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### **Endogenous Tradability and Macroeconomic Implications**

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June 22, 2005

Paper # 05-13

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# Endogenous Tradability and Macroeconomic Implications

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This draft: June 22, 2005

## **Abstract:**

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JEL classification: F4

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We thank seminar participants at Harvard, Johns Hopkins, Stanford, University of California at Santa Cruz, Yale, NBER, Federal Reserve System Committee for International Economic Analysis, International Monetary Fund, and European University Institute for helpful comments.

This paper is a revised version of NBER Working Paper No. 9739 "Endogenous Nontradability and Macroeconomic Implications." The views expressed below do not represent those of the Federal Reserve Bank of San Francisco or the Board of Governors of the Federal Reserve System.

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## 1. Introduction

Open economy macroeconomics has made significant strides in incorporating microeconomic foundations, finding strong implications for basic macroeconomic questions and policy analysis. Recent evidence regarding trade costs suggests that some of the yet unresolved questions in the new open economy macroeconomic literature may be addressed by expanding the set of microeconomic foundations to include lessons from international trade theory. Research in international trade has long taken seriously the notion that the trade pattern in the international goods market is endogenously determined. This paper develops a simple approach for incorporating into a macro model heterogeneous trade costs and endogenous decisions by individual firms regarding international trade. Endogenizing trade in this manner offers a natural explanation to a long-standing puzzle in international macroeconomics regarding the low degree of volatility in the relative price of nontraded goods. It also is found to possess implications for other fundamental macroeconomic issues. Given the analytical tractability of the approach taken here, it provides a highly suitable starting point for integrating trade costs and other trade elements into macroeconomics in a transparent manner.

While open economy macroeconomics by definition analyzes trade across national borders, the field has long found it useful to allow for the fact that some portion of goods tend not to be traded internationally. The idea of nontraded goods has played the central role in some important models in the field over time. Balassa (1964) and Samuelson (1964) used nontraded goods to help explain why real exchange rate levels differ between countries. Dornbusch (1983) used them to show how such real exchange rate movements over time may limit intertemporal trade and shape the current account. And Stockman and Tesar (1995) used them to help explain some key features of international business cycles. But in all these models, the share of nontraded goods is taken to be exogenously determined; a good is by nature either tradable in the international market, or it is by nature not tradable.

This perspective contrasts with that in the international trade literature. Beginning with Dornbusch, Fisher and Samuelson (1977), there has been an interest in seeing how trade patterns along a continuum of goods are determined endogenously, including a range of goods that remain untraded due to trade costs. Recent work has proposed clever ways of parameterizing such firm heterogeneity.<sup>1</sup> But in this work, goods are ranked by their productivities, while the size of trade costs are assumed to be uniform across goods. Those goods with the greatest comparative

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<sup>1</sup> See Melitz (2003) who develops a model with endogenous entry into domestic and foreign goods markets. See also Bernard, Eaton, Jensen, and Kortum (2003), which models heterogeneity of productivity across many countries and many goods. While the latter paper allows trade costs to differ between country pairs, it does not allow for heterogeneity of trade costs between goods, which drives our results.

advantage in one country or the other are traded, while those goods with small gains from trading relative to the uniform trade costs remain nontraded.

In contrast to this convention, we think that when the issue of primary interest is tradability, it makes more sense to focus on the variation of trade costs among goods<sup>2</sup>. Clearly some goods are much more difficult to trade than others, and the identity of a good as traded or nontraded is likely to be determined by this factor more strongly than any other. For example, the reason that many types of services are nontraded is not because countries are so similar in their productivities in these sectors; rather, they remain nontraded primarily because such services are particularly costly to trade across borders. Further, the usual convention has some strongly counterfactual implications regarding nontraded goods. For example, it does not account for the empirical observations that there is a great deal of heterogeneity among goods in terms of their deviations from the law of one price across countries, nor that these deviations systematically tend to be greater for nontraded goods than for traded goods (Crucini, Telmer, and Zachariadis, forthcoming). Models featuring heterogeneity in productivity with a uniform trade cost, such as Dornbusch, Fisher, and Samuelson (1977), imply exactly the opposite to this last observation. While such models are appropriate for explaining the distinction between exported versus imported goods, we argue that it probably is not the most appropriate model for understanding the distinction between traded versus nontraded goods.

Trade costs have received great interest of late in the empirical trade literature. Empirical work by Hummels (1999, 2001) has emphasized that trade costs -- including tariff and nontariff barriers, shipping costs, and other associated costs of marketing and distribution -- vary greatly across classes of goods and play an important role in trade decisions. Collecting detailed trade data for individual goods, he finds that freight costs alone can range from more than 30 percent of value for raw materials and mineral fuels down to 4 percent for some manufactures. Depending on factors such as weight, distance, and the time sensitivity of demand, trade costs can be high and variable for many manufactured goods as well. Hummels (2001) documents that in 1998 a substantial proportion of U.S. trade was airshipped with air-freight costs typically amounting to 25 percent of transported good value in some cases.<sup>3</sup> In a broad survey of trade cost evidence,

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<sup>2</sup> The macro model here will differ also in several other respects from the related trade literature. The model describes a small open endowment economy where world price levels are exogenously given. We abstract from production and entry decisions. We also abstract from monopolistic competition and markup pricing by firms. In this context, we do not need fixed costs of trade to induce some firms to forgo international trade; iceberg costs alone are sufficient. See section 2 for details of the model.

<sup>3</sup> Even these measured trade cost margins may be severely biased downwards. Average transportation cost measures that weight costs of individual goods by the value of observed trade flows underestimate costs to the extent that goods with higher costs are traded less. Second, if vertical production arrangements imply

Anderson and van Wincoop (2004) likewise reach the conclusion that trade costs are very large and very heterogeneous among goods. Empirical work has also found support for the idea that there is switching over time between status as traded and nontraded. Using a panel of U.S. manufacturing plants from 1987 to 1997, Bernard and Jensen (2001) find that year to year transition rates are noteworthy: on average 13.9% of non-exporters begin to export in any given year during the sample, and 12.6% of exporters stop.<sup>4</sup>

The conclusion arising from this empirical research is that there is need for a method of incorporating heterogeneous trade costs and endogenous tradedness into our macroeconomic models. This paper proposes a very simple method for doing so. It posits a continuum of differentiated home goods that are heterogeneous in terms of iceberg trade costs, and it ranks them in this dimension. A convenient distribution is posited for these trade costs which makes expressions for macroeconomic aggregates easy to derive despite the heterogeneity. From the perspective of new open economy macroeconomics, the approach takes a standard intertemporal small open economy model, and adds one endogenous variable, the share of nontraded goods. The equilibrium value of this variable is pinned down by one additional equilibrium condition, relating the nontraded goods share to the nontraded goods price. The macro literature is familiar with thinking about this price as an endogenous variable, and the distribution we choose for trade costs implies that the nontraded share has a very simple and tractable relationship to this price.

This way of looking at things offers new insights into international integration and the behavior of international relative prices. As one example, consider the puzzling stylized fact featured in several recent empirical papers that the relative price of nontraded goods to traded goods is not very volatile. Empirical measures in Betts and Kehoe (2001a) indicate that movements in the relative price of nontraded goods are only about 37% as large as movements in the real exchange rate. Empirical work by Engel (1993, 1999) indicates this ratio may be a good deal smaller yet. This fact stands in contrast to standard theoretical models such as that used by Balassa-Samuelson, which presume traded goods are constrained by the law of one price and explain movements in the real exchange rate primarily in terms of movements in the relative price of nontraded goods. But the basic idea of endogenous tradability offers an elegant and simple explanation. On the margin there is a seller who is indifferent between selling his good

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transshipment of raw materials and intermediate goods, the cumulative transportation costs can be much higher than those on the exports of the final product alone.

<sup>4</sup> It should be noted that the results of this paper in no way rely upon implausibly large numbers of firms switching between traded and nontraded status, but rather upon the simple fact that firms have the ability to make such a switch. In fact, we show that the results of the model here are the strongest in those cases where only a small number of firms actually do switch in equilibrium.

domestically only, or branching out into the international market. As a result, this marginal nontraded good forms a link between the prices of goods that are traded and other similar goods that are nontraded. In the aggregate, this linkage prevents the price indices of traded and nontraded goods from wandering too far apart.

