in the domestic GDP. The first parameter is defined as $S_H \equiv E_{HH}/Y_H$ and equals to (see "Appendix" for details):

$$S_H = \left(\frac{1}{2}(1-\mu_H^a)\theta_H^a + \frac{\mu_H^a\theta_H^a}{1+\nu^{-1}\xi_H^{-(\sigma_H^a-1)}} + \frac{1}{2}(1-\mu_H^m)\omega_H\theta_H^m + \frac{\mu_H^m\omega_H\theta_H^m}{1+\nu^{-1}\xi_H^{-(\sigma_H^m-1)}}\right) \Big/ \left(\theta_H^a + \omega_H\theta_H^m\right). \tag{21}$$

The second parameter is defined as $T_H \equiv E_{FH}/Y_H$ and equals to

$$T_H = \left(\frac{1}{2}(1-\mu_H^a)\theta_H^a + \frac{\mu_H^a\theta_H^a}{1+\nu\xi_H^{\sigma_H^a-1}} + \frac{1}{2}(1-\mu_H^m)\omega_H\theta_H^m + \frac{\mu_H^m\omega_H\theta_H^m}{1+\nu\xi_H^{\sigma_H^m-1}}\right) \Big/ \left(\theta_H^a + \omega_H\theta_H^m\right). \tag{22}$$

Mirror expressions hold for the S_F and T_F in country F. It is easily verified that $S_H + T_H = 1$, with S_H/T_H ratio providing convenient measure of home bias. The larger is this ratio the more pattern of trade is skewed in favor of domestic consumption. Notice that neglecting trade costs by setting $\tau = 1$ results in the minimum degree of home bias with $S_H = T_H = 1½$and $S_H/T_H = 1$.

In order to show how taste and income heterogeneity combined with trade costs can provide a sizable increase in home consumption spending, consider first a case of the two symmetric countries identical in all respects including consumer preferences. Having assumed identical countries, and denoting by $S = S_H + S_F$ the world economy expenditure share for domestically produced goods in the world GDP $Y = Y_H + Y_F$, and by $T = T_H + T_F$ the share of trade (equal to the sum of imports and exports) in the world GDP, we may put $S_H = S_F = S/2$, $T_H = T_F = T/2$.

Introducing notations ${\mu_H}^a = {\mu_F}^a = \mu^a$, ${\mu_H}^m = {\mu_F}^m = \mu^m$, $\xi_H = \xi_F = \xi$, $\omega_H = \omega_F = \omega$, and taking into account that ${\theta_H}^a = {\theta_H}^m = {\theta_F}^a = {\theta_F}^m$, $\nu = 1$, the system of Eq. (20) can be reduced to (for proof, see "Appendix"):

$$\begin{cases} \dfrac{\varepsilon_{tr}}{\varepsilon_{tr}-1}\dfrac{\varepsilon_{rr}-1}{\varepsilon_{rr}}\tau = \xi \\ \omega = \dfrac{\mu^a}{1-\mu^m} \end{cases}, \tag{23}$$

where

$$\varepsilon_{rr} = (1-\alpha_{rr})\cdot\sigma^a + \alpha_{rr}\cdot\sigma^m, \quad \varepsilon_{rt} = (1-\alpha_{rt})\cdot\sigma^a + \alpha_{rt}\cdot\sigma^m, \tag{24}$$

$$\alpha_{rr} = \left(\frac{\mu^m \omega}{1 + \xi^{-(\sigma^m - 1)}}\right) \bigg/ \left(\frac{\mu^a}{1 + \xi^{-(\sigma^a - 1)}} + \frac{\mu^m \omega}{1 + \xi^{-(\sigma^m - 1)}}\right)$$
$$\alpha_{rt} = \left(\frac{\mu^m \omega}{1 + \xi^{\sigma^m - 1}}\right) \bigg/ \left(\frac{\mu^a}{1 + \xi^{\sigma^a - 1}} + \frac{\mu^m \omega}{1 + \xi^{\sigma^m - 1}}\right) \tag{25}$$

Accordingly, the (21) and (22) simplifies to

$$S = \left(\frac{1}{2}(1 - \mu^a) + \frac{1}{2}(1 - \mu^m)\omega + \frac{\mu^a}{1 + \xi^{-(\sigma^a - 1)}} + \frac{\mu^m \omega}{1 + \xi^{-(\sigma^m - 1)}}\right) \bigg/ (1 + \omega)\,, \tag{26}$$

$$T = \left(\frac{1}{2}(1 - \mu^a) + \frac{1}{2}(1 - \mu^m)\omega + \frac{\mu^a}{1 + \xi^{\sigma^a - 1}} + \frac{\mu^m \omega}{1 + \xi^{\sigma^m - 1}}\right) \bigg/ (1 + \omega)\,, \tag{27}$$

where ω and ξ are the solutions of (23).

Now consider the baseline homogeneous case of consumers having identical tastes and equal expenditure shares for both types of goods across the world. Setting ${\sigma_H}^a = {\sigma_H}^m = \sigma$ in (24) provides $\varepsilon_{rr} = \varepsilon_{rt} = \sigma$. Plugging these values (together with $\mu^a = 0.5$, $\mu^m = 0.5$) in (23), allows one to get the solution of the general equilibrium system of equations, which is $\omega = 1$ and $\xi = \tau$.[4] Inserting this solution into (26)–(27) yields

$$\frac{S}{T} = \frac{1 + 3\tau^{\sigma - 1}}{3 + \tau^{\sigma - 1}}. \tag{28}$$

The upper bound of this ratio is achieved at $\tau \to \infty$ or/and $\sigma \to \infty$, and equals to 3: $\lim_{\tau\to\infty}(S/T) = \lim_{\sigma\to\infty}(S/T) = 3$. Taking into account that $S/T = 1$ at $\tau = 1$ we conclude that our model of trade sufficiently restricts the possible degree of home bias, provided the baseline economy has homogeneous structure ($1 \leq S/T \leq 3$).

Looking through the literature on home bias, we have found rather dispersed evidence on what the bounds of S/T ratio can be. One of the latest information on this issue is the data presented by EKN for nineteen economies showing that the ratio of country home to foreign spending sufficiently depends on the type of tradables. For durables this ratio varies from 0.17 (for Denmark) to 6.39 (for Japan). Nondurables exhibit more home bias and provide the ratio of home to foreign spending varying from 0.42 (for Denmark) to 8.00 (for India). Accounting for this information, we conclude that our limiting case fails to cover the observed range of home bias, suggesting the model has to have a broader and more sophisticated structure to match the data.