Our research is related to other recent work on trade costs in macroeconomic models, notably Obstfeld and Rogoff (2000), Betts and Kehoe (2001a, 2001b), and Bergin and Glick (2002). However, we find an extraordinarily tractable way of introducing trade costs, which allows us to consider a continuum of goods and still have discrete changes in the status of goods between being traded and fully nontraded. This is not true of the previous papers. Obstfeld and Rogoff (2000) only consider the case of one home good that switches between traded and nontraded status; Bergin and Glick (2002) extend this to two goods. By integrating over a continuum of goods, our approach allows us to avoid the difficulty implied by the Kuhn-Tucker conditions, whereby the relevant equilibrium conditions for an individual good change discontinuously as it switches between being traded and nontraded. Betts and Kehoe (2001b) allow heterogeneous trade costs and varying degrees of tradability to play a role in explaining relative goods prices, as we do. But unlike their model, ours allows a range of goods that take on the status of being fully nontraded, and thus permits us to derive and analyze the equilibrium share of nontraded goods.

This research is also related to Ghironi and Melitz (2004), which also works to incorporate trade features into a macro model with a continuum of heterogeneous firms. One significant difference is that they follow the trade literature in considering heterogeneity in terms of firm productivity, whereas we emphasize the importance and new insights of focusing instead on heterogeneity in trade costs.<sup>5</sup> We view Ghironi and Melitz (2004) and our paper as representatives of competing, but ultimately complementary, visions for how endogenous tradedness can best be used to advance the open economy macro literature. Later in the paper we extend our model to include production and heterogeneous productivity, consider both productivity as well as demand shocks, and draw direct comparisons between the two types of heterogeneity.

The model demonstrates that endogenous tradedness has implications for other basic macroeconomic issues. For example, we also explore the implications of endogenous tradability for the issue of intertemporal trade. Previous work assuming exogenously nontraded goods (Dornbusch, 1983) found that the presence of nontraded goods strongly discourages intertemporal

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<sup>5</sup> Their model also differs in many other details, as it is geared mainly to analyze business cycle regularities. It utilizes a two-county framework, with monopolistic competition and entry decisions into domestic production as well as international trade, which in turn requires fixed entry costs as well as per-unit costs of exporting.

trade, where countries with large current account imbalances are punished by high domestic interest rates. We find that if tradedness is endogenous, the share of nontraded goods will tend to adjust so as to minimize this friction.

The next two sections develop the benchmark endowment model and present results. Section 4 demonstrates that our main insights are robust to a more general specification including production.

## 2. Model

To focus on the issue of tradedness, we follow Obstfeld and Rogoff (2000) in considering a very simple small open endowment economy. This choice is a useful starting point for our analysis because it permits some analytical results and makes very transparent the new insights on which we wish to focus. An endowment economy is clearly a special case, but we demonstrate in a later section that the results are robust to including production in the model. The small open economy assumption is highly relevant for most countries in the world.

The country is endowed with a continuum of goods indexed by  $i$  on the unit interval, where  $y_i$  represents the level of endowment,  $c_i$  is the level of consumption, and  $p_i$  is the domestic price level of this good. All of these home goods have the potential of being exported, but some endogenously determined fraction of the goods,  $n$ , will be nontraded in equilibrium. For each traded home good there is a prevailing world price  $p_i^*$  that may differ from the home price because of trade costs. The small open economy may also import foreign goods for consumption purposes, with consumption level  $c_F$  and price level  $p_F$ . We initially omit time subscripts in the notation, but introduce them when extending the framework to two periods. For simplicity, we assume that the endowments and world price levels of all home goods are uniform, implying  $y_i = y$ ,  $p_i^* = p^*$  for all  $i$ .

The aggregate consumption index is specified as:<sup>6</sup>

$$c = \frac{c_H^q c_F^{1-q}}{q^q (1-q)^{1-q}}. \quad (1)$$

Here  $c_H$  is an index of home goods consumption:

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<sup>6</sup> For simplicity we limit ourselves here to a Cobb-Douglas specification, implying a unitary elasticity of substitution between home and foreign goods. Empirical work on this elasticity suggests a value between 0.5 and 1.5, with our value of 1 in the middle; e.g., see Pesenti (2002). In the present case, the Cobb-Douglas specification has the added benefit of making the algebraic results more easily interpretable. See the appendix of the working paper version (Bergin and Glick, 2003) for the derivations of the CES case.

$$\begin{aligned}
c_H^{(f-1)/f} &= \int_0^n (c_i)^{(f-1)/f} di + \int_n^1 (c_i)^{(f-1)/f} di \\
&= n \left( \frac{c_N}{n} \right)^{(f-1)/f} + (1-n) \left( \frac{c_T}{1-n} \right)^{(f-1)/f}
\end{aligned} \tag{2}$$

where

$$\begin{aligned}
c_N &\equiv n \left( \frac{1}{n} \int_0^n c_i^{(f-1)/f} di \right)^{f/(f-1)} \\
c_T &\equiv (1-n) \left( \frac{1}{1-n} \int_n^1 c_i^{(f-1)/f} di \right)^{f/(f-1)}
\end{aligned}$$

are consumption indexes of nontraded and traded goods, respectively, and  $n$  is the share of goods on the continuum  $\{0,1\}$  that are nontraded. Price indexes are defined as usual for each category of goods, in correspondence to the consumption indexes above:

$$p = p_H^q p_F^{1-q} \tag{3}$$

$$\begin{aligned}
p_H^{1-f} &= \int_0^n (p_i)^{1-f} di + \int_n^1 (p_i)^{1-f} di \\
&= n p_N^{1-f} + (1-n) p_T^{1-f}
\end{aligned} \tag{4}$$

where  $p$  is the aggregate price level,  $p_H$  is the price index of all home goods, and the price index of home nontraded goods  $p_N$  and the price index of home traded goods  $p_T$  are defined as

$$\begin{aligned}
p_N &\equiv \left( \frac{1}{n} \int_0^n p_i^{1-f} di \right)^{1/(1-f)} \\
p_T &\equiv \left( \frac{1}{1-n} \int_n^1 p_i^{1-f} di \right)^{1/(1-f)}
\end{aligned}$$

Note that if world prices are normalized to unity, i.e.  $p^* = 1$ ,  $p_F = 1$ ,  $p$  may be interpreted as the reciprocal of the real exchange rate for this small open economy.

The home goods are distinguished from each other by the presence of good-specific iceberg costs,  $(t_i)$  where a certain fraction of the good disappears in transport. We assume that the home country pays for this cost so that the domestic price will be  $p_i = p^*/(1+t_i)$  if the country exports good  $i$ .<sup>7</sup> These trade costs are specified to follow the distribution:

$$1 + t_i = a i^{-b}; \quad a \geq 1, \quad b \geq 0$$

which implies the following distribution of export prices

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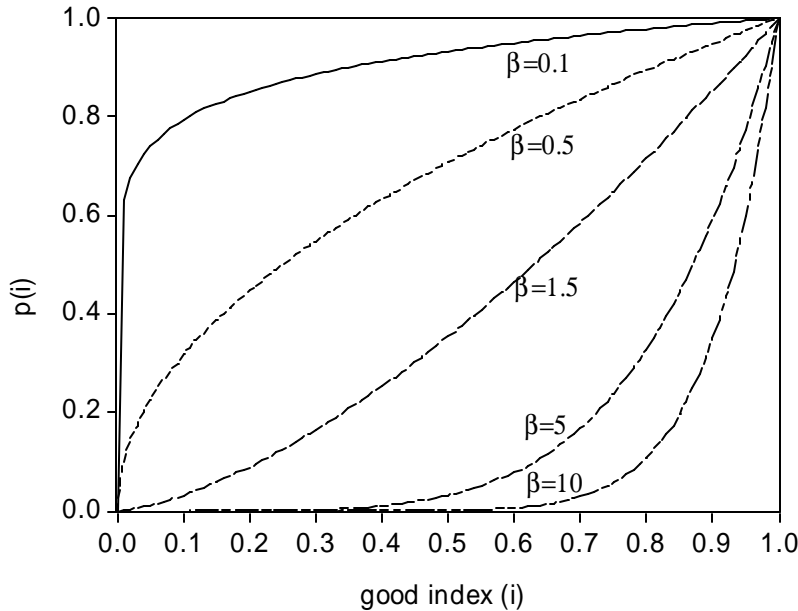
<sup>7</sup> The presence of trade costs (obviously) implies segmentation between domestic and foreign markets.



$$p_i = \frac{p^*}{1+t_i} = \frac{p^* i^b}{a}. \quad (5)$$

The parameter  $\mathbf{b}$  controls the curvature of the distribution, while  $\mathbf{a}$  controls the level.<sup>8</sup> Figure 1 illustrates how the distribution of export prices varies with  $\mathbf{b}$  (assuming  $p^*/a = 1$ ). The goods at the left end of the continuum ( $i$  near 0) tend to have lower prices when exported because the trade cost is large; these goods are less tradable. Goods toward the right end of the continuum ( $i$  near 1) have higher prices because the trade cost is low; they are more tradable.  $\mathbf{b}$  characterizes how quickly the price of an individual good rises with the goods index -- in fact, it can be viewed as an elasticity. For example, for a high  $\mathbf{b}$ , the percent change in costs is high for a given percent change in the index.<sup>9</sup>

**Fig. 1: Price of good if traded ( $p^*/a = 1$ )**



In positing a distribution of transport costs over a continuum of firms, we do not take a stand on how much of this heterogeneity is due to differences across industries versus differences across plants within an industry, as there is empirical evidence indicating heterogeneity on both

<sup>8</sup> This cost distribution is related to the Pareto function, where  $\mathbf{a}$  is the “scale” parameter and  $\mathbf{b}$  is the “shape” parameter.

<sup>9</sup> That the domestic price of more tradable goods is greater than that of less tradable goods can be attributed to our normalization that the world price of all goods is constant. Had we assumed that the foreign price  $p_i^*$  rises with  $i$  at a rate faster than trade costs fall, the domestic price of exported goods could be higher than that of nontraded goods. In Section 4 in an extension to the model we show how export prices may be relatively higher as a result of heterogeneous productivity in domestic production. Note also that we abstract from possible heterogeneity in import goods; see footnote 17.

levels. Our continuum simply ranks all firms according the trading costs they face, without regard for whether this coincides with any notion of industrial grouping.

In the endowment economy in our model the decision of whether to export a good is determined solely on the basis of whether the export price (i.e. the world price) less iceberg costs, exceeds the domestic price. If the export price is higher, then the good is exported, if it is lower, then it is not traded.

Given the cutoff between traded and nontraded goods at index  $n$ , it is straightforward to compute the price index for traded goods from the price distribution of exported varieties:

$$\begin{aligned}
p_T &= \left( \left( \frac{1}{1-n} \right) \left[ \int_n^1 \left( \frac{p^* i^b}{a} \right)^{1-f} di \right] \right)^{1/(1-f)} \\
&= \left( \left( \frac{1}{1-n} \right) \left( \frac{p^*}{a} \right)^{1-f} \left[ \frac{1}{1-[b(f-1)]} \left( i^{1-[b(f-1)]} \right) \right]_n^1 \right)^{1/(1-f)} \quad (6) \\
&= \left( \frac{p^*}{a} \right) \left( \left( \frac{1}{1-n} \right) \left( \frac{1}{w} \right) \left[ \left( \frac{1}{n} \right)^w - 1 \right] \right)^{1/(1-f)}
\end{aligned}$$

where we define  $w \equiv b(f-1) - 1$ ,  $w \geq -1$  (since  $b \geq 0$  and  $f > 1$ ).<sup>10</sup> Keep in mind that this  $n$  is itself an endogenous variable that will be solved as part of the general equilibrium system. Equation (6) expresses the price of traded goods as a function of the share of traded goods  $n$ , the elasticity of substitution across domestic goods  $f$ , and the trade cost parameters,  $b$  and  $a$ . It is straightforward to establish that  $\partial p_T / \partial n > 0$ ; i.e. the price of traded goods increases with the share of nontraded goods. The reason is that, as the proportion of home goods that are nontraded rises, it is no longer profitable to export goods with marginally higher trade costs; as these goods are withdrawn from export markets, the average price of the remaining export goods rises.<sup>11</sup>

The price index of nontraded goods is even easier to determine. As usual, intratemporal optimization implies relative demands for each pair of home goods  $i$  and  $j$ :

<sup>10</sup> Note  $p_T \geq 0$  with our specification of trade costs, since for  $0 > w \geq -1$  and for  $w > 0$ , it follows that

$(1/w) \{n^{-w} - 1\} > 0$  for  $1 \geq n \geq 0$ ; for  $w = 0$ ,  $p_T = \left( \frac{-p^* \log(n)}{a(1-n)} \right) \geq 0$  as well.

<sup>11</sup> This conclusion is robust to the particular definition of the price index. If a naïve statistician did not know the set of traded goods had changed, but collected price data on all goods that previously had been traded, this average price level would still rise. However, the reason would be that the average includes newly nontraded goods, whose individual prices have risen, rather than the fact that an average is being taken over a subset of goods where the lower price items have been removed.

$$\frac{c_i}{c_j} = \left( \frac{p_i}{p_j} \right)^{-f}.$$

Since consumption must equal the endowment of nontraded goods, and endowments are uniform for all goods here (i.e.  $y_i = y$  for all  $i$ ), we can conclude that for any pair of nontraded goods it will be true that  $c_i / c_j = y_i / y_j = 1$ , and so  $p_i / p_j = 1$ .<sup>12</sup> In other words, the price of each nontraded good will be identical, because they each are by definition not affected by the trade costs which vary by good. This logic applies equally well to the home good that is just on the margin between being traded and nontraded ( $i=n$ ). The marginal trader decides to export solely on the basis of whether the world price less iceberg costs exceeds the domestic price. But because this good is on the margin of being traded, the domestic price must be the same as that as if it were sold in the world market:  $p_n = (p^*/\mathbf{a})n^b$ . As a result, the price index of nontraded goods is pinned down as the price of the marginal traded good:

$$\begin{aligned} p_N &= \left( \left( \frac{1}{n} \right) \left[ \int_0^n (p_i)^{1-f} di \right] \right)^{1/(1-f)} = \left( \left( \frac{1}{n} \right) \left[ \int_0^n (p_n)^{1-f} di \right] \right)^{1/(1-f)} \\ &= p_n = \left( \frac{p^*}{\mathbf{a}} \right) n^b. \end{aligned} \tag{7}$$

This equilibrium condition will be important in the analysis to follow, and it will be referred to as the “marginal nontraded condition.” It implies that the price of nontraded goods rises with the share of nontraded goods with elasticity  $b$ . Figure 2 below illustrates how this equilibrium price level varies with the share of nontraded goods (still assuming  $p^*/\mathbf{a} = 1$ ).

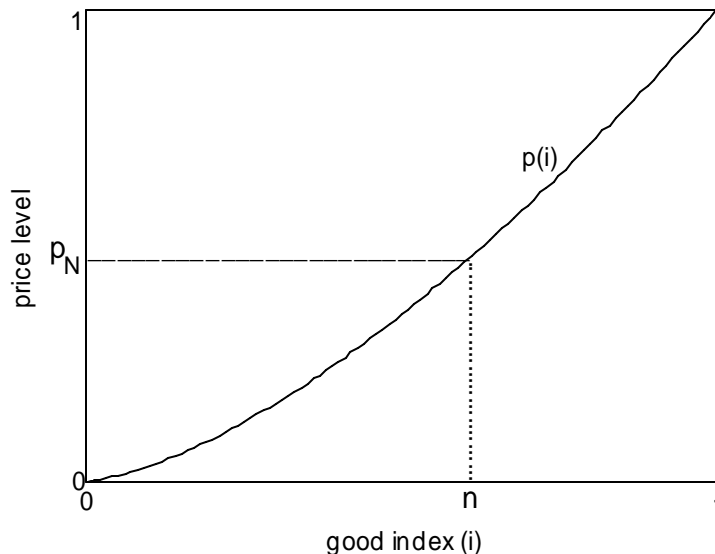
It is easily verified that there can be no discontinuous jump in price either up or down between the last nontraded good and the first traded good. Note that the iceberg trading costs for adjacent goods are essentially identical and that there is no fixed cost to trade. Suppose that the price of the first traded good jumped discontinuously above the price of the last nontraded good; then it would be profitable for the last nontraded good to become traded instead. Similarly, suppose that the

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<sup>12</sup> This assumption can be relaxed without undermining our ability to compute a price index for nontraded goods; the only difference is that the distribution of productivities and endowments would have to be included in the integral, making the resulting price index more complicated. Because our focus here is on the role of heterogeneous trade costs, we utilize the assumption of uniform endowments to make the results more transparent.

price of the first traded good jumped discontinuously below the price of the last nontraded good; then it would be profitable for the first traded good to become nontraded instead.<sup>13</sup>

**Fig. 2: Aggregate price level of nontraded goods**  
(shown for  $b = 1.5$ ,  $p^*/a = 1$ )



The price indices of traded and nontraded goods are related to each other. Figure 3 shows their relationship as the share of nontraded goods varies. Observe that (i)  $p_T$  is everywhere higher than  $p_N$ , since traded goods are less costly to transport,<sup>14</sup> and (ii) both  $p_N$  and  $p_T$  rise with  $n$ .<sup>15</sup>

Equations (6) and (7) can be combined to obtain a characterization of how the relative price structure is pinned down by the share of nontraded goods  $n$ , the elasticity of transportation costs  $b$ , and the elasticity of substitution of home goods  $f$ :<sup>16</sup>

<sup>13</sup> If we included a constant fixed cost of exporting per firm  $f_x$ , the price setting condition for the marginal exporter changes from  $p_n = p^*/(1+t_n)$  to  $p_n = p^*/(1+t_n) - f_x$ . This implies a vertical jump down in our figure 2. Note that these price setting conditions are equivalent to zero profit conditions in our endowment economy framework with quantities normalized to unity.