An additional reasoning for this claim can be found in the related literature. Having explicitly obtained the S/T ratio in the homogeneous case allows one to compare results of the present paper with those in OR. To explain home bias in trade, OR developed a two-country trade model with identical consumers which was calibrated to an observed ratio of home to foreign consumption spending of 4.2 and matched

[4] An economy structure having $\mu^a = \mu^m \neq 0.5$ is not homogenous because it provides different incomes of consumers/workers belonging to different groups ($\omega \neq 1$ or $w^m \neq w^a$).

this ratio by introducing trade costs $\tau = 4/3$ and elasticity of substitution $\sigma = 6$.[5] Taking these magnitudes as inputs, the authors calculated the elasticity of home bias ratio S/T with respect to trade costs and obtained $d \ln (S/T)/d \ln \tau = 1.67$. In contrast to OR, our baseline case obviously fails to match the magnitude of $S/T = 4.2$ as it is bounded above by $S/T = 3$. Taking as given the same τ and σ as in OR, we come up with $S/T = 1.89$, which is sufficiently smaller than the magnitude postulated in OR, indicating the difference between the two models. Interestingly, the elasticity of home bias ratio with respect to trade costs in our baseline case turns out to be $d \ln (S/T)/d \ln \tau = 8\tau^{\sigma-1}(\sigma - 1)/[(1 + 3\tau^{\sigma-1})(3 + \tau^{\sigma-1})] \approx 1.71$, which is close to 1.67 in OR.

Recognizing the limits of the previous example, we now extend it to the heterogeneous case by still holding the same highly symmetric structure of the economy but changing the taste parameter of consumers in each of the two groups. By doing so, we will neglect the possible correlation of taste parameters with expenditure shares of consumers in order to isolate the impact of tastes on home bias in trade. Inserting $\mu^a = 0.5$, $\mu^m = 0.5$, $\omega = 1$ in (26)–(27), we get the following shares of spending on home and foreign goods:

$$\begin{aligned} S &= \frac{1}{4}\left(1 + \frac{1}{1+\xi^{-(\sigma^a-1)}} + \frac{1}{1+\xi^{-(\sigma^m-1)}}\right), \\ T &= \frac{1}{4}\left(1 + \frac{1}{1+\xi^{\sigma^a-1}} + \frac{1}{1+\xi^{\sigma^m-1}}\right). \end{aligned} \tag{29}$$

Here σ^a and σ^m are the new values of taste parameters of consumers, ξ is the solution of (23). Plugging $\sigma^a = \sigma + \Delta\sigma/2$, $\sigma^m = \sigma - \Delta\sigma/2$[6] at $\sigma = 6$ and $\tau = 4/3$ (which was used by OR) in (23), we obtain numerically an equilibrium solution for ξ at different values of the taste differential $\Delta\sigma$ between the two groups of consumers/workers and use it further in calculating S and S/T ratios.

Figure 1 shows that the share of domestic spending on home-produced goods S in this case is positively related with taste differential $\Delta\sigma$. The greater the difference in tastes between skilled and unskilled workers the larger is S ratio and, hence, the more pronounced is the home bias in trade.

Notice also that zeroing out the heterogeneity in tastes of consumers doesn't lead to the annihilation of the home bias effect, as the share of home absorption in the country's GDP stays greater than the share of trade (see the initial point in Fig. 1). Nevertheless, one has to recognize that accounting for taste heterogeneity between the two groups of consumers provides very small increase in the magnitude of home bias (at list in the particular case, considered here), suggesting that unobserved taste heterogeneity being isolated exerts only minor influence on the degree of home bias in trade.

Figure 2 depicts the S/T ratio and shows that it varies from 1.89 to 2.05, demonstrating an insignificant increase provided by large values of taste differential.

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[5] Rationale in favor of this choice can be found in Obstfeld and Rogoff (2001).

[6] In accordance with (29), this substitution is equivalent to $\sigma^a = \sigma - \Delta\sigma/2$, $\sigma^m = \sigma + \Delta\sigma/2$ due to assumed symmetry of the current economic structure and zero correlation between tastes and expenditure shares.

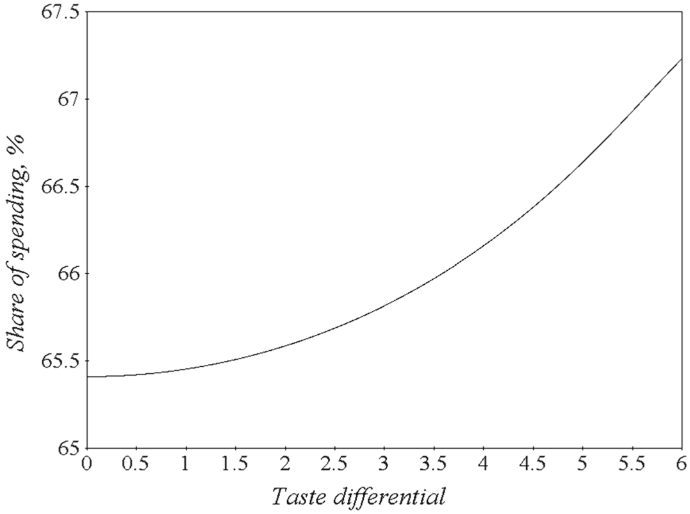

Fig. 1 Share of spending on domestically produced goods in the home country GDP versus taste differential

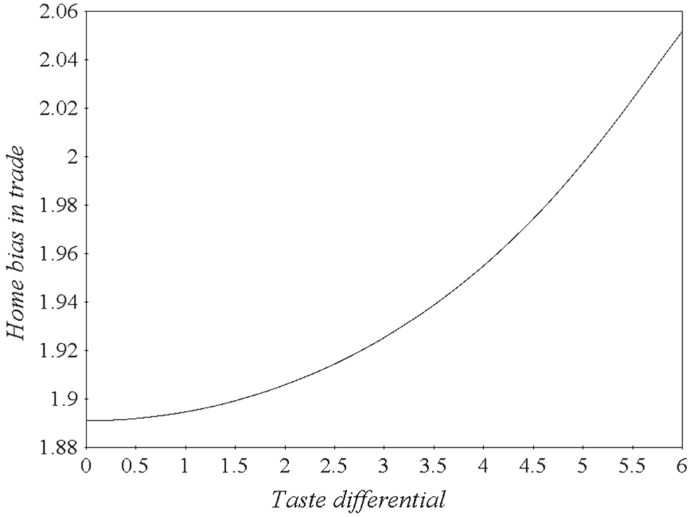

Fig. 2 Home bias in trade versus taste differential

Figures 3 and 4 reveal the mechanism of the within country taste heterogeneity influence on home bias. Figure 3 shows how difference in consumers' tastes impacts the price elasticities of the market demand for domestically produced and imported goods (solid line corresponds to ε_{rr}, dotted line corresponds to ε_{tr}).