<sup>14</sup> It is not clear how one should compare this prediction to data, given that in the model quantity units are normalized to be constant for all goods, while in actual data they obviously vary across goods. The main testable implication is that there is a greater price wedge on average between the level of prices of individual nontraded goods across countries than there is for the prices of traded goods across countries. This implication is easily verified in data (e.g., see Crucini, Telmer, and Zachariadis, forthcoming).

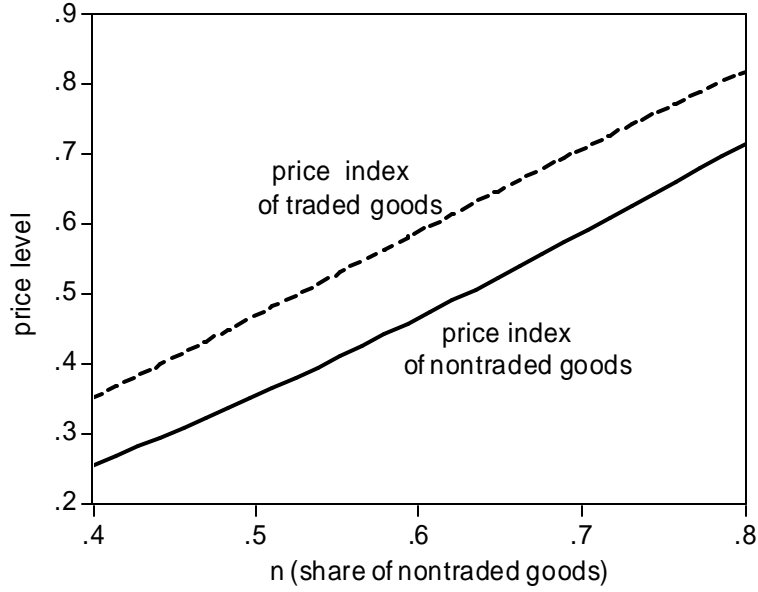
<sup>15</sup> These results should hold for any cost distribution that is monotonically increasing in  $i$ . We can verify this at least for the class of power functions  $(I_0 + I_1 i)^b$ , which are easily integrable.

<sup>16</sup> Note that the absence of trade cost heterogeneity ( $b = 0$ ) implies  $w = -1$  and  $p_N = p_T$ .

$$\frac{p_N}{p_T} = \left[ \left( \frac{n}{1-n} \right) \left( \frac{1}{w} \right) (1-n^w) \right]^{\frac{1}{f-1}}$$

where once again  $w \equiv b(f-1) - 1$ .

**Fig. 3: Price indexes of traded and nontraded goods as a function of n**  
(shown for  $b = 1.5$ ,  $p^*/a = 1$ ,  $f = 10$ )



As additional equilibrium conditions, intratemporal optimization implies the demand functions:

$$c_N = n \left( \frac{p_N}{p_H} \right)^{-f} c_H \quad (8)$$

$$c_T = (1-n) \left( \frac{p_T}{p_H} \right)^{-f} c_H \quad (9)$$

$$c_H = q \left( \frac{p_H}{p} \right)^{-1} c \quad (10)$$

$$c_F = (1-q) \left( \frac{p_F}{p} \right)^{-1} c \quad (11)$$

It is assumed that residents of the small open economy must pay the cost of transport for imports of foreign goods. The price of imported foreign goods is normalized to unity in the world market, so its domestic price is set exogenously as

$$p_F = 1 + \mathbf{t}_F \equiv \mathbf{a}_F$$

for some given  $\mathbf{t}_F$  representing iceberg trade costs for imported goods.<sup>17 18</sup>

Market clearing for nontraded goods requires

$$c_N = \int_0^n y_i \frac{p_i}{p_N} di = ny \quad (12)$$

given our assumption  $y_i = y$  for all  $i$  and that  $p_i = p_n = p_N$  for all  $i \in \{0, n\}$ .

The goods market described above will be analyzed in the context of a two-period model with a representative consumer. The consumer maximizes two-period utility

$$\mathbf{d}U(c_1) + U(c_2)$$

subject to the intertemporal budget constraint.

$$\left( \frac{p_{H2}}{p_2} y_{H2} - c_2 \right) = - \left( \frac{p_1}{p_2} \right) (1+r) \left( \frac{p_{H1}}{p_1} y_{H1} - c_1 \right). \quad (13)$$

Here  $r$  is the world interest rate. The term  $\mathbf{d}$  is an exogenous discount factor that can change, thereby allowing us to consider shifts in demand from one period to the next. Intertemporal optimization implies the usual intertemporal Euler equation:

$$U'_{c1} = \frac{1}{\mathbf{d}} \left( \frac{p_1}{p_2} (1+r) \right) U'_{c2}. \quad (14)$$

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<sup>17</sup> We assume transport costs on imports may differ from those on exports (i.e.,  $\mathbf{a} \neq \mathbf{a}_F$ ) because of, for example, differential tariff costs. We do not consider heterogeneity in the trade costs of foreign goods nor the endogenous determination of which goods produced abroad are traded (and imported by the domestic economy), and which are nontraded, as the small open economy framework is better suited for considering the endogeneity of home-country variables. Extending the model to endogenize heterogeneous imports from abroad would not harm our main results, since our price indices are defined in terms of exported, not imported, goods. Further, including the latter under heterogeneity would likely only enhance our result that positive demand shocks raise the price of traded goods, since a rise in demand would induce the importing of foreign goods with higher trade costs and lead to higher import prices and hence higher traded good prices in the domestic market.

<sup>18</sup> The existence of a world price for all varieties of home goods implies that these goods must all be available abroad as well as in the home country. We rule out the possibility that any goods with which the home country is endowed are ever imported because of the transport costs incurred by domestic residents of doing so. Specifically, if the home country started importing what it had previously been exporting, the price of these goods would jump from below the world price to above the world price. It would only be an extreme case where domestic residents would be willing to pay this price and still consume enough of these good to import them. Moreover, as long as some goods are always exported each period (i.e.  $n < 1$ ), such an extreme case will never be reached. Intuitively, since the last goods to stop being exported have the lowest transport costs, they would also have to be the first ever to be imported. Hence, the exporting of *all* home goods would need to cease in a period before importing any of them would begin, implying a huge current account deficit and a zero level of gross (not merely net) exports. This is ruled out as long as  $n < 1$ .

Equilibrium here determines values each period for the variables  $c_t, c_{Ht}, c_{Tt}, c_{Nt}, c_{Ft}, p_t, p_{Ht}, p_{Tt}, p_{Nt}, n_t$ , satisfying equations (3-4, 6-12) for each period as well as the intertemporal budget constraint (13) and the intertemporal consumption Euler equation (14). This system is identical to a standard two-period model, with the addition of one extra endogenous variable,  $n$ , which is pinned down by one additional equilibrium condition, the marginal nontraded condition (7).

### 3. Results

#### A. Solution for the share of nontraded goods under balanced trade

Viewing nontradedness as endogenous offers some new insights into what drives the degree of international integration and the openness of a country's goods markets. Consider first a static version of the model where  $\mathbf{d}$  is constant at a value of unity (and accordingly  $r = 0$ ). We will refer to this version as a steady state of the model, in that consumption and all other variables are constant across the two periods. According to the intertemporal budget constraint, the value of domestic production equals the value of domestic consumption in this case, and the trade balance is zero:  $p_{H1}y_{H1} - p_1c_1 = p_{H2}y_{H2} - p_2c_2 = 0$ . In the appendix we show that the equilibrium conditions above can be solved together to yield the following expression for the equilibrium trade balance (surplus)  $Z$ :

$$Z \equiv \frac{1 + n^{b+1}\mathbf{b}}{1 + \mathbf{b}} - \frac{1}{\mathbf{w}\mathbf{q}} [n^{b+1}(\mathbf{w} + 1) - n^{bf}] = 0 \quad (15)$$

where  $\mathbf{w} \equiv \mathbf{b}(\mathbf{f} - 1) - 1$  (and time subscripts are still omitted). In appendix A we show that the trade balance  $Z$  falls as  $n$  increases. Intuitively, increasing  $n$  implies trade in fewer varieties of goods and lowers the trade surplus. Condition (15) implies that the balanced trade condition determines the steady-state share of nontraded goods,  $\bar{n}$ . It is easily verified that this solution is the unique solution that lies within the permissible range of zero to one (see the appendix). It is clear that if  $n$  were 0 and all goods were traded, then the trade balance is positive here. For some  $n > 0$ , the trade balance will fall to zero.

Condition (15) provides a number of insights concerning the determinants of the equilibrium share of nontraded goods. One observation is that the curvature parameter in the distribution of trade costs ( $\mathbf{b}$ ) plays an important role in determining  $\bar{n}$ . Table 1 reports numerical simulations for a benchmark calibration of  $\mathbf{f} = 10$ ,  $p^*/\mathbf{a} = 1$ ,  $\mathbf{q} = 0.5$ ,  $\mathbf{t}_F = 0.1$ . Column 2 shows that a rise in  $\mathbf{b}$  progressively raises the share of home goods that are nontraded.

This result is fairly intuitive: if trade costs rise very quickly as one exports more classes of goods, it is optimal to export a smaller number of classes of goods. A country should then concentrate its exports in those commodities for which international trade is so much less costly.

Another important determinant of tradedness is the elasticity of substitution between home goods ( $f$ ). Table 2 shows in column 2 that as this elasticity rises,  $\bar{n}$  rises gradually. The intuition is that if home goods are highly substitutable in consumption, one can conserve on trade costs by concentrating one's exports in the goods that are easiest to trade. This means there will be a smaller quantity of these particular classes of goods to consume, but under a high elasticity, it is easy to compensate for this by consuming a greater quantity of other types of goods. On the other hand, if home goods were less substitutable with each other, one would want to consume a more even distribution of home goods, thereby requiring the country to export a smaller portion of a larger number of goods to pay the bill for imports.

Lastly, observe that the scale parameter in the distribution of trade costs,  $\mathbf{a}$ , does not appear in equation (15) above. When one considers the effects of trade costs here, it is their relative levels between goods (summarized in  $\mathbf{b}$ ), not their overall level (summarized in  $\mathbf{a}$ ) which determines the varieties of goods that are nontraded. In part, this last implication results from the assumption of Cobb-Douglas preferences over home and foreign goods, which is a common assumption in this literature, known to have certain implications that help simplify analytical solutions.<sup>19</sup> Some intuition can be found in the fact that a unitary elasticity of substitution between home and foreign goods implies that a constant share of consumption expenditure goes toward foreign goods, regardless of the relative price between goods, and hence regardless of the size of transport costs. A sufficient quantity of home goods then must be traded and exported to pay for these imports under balanced trade.<sup>20</sup>

However, if we consider a more general CES specification between home and foreign goods, the scale of trade costs does affect the share of nontraded goods. The counterpart to equation (15) for the CES case is:<sup>21</sup>

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<sup>19</sup> See Corsetti and Pesenti (2001) for an example.

<sup>20</sup> Condition (A6) in the appendix shows that under balanced trade and Cobb-Douglas preferences, a constant fraction of home goods will be consumed domestically and a constant fraction will be exported, without any regard for the relative price of home to foreign goods. Because the scale parameter of transport costs enters only through price terms, it does not enter in this condition. As long as the world prices of home goods are uniform, the same result holds for changes in  $p^*$ .

<sup>21</sup> See the appendix in the working paper version of Bergin and Glick (2002) for the derivation of this condition. In the case of Cobb-Douglas preferences for the home and foreign good,  $\mathbf{g} = 1$ , and (15') reduces to (15).



$$\begin{aligned} & \left[ \frac{1+n^{b+1}\mathbf{b}}{1+\mathbf{b}} \right] \left[ n^{-w} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{f-g}{1-f}} \\ & = n^{bf} \left( \frac{1}{\mathbf{q}} \right) \left( \mathbf{q} \left[ n^{-w} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{1-g}{1-f}} + (1-\mathbf{q})(\mathbf{a} p_F)^{1-g} \right) \end{aligned} \quad (15')$$

where  $\mathbf{g}$  is the elasticity of substitution between home and foreign goods and  $1 > \mathbf{q} > 0$  reflects the degree of bias for home goods. A rise in  $\mathbf{a}$  raises trade costs which lowers the price of home goods and raises the price of imported goods in our model, shifting demand towards home goods. For an elasticity of substitution between home and foreign goods greater than unity, it can be confirmed that a rise in the scale of trade costs ( $\mathbf{a}$ ) then raises the share of nontraded goods,  $\bar{n}$ , as one might expect. In words, expenditures on home goods rise and expenditures on foreign goods falls. Since the domestic country is importing less, it need not export as much to balance trade. Hence it need not export as many varieties of goods, leading to a rise in  $\bar{n}$ . This result is reversed if the elasticity between home and foreign goods is less than unity; in this case a rise in  $\mathbf{a}$ , increases expenditures on imports relative to that on home goods, leading to lower exports, and lower  $\bar{n}$ . For a unitary elasticity, as shown here for the Cobb-Douglas case,  $\mathbf{a}$  has no effect on  $\bar{n}$ , since the level of relative expenditures on home and foreign goods is unchanged. Empirical work on this elasticity suggests a value between 0.5 and 1.5, with our value of 1 in the middle (see Pesenti, 2002).

## B. Implications for the relative price of nontraded goods

Viewing nontradedness as endogenous also offers some new insights into the behavior of international relative price dynamics. If we wish to solve for the dynamics of the model when trade is not restricted to be balanced, the equilibrium conditions cannot be summarized in a single equation as in (15); instead there is a system of four equations that must be solved numerically for  $n_1$ ,  $n_2$ ,  $c_1$  and  $c_2$ :

$$y_1 n_1^{bf} \left\{ \frac{1}{\mathbf{w}} \left[ n_1^{-w} (1+\mathbf{w}) - 1 \right] \right\}^{\frac{1-f-q}{1-f}} = \mathbf{q} \mathbf{a}^{1-q} p_{F1}^{1-q} c_1 \quad (16)$$

$$y_2 n_2^{bf} \left\{ \frac{1}{\mathbf{w}} \left[ n_2^{-w} (1+\mathbf{w}) - 1 \right] \right\}^{\frac{1-f-q}{1-f}} = \mathbf{q} \mathbf{a}^{1-q} p_{F2}^{1-q} c_2 \quad (17)$$

$$c_2 = \left[ (1+r) \left( \frac{y_1 [1+n_1^{b+1} \mathbf{b}]}{\mathbf{b}+1} - \left\{ \left[ n_1^{-w} \left( \frac{1+w}{w} \right) - \frac{1}{w} \right]^{\frac{1}{1-f}} \right\}^q (\mathbf{a} p_{F1})^{1-q} c_1 \right) \right. \\ \left. + \frac{y_2 [1+n_2^{b+1} \mathbf{b}]}{\mathbf{b}+1} \right] \bullet \left\{ \left[ n_2^{-w} \left( \frac{1+w}{w} \right) - \frac{1}{w} \right]^{\frac{1}{1-f}} \right\}^{-q} (\mathbf{a} p_{F2})^{q-1} \quad (18)$$

$$c_1 = \mathbf{d} \left( \frac{p_2}{p_1(1+r)} \right) c_2 \quad (14')$$

See the appendix A for derivations. Equations (16) and (17) reflect the intratemporal allocation of domestic consumption for home goods in periods 1 and 2 respectively, while (18) reflects the effects of the budget constraint on intertemporal allocation. Together these three equations define the set of combinations of  $c_1$  and  $c_2$  that are permissible for the small open economy, characterizing the intertemporal tradeoffs that are possible. The fourth equation is the intertemporal Euler equation (14) written for the particular case of additively separable log utility. This condition indicates the intertemporal tradeoff between  $c_1$  and  $c_2$  that consumers in the small open economy prefer, and captures how demand shocks to  $\mathbf{d}$  enter the system.