What is important is that an increase in the taste differential $\Delta\sigma$ between the two groups of consumers/workers provides splitting of the price elasticities ε_{rr} and ε_{tr}, thus making the demand for domestic (imported) goods more (less) elastic. As Fig. 4 reports, the divergence of the market demand elasticities ε_{rr} and ε_{tr} leads to an increase

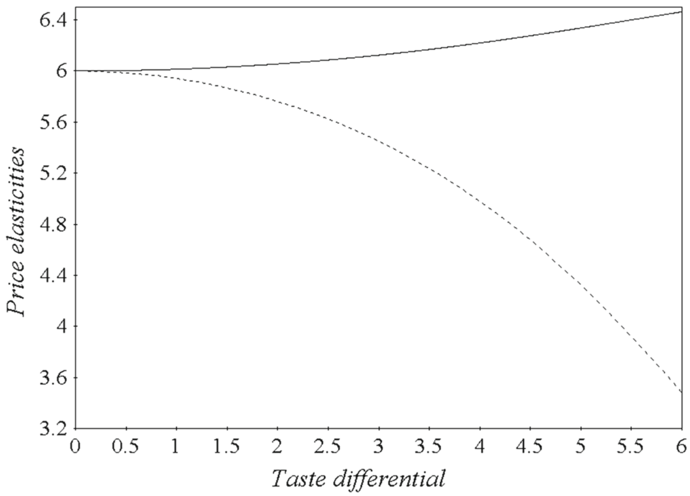

Fig. 3 Price elasticities of the market demand for domestically produced (solid curve) and imported (dotted line) goods versus taste differential

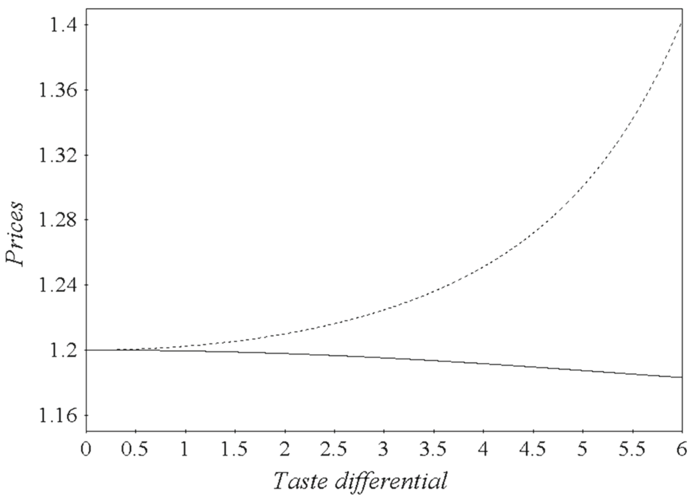

Fig. 4 Prices of the domestically produced (solid curve) and imported (dotted line) goods versus taste differential

in the price of imported goods relative to local goods, thus fostering consumers to buy relatively cheaper domestically produced goods and enhancing the home bias in consumption spending.

As far as the heterogeneity of consumers in our model originates from two sources, consider now the case of identical countries, where consumes/workers in agricultural and manufacturing sectors have the same taste parameters but may differ in their expenditure shares. By doing so we still neglect the possible correlation between tastes and expenditure shares in order to isolate the effect of income heterogeneity on

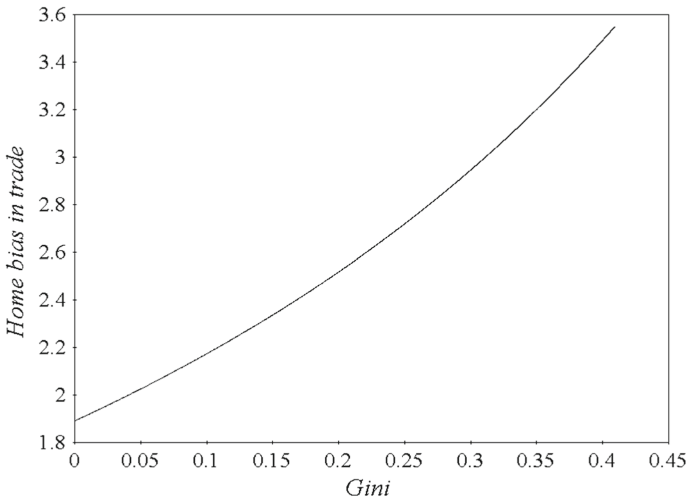

Fig. 5 Home bias in trade versus Gini coefficient

home bias in trade. Inspecting (23), one can get $\varepsilon_{rt} = \sigma$ and, hence, $\xi = \tau$. Plugging this solution together with $\omega = \mu^a/(1 - \mu^m)$ into (26)–(27), yields

$$\frac{S}{T} = \left(\frac{1}{2\omega} + \frac{1}{1 + \tau^{-(\sigma-1)}}\right) \Big/ \left(\frac{1}{2\omega} + \frac{1}{1 + \tau^{\sigma-1}}\right). \tag{30}$$

The latter shows that alongside with transportation costs and tastes of consumers, there exists an additional parameter influencing home bias in trade. This is the wage ratio $\omega = w^m/w^a$ reflecting the inhomogeneity of the within country income distribution. Indeed, the wage ratio is positively related with Gini coefficient, which equals to *Gini* $= 0.5 \cdot (\omega - 1)/(\omega + 1)$ in our symmetric case. As a consequence, the rising wage ratio ω, by providing the greater degree of within country income inequality, results in greater home bias in trade (see Fig. 5 below).

This suggests that countries having highly unequal income distribution should presumably have a relatively larger home bias in consumption spending. The data of EKN, as it seems, support this observation by showing that the largest bias in consumption spending is registered for India, i.e. country with extremely high degree of income inequality. In contrast, very low value of home bias observed for Denmark can be attributed to the relatively even income distribution in this country.

Despite the fact that our current example shifts the magnitude of the upper bound of the home bias ratio S/T from 3 to infinity (it is easily verified that $\lim_{\omega\to\infty}\{\lim_{\tau\to\infty}(S/T) = \lim_{\sigma\to\infty}(S/T)\} = \lim_{\omega\to\infty}\{1 + 2\omega\} = \infty$, $\lim_{\sigma\to\infty}\{\lim_{\omega\to\infty}(S/T)\} = \lim_{\sigma\to\infty}\{\tau^{\sigma-1}\} = \infty$, and $\lim_{\sigma\to\infty}\{\lim_{\omega\to\infty}(S/T)\} = \lim_{\sigma\to\infty}\{\tau^{\sigma-1}\} = \infty$), we have to realize that this upper bound is unachievable as it requires the unrealistically high values of transportation costs (taste parameter) and wage ratio. Using the economically plausible values for parameters τ, σ and ω, instead of unrealistic ones, shows that our model still fails to cover the range of home bias in consumption spending, observed in the data. For example, this proposition holds true for values of τ and σ, used in OR. Indeed, the maximum value of S/T ratio that could be achieved by plugging $\tau = 4/3$ and $\sigma = 6$ in (30) and assuming the implausibly high degree of within country income stratification is $\lim_{\omega \to \infty}(S/T) = \tau^{\sigma-1} \approx 4.2$, which is less than its maximum value observed in the data.