**Table 1: Demand shock, role of  $\mathbf{b}$**

		Endogenous $n$				Exogenous $n^*$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\mathbf{b}$	$\bar{n}$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$	$\log\left(\frac{n_1}{n_2}\right)$	$sdev(p_N)$	$sdev(p_T)$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$
0.1	0.1966	3.5350	0.0458	0.0023	0.0008	5.5679
0.5	0.4507	0.8988	0.0239	0.0059	0.0038	2.5509
1.5	0.5802	0.3810	0.0167	0.0124	0.0103	2.1689
5	0.7184	0.1623	0.0085	0.0209	0.0193	2.0500
10	0.7963	0.1109	0.0025	0.0246	0.0232	2.0251

Benchmark parameter values:  $\mathbf{f} = 10$ ,  $p^*/\mathbf{a} = 1$ ,  $\mathbf{q} = 0.5$ ,  $\mathbf{t}_F = 0.1$ ,  $r = 0$ .

Computed for a taste shock that leads to a 1.5% rise in period one consumption.

The volatility of variables, reported as 'sdev,' is computed as the absolute value of the log deviation between the period 1 and steady-state values. For example:  $\frac{sdev(p_N/p_T)}{sdev(1/p)} = \left| \log\left(\frac{p_N/p_T}{p_N/p_T}\right) \right| / \log\left(\frac{\bar{p}}{p_1}\right)$ .

\*Computed for the corresponding level of  $\bar{n}$ , to facilitate comparison with the endogenous  $n$  case.

Columns (3-6) of Table 1 show the dynamics of the model for various values of  $\mathbf{b}$ . This is done for the case of a shock to  $\mathbf{d}$  that raises period-one consumption by 1.5 percent relative to its steady-state level under balanced trade. (This is the standard deviation of U.S. consumption typically used in calibration studies.)<sup>22</sup> The benchmark calibration will be used again here:

$$\mathbf{f} = 10, \mathbf{p}^*/\mathbf{a} = 1, \mathbf{q} = 0.5, \mathbf{t}_F = 0.1, \mathbf{r} = 0.$$

Column (3) shows that the volatility of the relative price of nontraded goods depends a great deal on the curvature parameter  $\mathbf{b}$ . As there is only one intertemporal shock in this two-period experiment, this column reports the percentage “standard deviation” of  $p_N / p_T$  as

$$\log \left( \frac{\overline{p_{N1}} / \overline{p_N}}{\overline{p_{T1}} / \overline{p_T}} \right),$$

where overbars indicate levels in the balanced trade steady state. This volatility

is reported as a ratio to the percentage standard deviation in the real exchange rate for  $1/p$  computed in the same manner in absolute value. This relative volatility falls dramatically as the curvature of trade costs rises, and for a value of  $\mathbf{b} = 1.5$ , the model is able to approximately replicate the value of 0.37 found in the empirical study by Betts and Kehoe (2001a).<sup>23</sup> Empirical work by Engel (1999) finds that the volatility of nontraded prices may yet be lower than this, but the table shows that the model is capable of replicating even very low values of volatility as the curvature parameter  $\mathbf{b}$  is assumed to be progressively larger.

This result stands in sharp contrast to the standard result of open economy models in the literature, where the share of nontraded goods is taken to be exogenous. For example the classic Balassa-Samuelson model explains real exchange rate levels exclusively in terms of shifts in the relative price of nontraded goods. The same is true for the well-known two-period model of Dornbusch (1983), which is very similar to the model considered here, except for the assumption that the share of nontraded goods is fixed. Under such an assumption, a rise in consumption demand will tend to push up the price of consumption goods, but this will be expressed only for

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<sup>22</sup> The rise in consumption requires a shock to  $\mathbf{d}$  that varies from 3.14% for the case of  $\mathbf{b} = 0.1$ , to 4.26% for  $\mathbf{b} = 1.5$ , and 4.96% for  $\mathbf{b} = 10$ .

<sup>23</sup> The traded goods included in the aggregate price index include only home traded goods and exclude imported foreign goods. This is in part a matter of technical necessity: the model is designed to avoid an a priori demarcation between different types of home goods, so there is no clear way to define a price index combining imported foreign goods together with a subset of goods in the home goods CES index, while excluding other goods in this CES index. Very fortunately, the stylized fact which the model is trying to replicate is defined in precisely the same manner. When Betts and Kehoe (2001a) compute the relative price of nontraded to traded goods, they likewise define  $p_t$  in terms of the prices of goods in traded sectors that are produced at home (using either gross output deflators by sector or a domestic producer price index). In addition, the statistic we report for our model likewise reflects Betts and Kehoe by using the full consumer price index for the domestic price level,  $p$ .

nontradeds, because the price of traded goods is pinned down to the world price level by arbitrage. A rise in the relative price of nontraded goods is necessary for equilibrium, to convince households to take their extra consumption in the form of additional imports of tradable goods, given that the consumption of nontraded goods is limited by definition to the domestic supply of such goods.

This conclusion is illustrated in column (7) of Table 1, where the movement in the relative price of nontraded goods is solved for a version of the model here where  $n$  is taken to be exogenous. The model is identical to the one reported in the earlier columns, except that the “marginal nontraded condition” (equation 7) is dropped. To maintain comparability with the earlier columns of the table the exogenous value of the nontraded share,  $n$ , is set at the level of  $\bar{n}$  found for the corresponding endogenous nontraded model reported in the preceding columns. Note that it is true for all the cases in the table, that the relative price of nontraded goods moves much less under the assumption of endogenous tradedness than for the standard assumption of exogenous tradedness. In fact, it is easy to demonstrate that the ratio of volatilities reported in column (7) must always be greater than unity when  $n$  is exogenous. Since the aggregate price level  $p$  is a weighted average of nontraded prices ( $p_N$ ), traded home goods prices ( $p_T$ ), and import prices ( $p_F$ ), where the latter two are fixed by world levels, the movement in the first component must always be larger than the movement in the overall average that it induces. This explains why a small open economy model with exogenously determined nontraded goods has such difficulty explaining a low volatility in the price of nontraded goods relative to the overall real exchange rate.

A comparison of columns (3) and (7) makes clear that the one change of making  $n$  endogenous has a very dramatic effect on the ability of the model to explain this empirical regularity. The chain of events characteristic of standard models, explained above, no longer applies. Now, as a rise in demand starts to push up the relative price of nontraded goods, some traded goods sellers on the margin will find it profitable to sell more in the home market, to the point of abandoning attempts to market their good abroad where they need to deal with costs of trade. This endogenous rise in the share of nontraded goods allows the supply of nontraded goods to rise, despite the fact that the endowment of each individual good is fixed. This rise in supply reduces the pressure for the relative price of nontradeds to rise in the face of the higher demand.

The main insight here is that, when one begins to view nontraded goods as being endogenously determined, one can see there is a potentially strong force limiting the movement in the relative price of these nontraded goods. The marginal trading condition from the model (eqn.

7) is useful in seeing how this result arises. Recall that this equation states that the price index of nontraded goods will equal the price of the marginal traded good. This linkage between nontraded and traded prices prevents one price index from straying too far from the other, and thus helps dampen the volatility in their ratio.

It is interesting to note that this dampened volatility in the relative price of nontradeds does not rule out volatility in the overall price index or real exchange rate here. Columns (5) and (6) in Table 1 show that for high levels of  $b$ , the price of nontraded and traded goods tend to move more volatility and in a synchronized fashion. Given that these two prices are important components in the overall CPI, this overall price index moves a good deal. But because the two components are moving in synchronization, the relative price of one in terms of the other is not moving significantly. This explains why the ratio reported in column (3) is able to take on such small values under endogenous tradedness, whereas it can never take a value less than unity under the assumption of exogenous tradedness.

Why does this mechanism work best for high values of  $b$ ? Looking at the marginal condition (equation 7), it becomes clear that  $b$  is the elasticity of the nontraded price index with respect to changes in  $n$ . It is at high values of  $b$  where the demand shock induces a small change in  $n$  and a large change in the price of nontraded goods. But this also requires a larger change in the price index of traded goods, so the overall price index changes more. One interesting implication of this logic, is that the mechanism outlined here to explain the stylized fact does not require an implausible degree of movement in the share of nontraded goods. In fact, inspection of column (4) of Table 1 confirms that the mechanism is at its most potent when  $n$  moves the least between the two periods. For the benchmark case of  $b = 1.5$ , the nontraded share moves 1.67% between the periods, from a share of about 0.585 to 0.575, and this shift is yet smaller for cases with higher  $b$  in the table.

The curvature parameter is not the only parameter to play an important role in this mechanism. Table 2 shows that a higher elasticity of substitution between home goods ( $f$ ) also plays an important role. Column (3) shows that as  $f$  rises, the volatility in relative nontraded prices as a ratio to that of the real exchange rate falls. Intuitively, if the last nontraded good and the marginal traded good are highly substitutable, this makes the link between their two prices stronger. This in turn strengthens the linkages between the price indexes of traded and nontraded goods.

**Table 2: Demand shock, role of  $f$** 

<u>Endogenous <math>n</math></u>						<u>Exogenous <math>n^*</math></u>
(1)	(2)	(3)	(4)	(5)	(6)	(7)
$f$	$\bar{n}$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$	$\log\left(\frac{n_1}{n_2}\right)$	$sdev(p_N)$	$sdev(p_T)$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$
5	0.5503	0.7787	0.0165	0.0124	0.0083	2.3895
10	0.5802	0.3810	0.0167	0.0124	0.0103	2.1689
20	0.5937	0.1801	0.0169	0.0126	0.0115	2.0815

Benchmark parameter values:  $b = 1.5$ ,  $p^*/a = 1$ ,  $q = 0.5$ ,  $t_f = 0.1$ ,  $r = 0$ .

Computed for a taste shock that leads to a 1.5% rise in period one consumption.

The volatility of variables, reported as ‘sdev,’ is computed as the absolute value of the log deviation between the period 1 and steady-state values.

\*Computed for the corresponding level of  $\bar{n}$ , to facilitate comparison with the endogenous  $n$  model.

### C. Implications for the intertemporal price and intertemporal trade

Now that it has been demonstrated that endogenous tradedness is relevant, inasmuch as it helps explain a puzzling empirical regularity, it is interesting to see what implications this feature has for other issues of interest to international macroeconomics. One such issue is intertemporal trade, the ability of a country to borrow in world financial markets to finance a current account deficit in a given period. It has long been thought that the presence of nontraded goods can be important for intertemporal trade. Dornbusch (1983) demonstrated that when nontraded goods are present, a change in their relative price can discourage intertemporal trade. Looking at the intertemporal budget constraint (equation 13), one sees that the cost of borrowing in foreign markets includes not only the world rate of interest,  $r$ , but also the change in the price level or real exchange rate over time. Since borrowing takes place in units of the world consumption index, a change in the relative price of home to foreign goods affects the cost of repaying the loan. In particular, if a temporary rise in consumption induces a temporary rise in the domestic price level, the expected fall in price for the next period implies that repayment of the loan will be larger in units of the home consumption index than implied by the interest rate alone. This rise in the “intertemporal price” can discourage such intertemporal trade.

This theory was extended in a limited but important way to endogenously nontraded goods by Obstfeld and Rogoff (2000). In a model with one home good that can switch into and out of being nontraded, they showed that changes in the intertemporal price may be highly nonlinear, and may come into effect only for large current account imbalances. Bergin and Glick

(2002) showed in the case of two home goods, that the nonlinear nature of the intertemporal price can lead to other interesting cases, and that the intertemporal price may rise more rapidly for a given current account imbalance than implied by exogenously nontraded goods in the model of Dornbusch (1983).

A significant disadvantage of the two models above is that they are extremely difficult to work with, given that Kuhn-Tucker conditions imply discrete changes in equilibrium conditions for various ranges of variable realizations. The model in the present paper reformulates the equilibrium conditions for the case of a continuum of goods. Rather than making the solution yet more complex, this permits us to eliminate the discrete changes and discontinuities in the prices of individual goods, and instead focus on smoothly changing levels of various integrals over regions of the continuum. As shown above, this method of dealing with endogenous tradeness is much easier to work with, and has the promise of being incorporated into a wide range of international macro models.

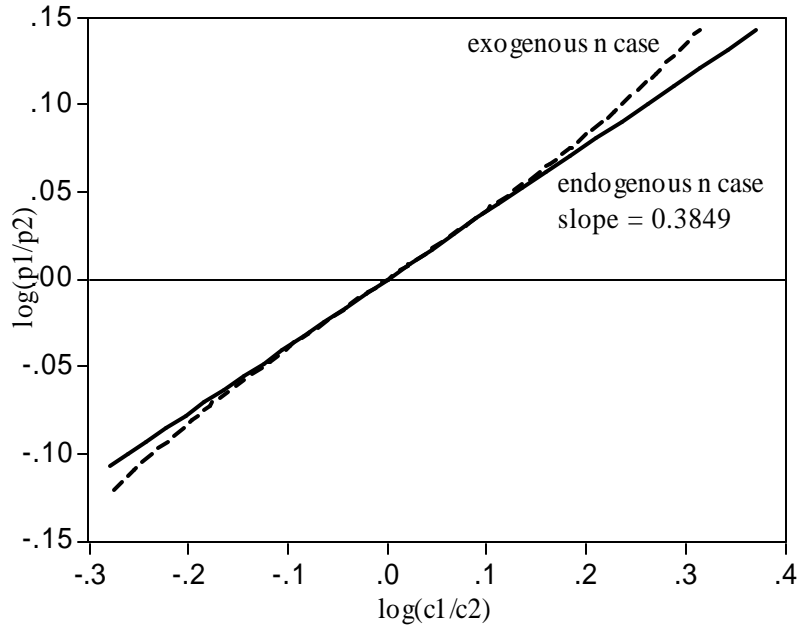
To gauge the effect of endogenous tradeness on intertemporal trade, we use our model to compute the intertemporal price ( $p_1/p_2$ ) for various levels of intertemporal borrowing. Figure 4 plots this intertemporal price against various levels of intertemporal reallocation of consumption ( $c_1/c_2$ ). The solid line represents the benchmark model, where we find that the log of the intertemporal price rises with consumption with a nearly constant elasticity of 0.385. It is interesting that these variables follow an approximately log-linear relationship. The dashed line represents the intertemporal price for the exogenous nontraded case defined above. The exogenous share of nontraded goods for this case is calibrated to equal the share of the endogenous model in its balanced-trade steady state.

Several conclusions emerge. First, the intertemporal price rises smoothly in the endogenously nontraded model, in contrast to the earlier papers with only one or two home goods. The absence of price changes for small shocks to the current account and the dramatic kinks and sudden price rises for large imbalances characteristic of the earlier models disappear here in the more realistic case of many goods.<sup>24</sup> This smooth rise in intertemporal price indicates that there is no special cost that kicks in to discourage only large current account deficits. The smoothing effect of endogenous tradability operates for small as well as large imbalances.

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<sup>24</sup> In these models the kinks in the price response occur because there are a finite number of domestic goods with discontinuously differing trade costs. Hence, as goods shift from being traded or nontraded, export prices jump suddenly.

**Fig 4: Intertemporal price,  $\log(p1/p2)$**



Plotted for  $\mathbf{b} = 1.5$ ,  $\mathbf{a} = 1$ ,  $\mathbf{q} = 0.5$ ,  $\mathbf{t}_f = 0.1$ , Cobb-Douglas preferences ,  
 where  $\bar{n}$  set to 0.5802 for the exogenous  $n$  case.

A second conclusion is that the intertemporal price rises less steeply when tradedness is endogenous, compared to the standard model with exogenous tradedness. The general insight of Dornbusch (1983) is still correct, that the rise in nontraded prices implied by the presence of nontraded goods drives up the intertemporal price. However, when goods can switch in and out of being nontraded, they will tend to do so in a way to minimize this cost. When consumption rises in period 1 and falls in period 2, the share of nontraded goods rises in period 1 to free up more domestic goods for home consumption, and the share of nontraded goods falls in period 2 as the country needs to export more goods to repay its debt. In each case, the endogenous movement in the quantity of nontraded goods partly insulates the price of nontraded goods and thereby the intertemporal price from the shock. The difference between the two models is small for small current account imbalances, where the share of nontraded goods is about the same for both models. But the difference grows for larger current account imbalances, as the share of nontraded goods in the endogenous model deviates more from the steady-state level, which is the nontraded share imposed on the exogenous model.

The fact that the key relationships here are approximately log-linear in form suggests that the endogenous tradedness mechanism advocated here has the potential to be incorporated into a



wide range of international macro models, including more complex models such as business cycle models, which typically need to be log-linearized for analysis.

#### 4. Generalizing to Production Economies

While the price implications of endogenous tradability were most transparently demonstrated in an endowment economy, we demonstrate here the robustness of the result to a more general environment, including production and productivity shocks. We begin by allowing production of home goods with a homogenous production function, while maintaining the assumption of heterogeneous trade costs. We then go on to consider an alternative case where productivity, rather than transport costs, vary heterogeneously across goods.