The failure of the current examples to explain the observed range of home bias in trade could be due to several reasons. One is that the economic structure provided by preceding examples is far too simple to realize this goal as it completely ignores the possible correlation between tastes and expenditure shares of consumers. In order to see to what extent an accounting for omitted correlation can improve the predictive power of the model, take up an additional example by assuming that expenditure shares of consumers may positively (negatively) correlate with their taste parameters. Positive (negative) correlation between tastes and expenditure shares in our setting implies that $\mu^m > \mu^a$ is accompanied with $\sigma^m > \sigma^a$ ($\sigma^m < \sigma^a$), meaning that consumers having larger share of consumption spending generate more (less) elastic individual demand.

It seems intuitively (and economically) plausible to assume that workers employed in industrial sector have a higher wage rate than those in agricultural one ($w_r^m > w_r^a$). The latter is equivalent to $\omega = \mu^a/(1 - \mu^m) > 1$ or $\mu^m > 1 - \mu^a$ in our current setting, meaning that the share of consumption spending of skilled workers on manufacturing goods should be larger than the corresponding spending of unskilled workers on food. Examining wage ratio $\omega = \mu^a/(1 - \mu^m)$, where $\mu^m > 1 - \mu^a$, one can see that the same magnitude of this ratio can be provided by different combinations of expenditure shares. For example, $\omega = 3$ corresponds to both ($\mu^a = 0.6$, $\mu^m = 0.8$) and ($\mu^a = 0.8$, $\mu^m = 0.6$). To avoid the aforementioned ambiguity we imply additionally that $\mu^m > \mu^a$.[7]

Taking this into account and considering the positive correlation between tastes and expenditure shares of consumers by plugging $\sigma^a = \sigma - \Delta\sigma/2$, $\sigma^m = \sigma + \Delta\sigma/2$ in (26)–(27), we calculated the home bias ratio S/T versus taste differential $\Delta\sigma$ at fixed μ^a, μ^m and different transportation costs. In doing so, we have chosen $\sigma = 6$, $\mu^a = 0.5$, $\mu^m = 0.9$ (corresponding to $\omega = 5$, $Gini = 0.33$) so as to get the highest magnitude of the S/T ratio in EKN data. As Fig. 6 shows, the maximum value for home bias, observed for India ($S/T = 8$), can be achieved at $\tau = 1.6$, and $\Delta\sigma = 6$.

In contrast, assuming negative correlation between tastes and expenditure shares of consumers by plugging $\sigma^a = \sigma + \Delta\sigma/2$, $\sigma^m = \sigma - \Delta\sigma/2$ in (26)–(27), provides diminishing S/T ratio, pointing out to the importance of the sign of this correlation. Figure 7 illustrates this peculiarity of the model for the same values of exogenous parameters as in Fig. 6 except for the correlation coefficient between tastes and expenditure shares.

The mechanism lying behind consumers'/workers' behavior in both of the two aforementioned cases can be formally explained by inspecting S and T shares in (26)–(27). Consider, for example, the last case featuring negative correlation between tastes and expenditure shares. At given μ^a, μ^m, ω, and τ we have σ^a, σ^m, and ξ,

[7] Industrial workers, being relatively richer than peasants, should spend a disproportionally larger share of their income on manufacturing goods compared with that of agricultural employees. Evidence in favor of this assumption can be found in the literature, suggesting that rich and poor consumers have substantially different consumption patterns (Broda et al. 2009).

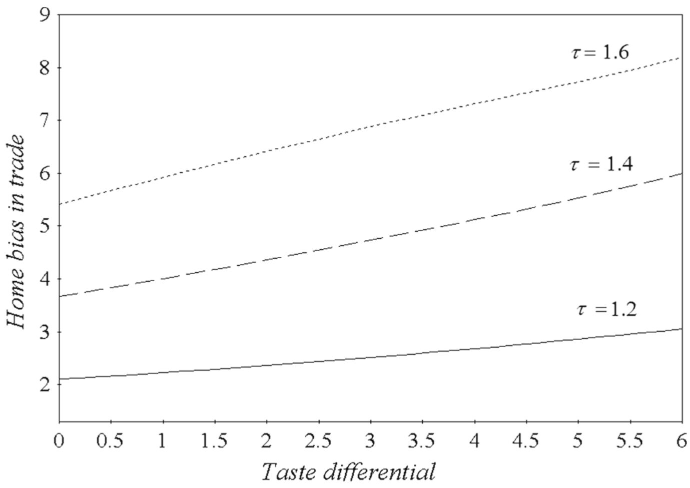

Fig. 6 Home bias in consumption versus taste differential (positive correlation between tastes and expenditure shares of consumers)

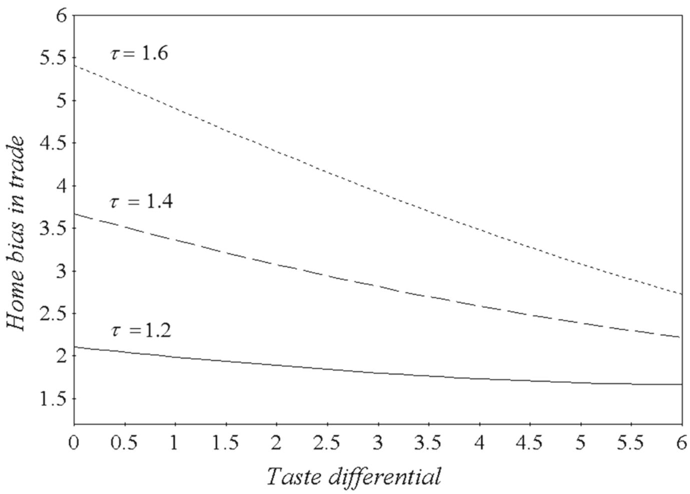

Fig. 7 Home bias in consumption versus taste differential (negative correlation between tastes and expenditure shares of consumers)

varying with taste differential $\Delta\sigma$. An increasing taste dispersion leads here to a fall of the manufacturing workers spending on manufactured goods $(\mu^m \omega)/[1+\xi^{-(\sigma^m-1)}]$ and growth in the corresponding spending of agricultural workers $\mu^a/[1+\xi^{-(\sigma^a-1)}]$. As numerical analysis shows, the rate of decrease of the first flow wins against the rate of increase of the second, this way resulting in the net decrease of the *S* ratio. Similar analysis applied to the *T* ratio shows that this ratio grows in response to an increase in the taste dispersion. As a consequence, the *S/T* ratio goes down.

It is worth noting also that growing taste dispersion at negative correlation between tastes and expenditure shares (income) results in decrease of the aggregate price elasticity of the world demand on manufactured goods. This leads to an in increase in the aggregate relative love for variety of consumers, fostering them to buy more importables despite these importables becoming relatively expensive in comparison with domestically produced goods.

4 Discussion

The modeling strategy applied in the present paper can be viewed complimentary to OR investigation underlining the role of trade costs in resolving still existing puzzles of trade. Indeed, the ignorance of trade costs in our setting results in complete annihilation of home bias effect as long as $\lim_{\tau \to 1}(S/T) = 1$, which means that trade costs play the dominant role in whole story, making income and taste heterogeneity play second fiddle. This finding supports both OR and EKN arguments in favor of trade frictions as the key element in resolving home bias puzzle.

Nevertheless, it should be emphasized that only in combination with income and taste heterogeneity the empirically plausible trade costs seem to be able to cover the range of observed home bias values. If it is so, than a number of additional questions immediately arises regarding an empirical consistency of the model. The first question to be answered is how the heterogeneity in tastes can be measured and, second, is what correlation should we expect between tastes and expenditure shares? Although these questions are currently beyond the scope of the present paper, we may refer to the recent literature in the field, investigating the unobserved heterogeneity in consumer preferences (Calvet and Comon 2003; Christensen 2014).

The study of Calvet and Comon (2003) introduces a semiparametric model of consumer demand that allows for diversity in tastes. This framework makes it possible to recover the joint density of households spending and tastes from cross sections by a nonparametric procedure involving a deconvolution. The authors estimated the model on British data in the period from 1968 to 1998 and found that taste heterogeneity explains a large fraction of the variation of budget shares with income. The study of Christensen (2014) uses a unique long panel dataset on household expenditures to test whether unobservable heterogeneity in budget share equations (tastes, etc.) is correlated with total expenditures (income). The main finding here is that tastes are indeed correlated with income for some goods, among which are food eaten outside home, alcohol, tobacco, transportation, and energy. Calculation of the income elasticities with and without accounting for correlated heterogeneity reveals large differences for the income elasticity for alcohol and tobacco, while transportation changes from being a luxury to being a necessity.

Addressing the role of unobserved taste heterogeneity in explaining home bias in consumption spending, both of the referenced contributions could be of value in taking the present model to data. Alongside with heterogeneity in tastes, the inhomogeneity of within country income distribution seems to play a significant role in explaining home bias in trade puzzle. This prediction of the model needs a more rigorous investigation.

5 Conclusions

The present paper develops a two-sector two-country trade model of monopolistic competition featuring the heterogeneity of consumer preferences within and across countries. The incorporation of heterogeneity into a monopolistic competition setting is achieved by assuming the nested Cobb–Douglas and CES preferences exhibiting both country and sector-specific consumer tastes and expenditure shares for manufacturing and traditional goods. This makes it possible to have different demand functions for the same variety across destinations when consumers in these countries have non-identical joint distributions of taste and expenditure shares.

Our main motivation in developing an extended model of trade is in trying to resolve the home bias in trade puzzle. The main finding here is that the impact of the within country taste and income heterogeneity may exert sufficient influence on home bias in trade but only in combination with substantially high trade costs. This result can be considered complimentary to that of Obstfeld and Rogoff (2001) seminal contribution.

Acknowledgements The authors acknowledge the financial support from RFBR fund Grant No. 17-06-00572.

Appendix

A1. The market demand and relationship between tastes and expenditure shares

Generally, the market demand for variety i in country r can be written as

$$q_{rt}(i) = \sum_{s=a,m} \sum_{s'=a,m} x_{rt}^{ss'}(i) L_t^{ss'} = L_t \sum_{s=a,m} \sum_{s'=a,m} x_{rt}^{ss'}(i) \theta_t^{ss'}$$
$$= L_t \sum_{s=a,m} \sum_{s'=a,m} \frac{(p_{rt}(i))^{-\sigma_t^s}}{\left(P_t^s\right)^{1-\sigma_t^s}} \mu_t^{s'} w_t^{s'} \theta_t^{ss'},$$

where $\theta_r^{ss'}$ is the joint distribution of tastes and expenditure shares of consumers. To avoid complications, we assume a one-to-one correspondence between ${\sigma_r}^s$ and ${\mu_t}^s$, considering limiting cases with correlation coefficient $\rho_{\sigma\mu} = \pm\, 1$ and $\rho_{\sigma\mu} = 0$. This allows for (10) with ${\theta_t}^s = {L_r}^s/L_r$ being the degenerate form of the joint taste and expenditure share distribution of consumers.

A2. Symmetric price equilibrium

Let $p_{rt}(i) = p_{rt}$ in (7), (11) and (12) for any variety, then price indexes simplify to

$$P_H^s = \left(N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}\right)^{1/(1-\sigma_H^s)}$$
$$P_F^s = \left(N_H p_{HF}^{-(\sigma_F^s-1)} + N_F (p_{FF})^{-(\sigma_F^s-1)}\right)^{-1/(\sigma_F^s-1)}$$

Inserting these expressions into (12) provides

$$\begin{aligned}\varepsilon_{HH} &= \left(\sum_{s=a,m} \frac{\sigma_H^s (p_{HH})^{1-\sigma_H^s}}{\left(P_H^s\right)^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s\right) \Bigg/ \left(\sum_{s=a,m} \frac{(p_{HH})^{1-\sigma_H^s}}{\left(P_H^s\right)^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s\right) \\ &= \left(\sum_{s=a,m} \frac{\sigma_H^s (p_{HH})^{1-\sigma_H^s}}{N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s\right) \\ &\quad \Bigg/ \left(\sum_{s=a,m} \frac{(p_{HH})^{1-\sigma_H^s}}{N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s\right)\end{aligned}$$

Multiplying nominator by N_H and denoting $\nu \equiv N_H/N_F$, $\xi_H \equiv p_{FH}/p_{HH}$, one can get:

$$\varepsilon_{HH} = \frac{\sum_{s=a,m} \frac{\sigma_H^s}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}} \mu_H^s w_H^s L_H^s}{\sum_{s=a,m} \frac{1}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}} \mu_H^s w_H^s L_H^s} = \frac{\sum_{s=a,m} \frac{\sigma_H^s}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}} \mu_H^s w_H^s \theta_H^s}{\sum_{s=a,m} \frac{1}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}} \mu_H^s w_H^s \theta_H^s},$$

where $\theta_H{}^s \equiv L_H{}^s/L_H$. Introducing $\alpha_{HH} = \left(\frac{\mu_H^m w_H^m \theta_H^m}{1+\nu^{-1}\xi_H^{-(\sigma_H^m-1)}}\right) \Big/ \left(\sum_{s=a,m} \frac{\mu_H^s w_H^s \theta_H^s}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}}\right)$, the price elasticity ε_{HH} can be represented as $\varepsilon_{HH} = (1 - \alpha_{HH}) \cdot \sigma_H{}^a + \alpha_{HH} \cdot \sigma_H{}^m$. All other price elasticities in (16)–(17) can be derived analogously.

A3. Zero profit equations

Zero profit conditions for home and foreign firms read as follows:

$$\begin{aligned} p_{HH}q_{HH} + p_{HF}q_{HF} - c w_H^m q_{HH} - c\tau w_H^m q_{HF} - f w_H^m = 0 \\ p_{FF}q_{FF} + p_{FH}q_{FH} - c w_F^m q_{FF} - c\tau w_F^m q_{FH} - f w_F^m = 0 \end{aligned}$$

Market demand functions appearing in these expressions, are

$$q_{HH} = \sum_{s=a,m} x_{HH}^s L_H^s = \frac{(p_{HH})^{-\sigma_H^a}}{\left(P_H^a\right)^{1-\sigma_H^a}} \mu_H^a w_H^a L_H^a + \frac{(p_{HH})^{-\sigma_H^m}}{\left(P_H^m\right)^{1-\sigma_H^m}} \mu_H^m w_H^m L_H^m$$

$$q_{HF} = \sum_{s=a,m} x_{HF}^s L_F^s = \frac{(p_{HF})^{-\sigma_F^a}}{\left(P_F^a\right)^{1-\sigma_F^a}} \mu_F^a w_F^a L_F^a + \frac{(p_{HF})^{-\sigma_F^m}}{\left(P_F^m\right)^{1-\sigma_F^m}} \mu_F^m w_F^m L_F^m$$

$$q_{FF} = \sum_{s=a,m} x_{FF}^s L_F^s = \frac{(p_{FF})^{-\sigma_F^a}}{\left(P_F^a\right)^{1-\sigma_F^a}} \mu_F^a w_F^a L_F^a + \frac{(p_F)^{-\sigma_H^m}}{\left(P_F^m\right)^{1-\sigma_F^m}} \mu_F^m w_F^m L_F^m$$

$$q_{FH} = \sum_{s=a,m} x_{FH}^s L_H^s = \frac{(p_{FH})^{-\sigma_H^a}}{\left(P_H^a\right)^{1-\sigma_H^a}} \mu_H^a w_H^a L_H^a + \frac{(p_{FH})^{-\sigma_H^m}}{\left(P_H^m\right)^{1-\sigma_H^m}} \mu_H^m w_H^m L_H^m$$

where price indexes for symmetric price equilibrium read as follows:

$$P_H^s = \left(N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}\right)^{1/(1-\sigma_H^s)}$$
$$P_F^s = \left(N_H p_{HF}^{-(\sigma_F^s-1)} + N_F (p_{FF})^{-(\sigma_F^s-1)}\right)^{1/(1-\sigma_F^s)}$$

Rewrite zero profit conditions as

$$p_{HH}\left(1-\frac{c w_H^m}{p_{HH}}\right) q_{HH} + p_{HF}\left(1-\frac{c\tau w_H^m}{p_{HF}}\right) q_{HF} - f w_H^m = 0$$
$$p_{FF}\left(1-\frac{c w_F^m}{p_{FF}}\right) q_{FF} + p_{FH}\left(1-\frac{c\tau w_F^m}{p_{FH}}\right) q_{FH} - f w_F^m = 0$$

Plugging

$$1-\frac{c_H w_H^m}{p_{HH}} = \frac{1}{\varepsilon_{HH}}; \quad 1-\frac{\tau c_H w_H^m}{p_{HF}} = \frac{1}{\varepsilon_{HF}}; \quad 1-\frac{c_F w_F^m}{p_{FF}} = \frac{1}{\varepsilon_{FF}}; \quad 1-\frac{\tau c_F w_F^m}{p_{FH}} = \frac{1}{\varepsilon_{FH}}$$

into the zero profits conditions (together with market demand functions) results in

$$\left(\frac{1}{\varepsilon_{HH}}\right) \sum_{s=a,m} \frac{N_H (p_{HH})^{1-\sigma_H^s}}{N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s$$
$$+ \left(\frac{1}{\varepsilon_{HF}}\right) \sum_{s=a,m} \frac{N_H (p_{HF})^{1-\sigma_F^s}}{N_F (p_{FF})^{1-\sigma_F^s} + N_H (p_{HF})^{1-\sigma_F^s}} \mu_F^s w_F^s L_F^s - N_H f w_H^m = 0$$
$$\left(\frac{1}{\varepsilon_{FF}}\right) \sum_{s=a,m} \frac{N_F (p_{FF})^{1-\sigma_F^s}}{N_F (p_{FF})^{1-\sigma_F^s} + N_H (p_{HF})^{1-\sigma_F^s}} \mu_F^s w_F^s L_F^s$$
$$+ \left(\frac{1}{\varepsilon_{FH}}\right) \sum_{s=a,m} \frac{N_F (p_{FH})^{1-\sigma_H^s}}{N_H (p_{HH})^{1-\sigma_H^s} + N_F (p_{FH})^{1-\sigma_H^s}} \mu_H^s w_H^s L_H^s - N_F f w_F^m = 0$$

Introducing $p_{FH}/p_{HH} \equiv \xi_H$, $p_{HF}/p_{FF} \equiv \xi_F$ and $N_H/N_F \equiv \nu$ into above equations, we have

$$\left(\frac{1}{\varepsilon_{HH}}\right) \sum_{s=a,m} \frac{\mu_H^s w_H^s L_H^s}{1+\nu^{-1}\xi_H^{-(\sigma_H^s-1)}} + \left(\frac{1}{\varepsilon_{HF}}\right) \sum_{s=a,m} \frac{\mu_F^s w_F^s L_F^s}{1+\nu^{-1}\xi_F^{-(\sigma_F^s-1)}} - N_H f_H w_H^m = 0$$
$$\left(\frac{1}{\varepsilon_{FF}}\right) \sum_{s=a,m} \frac{\mu_F^s w_F^s L_F^s}{1+\nu\xi_F^{-(\sigma_F^s-1)}} + \left(\frac{1}{\varepsilon_{FH}}\right) \sum_{s=a,m} \frac{\mu_H^s w_H^s L_H^s}{1+\nu\xi_H^{-(\sigma_H^s-1)}} - N_F f_F w_F^m = 0$$

Dividing the first equation by the second, yields:

$$\frac{\left(\frac{1}{\varepsilon_{HH}}\right)\left(\frac{\mu_H^a\theta_H^a}{1+\nu^{-1}\xi_H^{-(\sigma_H^a-1)}}+\frac{\mu_H^m\omega_H\theta_H^m}{1+\nu^{-1}\xi_H^{-(\sigma_H^m-1)}}\right)+\left(\frac{1}{\varepsilon_{HF}}\right)\left(\frac{\mu_F^a\theta_F^a}{1+\nu^{-1}\xi_F^{\sigma_F^a-1}}+\frac{\mu_F^m\omega_F\theta_F^m}{1+\nu^{-1}\xi_F^{\sigma_F^m-1}}\right)}{\left(\frac{1}{\varepsilon_{FF}}\right)\left(\frac{\mu_F^a\theta_F^a}{1+\nu\xi_F^{-(\sigma_F^a-1)}}+\frac{\mu_F^m\omega_F\theta_F^m}{1+\nu\xi_F^{-(\sigma_F^m-1)}}\right)+\left(\frac{1}{\varepsilon_{FH}}\right)\left(\frac{\mu_H^a\theta_H^a}{1+\nu\xi_H^{\sigma_H^a-1}}+\frac{\mu_H^m\omega_H\theta_H^m}{1+\nu\xi_H^{\sigma_H^m-1}}\right)}=\frac{\omega_H}{\omega_F}\nu$$

A4. The balance of trade equation

The balance of trade between the two countries means that the total spending of home country consumers on domestically produced and imported goods must be equal to the total spending of foreign country consumers on internally produced and imported goods:

$$\frac{1}{2}\sum_{s=a,m}(1-\mu_H^s)w_H^sL_H^s+N_Fp_{FH}q_{FH}=\frac{1}{2}\sum_{s=a,m}(1-\mu_F^s)w_F^sL_F^s+N_Hp_{HF}q_{HF}$$

Calculating combinations $N_Fp_{FH}q_{FH}$ and $N_Hp_{HF}q_{HF}$ by using market demand functions from the Sect. A3, yields

$$N_Fp_{FH}q_{FH}=\sum_{s=a,m}\frac{w_H^s\mu_H^sL_H^s}{1+\nu\xi_H^{\sigma_H^s-1}};\quad N_Hp_{HF}q_{HF}=\sum_{s=a,m}\frac{w_F^s\mu_F^sL_F^s}{1+\nu^{-1}\xi_F^{\sigma_F^s-1}}$$

Inserting these into trade balance equation provides

$$\begin{aligned}&\frac{1}{2}(1-\mu_H^a)w_H^aL_H^a+\frac{1}{2}(1-\mu_H^m)w_H^mL_H^m+\sum_s\frac{w_H^s\mu_H^sL_H^s}{1+\nu\xi^{\sigma_H^s-1}}\\&=\frac{1}{2}(1-\mu_F^a)w_F^aL_F^a+\frac{1}{2}(1-\mu_F^m)w_F^mL_F^m+\sum_s\frac{w_F^s\mu_F^sL_F^s}{1+\nu^{-1}\zeta^{\sigma_F^s-1}}\end{aligned}$$

This is equivalent to the forth equation in (20).

A5. Labor clearing condition in the traditional sector

The labor clearing condition for the perfectly competitive sector means that the total production of one unite of the agricultural good requires one unite of unskilled labor

$$\begin{cases}\sum_{s=a,m}\left(X_{AHH}^sL_H^s+X_{AHF}^sL_F^s\right)=L_H^a\\\sum_{s=a,m}\left(X_{AFF}^sL_F^s+X_{AFH}^sL_H^s\right)=L_F^a\end{cases}$$

Now take into account that each domestic consumer buys the home-produced and foreign goods in equal volumes, i.e.

$$X_{AHH}^a=X_{AFH}^a=\frac{1}{2}X_{AH}^a;\quad X_{AHH}^m=X_{AFH}^m=\frac{1}{2}X_{AH}^m;$$

$$X^a_{AFF} = X^a_{AHF} = \frac{1}{2} X^a_{AF}; \quad X^m_{AFF} = X^m_{AHF} = \frac{1}{2} X^m_{AF}$$

Plugging these expressions into the labor clearing conditions, yields

$$\begin{cases} X^a_{AH} L^a_H + X^m_{AH} L^m_H + X^a_{AF} L^a_F + X^m_{AF} L^m_F = 2L^a_H \\ X^a_{AF} L^a_F + X^m_{AF} L^m_F + X^a_{AH} L^a_H + X^m_{AH} L^m_H = 2L^a_F \end{cases}.$$

These two equations are not contradictory if and only if $L_H{}^a = L_F{}^a$, so the only one of these two equations remains. Accounting for this, we use here the demand functions of consumers on agricultural and manufacturing composites

$$X^a_{AH} = \left(1 - \mu^a_H\right) \frac{w^a_H}{p_A}; \quad X^m_{AH} = \left(1 - \mu^m_H\right) \frac{w^m_H}{p_A};$$
$$X^a_{AF} = \left(1 - \mu^a_F\right) \frac{w^a_F}{p_A}; \quad X^m_{AF} = \left(1 - \mu^m_F\right) \frac{w^m_F}{p_A}$$

Substituting these demands into the first of the two equations above and using some algebra, we have

$$(1 - \mu^a_H) + (1 - \mu^m_H) \frac{w^m_H}{w^a_H} \frac{L^m_H}{L^a_H} + (1 - \mu^a_F) \frac{w^a_F L^a_F}{w^a_H L^a_H} + (1 - \mu^m_F) \frac{w^m_F}{w^a_H} \frac{L^m_F}{L^a_H} = 2 \frac{p_A}{w^a_H}$$

Denoting $w_H{}^m / w_H{}^a \equiv \omega_H$, $w_F{}^m / w_F{}^a \equiv \omega_F$ and plugging $L_H{}^a = L_F{}^a$, $p_A = w_H{}^a = w_F{}^a = 1$ into above equation, we finally get the last equation in (20).

A6. The share of home spending on home-produced goods

The country-level spending of domestic consumers/workers on home-produced goods consists of the two parts: one is the spending on traditional good and second is the spending on manufacturing goods: $E_{HH} = \frac{1}{2} \sum_{s=a,m} (1 - \mu^s_H) w^s_H L^s_H + N_H p_{HH} q_{HH}$. Calculating the second part, yields $N_H p_{HH} q_{HH} = \sum_{s=a,m} \frac{\mu^s_H w^s_H L^s_H}{1 + \nu^{-1} \xi_H^{-(\sigma^s_H - 1)}}$. The share of domestic spending on home-produced goods in the gross domestic product equals to $S_H \equiv E_{HH}/Y_H$, where $Y_H = w^a_H L^a_H + w^m_H L^m_H$ is the home country GDP. Taking this into account and using notations $\theta^s_H \equiv L^s_H / L_H$, $w^m_H / w^a_H \equiv \omega_H$, $w^m_F / w^a_F \equiv \omega_F$, provides (21).

A7. General equilibrium equations for identical countries

Assuming that the two trading countries are identical in all respects, we have $\theta^a_H = \theta^m_H = \theta^a_F = \theta^m_F$, $\mu^a_H = \mu^a_F = \mu^a$, $\mu^m_H = \mu^m_F = \mu^m$. Taking into account that $N_H = N_F$, $w^m_H / w^a_H = w^m_F / w^a_F$, and $p_{FH}/p_{HH} = p_{HF}/p_{FF}$ (i.e. $\nu = 1$, $\omega_H = \omega_F = \omega$, $\xi_H = \xi_F = \xi$) due to countries' identity, the system of Eq. (20) can be reduced to (23).

Indeed, substituting corresponding parameters into the fifth equation (reflecting labor clearing condition)

$$(1-\mu_H^m)\omega_H \frac{L_H^m}{L_H^a} + (1-\mu_F^m)\omega_F \frac{L_F^m}{L_F^a} = \mu_H^a + \mu_F^a$$

results in $(1-\mu^m)\omega_r + (1-\mu^m)\omega_r = \mu^a + \mu^a$ or $(1-\mu^m)\omega_r = \mu^a$, which is exactly what we have in (23). Using the same notations in trade balance equation, one can find that it reduces to identity

$$\frac{1}{2}(1-\mu^m)\omega_r + \frac{\mu^a}{1+\xi^{\sigma^a-1}} + \frac{\omega_r\mu^m}{1+\xi^{\sigma^m-1}} = \frac{1}{2}(1-\mu^m)\omega_r + \frac{\mu^a}{1+\xi^{\sigma^a-1}} + \frac{\omega_r\mu^m}{1+\xi^{\sigma^m-1}}$$

The same conclusion holds true for zero profit equations

$$\frac{\left(\frac{1}{\varepsilon_{HH}}\right)\left(\frac{\mu_H^a L_H^a}{1+\nu^{-1}\xi^{-(\sigma_H^a-1)}} + \frac{\mu_H^m \omega_H L_H^m}{1+\nu^{-1}\xi^{-(\sigma_H^m-1)}}\right) + \left(\frac{1}{\varepsilon_{HF}}\right)\left(\frac{\mu_F^a L_F^a}{1+\nu^{-1}\zeta^{\sigma_F^a-1}} + \frac{\mu_F^m \omega_F L_F^m}{1+\nu^{-1}\zeta^{\sigma_F^m-1}}\right)}{\left(\frac{1}{\varepsilon_{FF}}\right)\left(\frac{\mu_F^a L_F^a}{1+\nu\zeta^{-(\sigma_F^a-1)}} + \frac{\mu_F^m \omega_F L_F^m}{1+\nu\zeta^{-(\sigma_F^m-1)}}\right) + \left(\frac{1}{\varepsilon_{FH}}\right)\left(\frac{\mu_H^a L_H^a}{1+\nu\xi^{\sigma_H^a-1}} + \frac{\mu_H^m \omega_H L_H^m}{1+\nu\xi^{\sigma_H^m-1}}\right)} = \frac{\omega_H}{\omega_F}\nu,$$

which can be transformed into the identity

$$\begin{aligned}&\left(\frac{1}{\varepsilon_{rr}}\right)\left(\frac{\mu^a}{1+\xi^{-(\sigma^a-1)}} + \frac{\mu^m\omega}{1+\xi^{-(\sigma^m-1)}}\right) + \left(\frac{1}{\varepsilon_{rt}}\right)\left(\frac{\mu^a}{1+\xi^{\sigma^a-1}} + \frac{\mu^m\omega}{1+\xi^{\sigma^m-1}}\right)\\ &\quad = \left(\frac{1}{\varepsilon_{rr}}\right)\left(\frac{\mu^a}{1+\xi^{-(\sigma^a-1)}} + \frac{\mu^m\omega}{1+\xi^{-(\sigma^m-1)}}\right) + \left(\frac{1}{\varepsilon_{rt}}\right)\left(\frac{\mu^a}{1+\xi^{\sigma^a-1}} + \frac{\mu^m\omega}{1+\xi^{\sigma^m-1}}\right)\end{aligned}$$

Now consider price equations. Substituting $\omega_H = \omega_F = \omega$ into

$$\frac{\varepsilon_{FH}}{\varepsilon_{FH}-1}\frac{\varepsilon_{HH}-1}{\varepsilon_{HH}}\frac{\omega_F}{\omega_H}\tau = \xi_H, \quad \frac{\varepsilon_{HF}}{\varepsilon_{HF}-1}\frac{\varepsilon_{FF}-1}{\varepsilon_{FF}}\frac{\omega_H}{\omega_F}\tau = \xi_F$$

these two equations degenerate into one equation

$$\frac{\varepsilon_{tr}}{\varepsilon_{tr}-1}\frac{\varepsilon_{rr}-1}{\varepsilon_{rr}}\tau = \xi,$$

where

$$\varepsilon_{rr} = (1-\alpha_{rr})\cdot\sigma^a + \alpha_{rr}\cdot\sigma^m; \quad \varepsilon_{rt} = (1-\alpha_{rt})\cdot\sigma^a + \alpha_{rt}\cdot\sigma^m,$$

and the coefficients α_{rt} are given by

$$\begin{aligned}\alpha_{rr} &= \left(\frac{\mu^m\omega}{1+\xi^{-(\sigma^m-1)}}\right) \Big/ \left(\frac{\mu^a}{1+\xi^{-(\sigma^a-1)}} + \frac{\mu^m\omega}{1+\xi^{-(\sigma^m-1)}}\right);\\ \alpha_{rt} &= \left(\frac{\mu^m\omega}{1+\xi^{\sigma^m-1}}\right) \Big/ \left(\frac{\mu^a}{1+\xi^{\sigma^a-1}} + \frac{\mu^m\omega}{1+\xi^{\sigma^m-1}}\right)\end{aligned}$$

As a result, we have only two equations, constituting (23).

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