##### A. Homogenous productivity and heterogeneous transport costs

We introduce output through a Ricardo-Viner specific factors production function which implies a decreasing returns to scale in the variable factor:

$$y_i = A (l_i)^a, \quad 0 \leq a \leq 1 \quad (19)$$

where  $l_i$  denotes workers employed in production of each individual good  $i$ , and  $A$  is a productivity level parameter. This approach is necessary here to ensure a non-degenerate set of traded goods -- the “full specialization problem” -- and is a common device in the trade literature (see Jones, 1971; Samuelson, 1971; and Mussa, 1974 for early examples). Under a constant returns alternative, the small open economy would concentrate production for export in only the final variety in the continuum that has the lowest transport cost. We employ the usual assumption that labor is mobile across sectors within each economy, but immobile internationally.

With perfect competition, marginal costs are equalized to price:

$$p_i = \frac{W}{a y_i / l_i} = \frac{W}{a(A)^{1/a}} (y_i)^{1/e},$$

implying output of good  $i$  is <sup>25</sup>

$$y_i = \left( p_i \frac{a(A)^{1/a}}{W} \right)^e, \quad e \equiv a/(1-a) > 0 \quad (20)$$

where  $W$  denotes the domestic wage rate and  $e$  is the price elasticity of output. Output rises as productivity increases or wages decline.

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<sup>25</sup> Note  $\lim_{a \rightarrow 0} a^a = 1$ .

As in the endowment case, the small open economy assumption implies traded goods prices are pinned down by the world price (still normalized to a uniform constant for all goods) and transport costs. Thus the export prices of individual goods  $p_i$  are still given by (5) and the price index for traded goods  $p_T$  is still given by (6).

To determine the price of nontraded goods, note that (20) implies that the relative supplies for each pair of goods  $i$  and  $j$  depend positively on their relative prices:

$$\frac{y_i}{y_j} = \left( \frac{p_i}{p_j} \right)^e,$$

while intratemporal optimization implies their relative demands are

$$\frac{c_i}{c_j} = \left( \frac{p_i}{p_j} \right)^{-f}.$$

Since consumption must equal production of nontraded goods,  $c_i/c_j = y_i/y_j$ , it follows that  $p_i/p_j = 1$ ,  $y_i/y_j = 1$  in equilibrium for  $i, j \in \{0, n\}$ . In other words, if there are no productivity differences among home goods, then their prices and quantities are identical when they are not traded. (When they are traded, their prices differ if trade costs are heterogeneous.) The uniformity of nontraded prices is the same result derived in the uniform endowment case. As before, the price of the marginally traded good  $n$ ,  $p_n = (p^*/\mathbf{a})n^b$ , pins down the price level of all nontraded goods, and the average price of nontraded goods  $p_N$  is still given by (7). So the inclusion of production has no effect on the equilibrium condition for nontraded prices, and it can only influence the equilibrium value of these prices via its effects on the share of nontraded goods,  $n$ , in that condition.

Output levels reflect the pattern of prices. Inserting the expression for traded goods prices (5) into (20) yields

$$y_i = \left( \frac{p^* i^b a(A)^{1/a}}{\mathbf{a} W} \right)^e \quad i \in \{n, 1\} \quad (21)$$

while the price of the marginally traded good  $n$ , and the property of uniform nontraded prices imply

$$y_i = y_n = \left( \frac{p^* n^b a(A)^{1/a}}{\mathbf{a} W} \right)^e \quad i \in \{0, n\}. \quad (22)$$

Thus, for given levels of wages and the nontraded share, the output of nontraded goods is constant, while the output of tradeds increases as trade costs fall.

In appendix B we show that the labor market equilibrium condition yields an equation linking wages to the share of nontraded goods and other exogenous variables:

$$W = \frac{p^* a A}{\mathbf{a} L^{1-a}} \left[ \frac{1 + n^{b(1+\theta) + \mathbf{b}(1+e)}}{\mathbf{b}(1+e) + 1} \right]^{1-a} \quad (23)$$

where  $L$  is the fixed labor supply. With export prices pinned down by the world market, wages rise in response to an increase in productivity or to an increase in the share of nontraded goods  $n$ . In the single period setting the model is closed by the trade balance condition (see the appendix):

$$Z \equiv \frac{1 + n^{b(1+\theta) + \mathbf{b}(1+e)}}{1 + \mathbf{b}(1+e)} - \frac{1}{\mathbf{w}q} \left[ n^{b(1+\theta) + \mathbf{b}(1+e)} (\mathbf{w} + 1) - n^{b(f+e)} \right] = 0 \quad (24)$$

It is readily apparent that (24) is a generalized version of the trade balance condition derived in the endowment case that determines the equilibrium share of nontraded goods  $\bar{n}$ . (In the special case that the price elasticity of output  $e$  is zero eqn. (24) reduces to eqn. (15)). As in the prior case, with Cobb-Douglas preferences,  $\bar{n}$  is independent of homogenous shocks to transport costs  $\mathbf{a}$ ; here it is independent of homogenous productivity level shocks in  $A$  as well.

In the multiperiod case allowing unbalanced trade, equilibrium involves solving a set of equations analogous to (16)-(18). However, in addition to solving for  $n_1$ ,  $n_2$ , and  $c_2$ , given a value of  $c_1$ , now we must also determine wages  $W_1, W_2$ . We do so by adding to the system the wage equation (23) for periods 1 and 2. We relegate a listing of this system of equations to appendix B and report in Table 3 the results of a demand shock in the production model. Numerical experiments in this expanded model require calibration of some additional parameters. We set the steady-state level of technology  $A$ , and the labor supply  $L$  to unity. This implies that as the production scale term  $a$  goes to zero, the economy converges to the endowment economy shown earlier in the paper. For the purpose of our experiments, we set  $a$  at 0.5. All other parameters are the same as in the endowment model, as reported in Table 1. Once again, the shock is a rise in  $\mathbf{d}$  sufficient to raise consumption in period one by 1.5%.<sup>26</sup>

The results of the experiment are similar to those in Table 1 for the endowment economy. Increases in  $\mathbf{b}$  and greater heterogeneity in transport costs dampen movements in the relative price of nontradables to tradables, so it is still true that a low magnitude in the movement of this relative price is possible for the appropriate choice of heterogeneity in transport costs.

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<sup>26</sup> This implies a rise in  $\mathbf{d}$  of 3.9% for the main case of  $\mathbf{b} = 1.5$ , compared to 4.26% in the endowment model.

**Table 3: Demand shock in production economy, role of  $\mathbf{b}$** 

(1)	(2)	(3)	(4)	(5)	(6)
$\mathbf{b}$	$\bar{n}$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$	$\log\left(\frac{n_1}{n_2}\right)$	$sdev(p_N)$	$sdev(p_T)$
0.1	0.2214	3.3072	0.0417	0.0021	0.0008
0.5	0.4974	0.9302	0.0196	0.0049	0.0031
1.5	0.6490	0.4487	0.0115	0.0086	0.0068
5	0.7948	0.2225	0.0049	0.0122	0.0109
7.5*	0.8363	0.1845	0.0035	0.0130	0.0118

Benchmark parameter values:  $\mathbf{f} = 10$ ,  $p^*/\mathbf{a} = 1$ ,  $\mathbf{q} = 0.5$ ,  $\mathbf{t}_F = 0.1$ ,  $r = 0$ ,  $A = 1$ ,  $L = 1$ ,  $a = 0.5$ .

Computed for a taste shock that leads to a 1.5% rise in period one consumption.

The volatility of variables, reported as ‘sdev,’ is computed as the absolute value of the log deviation between the period 1 and steady-state values.

\* Numerical solutions converge for values of  $\mathbf{b}$  only up to 7.5.

Several differences with the endowment economy model are worth highlighting. First, the steady-state share of nontraded goods in column 2 is somewhat higher with production. Intuitively, endogenous production allows the small open economy to take advantage of the heterogeneity in transport costs more fully. Even in the endowment economy trade was concentrated in sectors with low trade costs, though this came at the cost of shifting consumption toward the remaining sectors; now production can be concentrated in these sectors to permit greater exports in these tradable sectors with smaller costs for consumption allocations. The dynamic response of the share of nontrades to the shock is also somewhat smaller than that in the endowment economy, on a percentage basis.

Second, the fact that the values of  $n$  differ somewhat from the endowment economy case means that the behavior of prices differs somewhat. In general, the movement in the relative price of nontraded goods (column 3) is somewhat higher than that in the endowment economy for each magnitude of  $\mathbf{b}$  listed. We know from the analytical results above that this difference comes about simply because of the different values of  $n$ ; conditional on  $n$ , the equilibrium conditions for prices are identical in the production and endowment economies. Nevertheless, the differences in prices are rather small, and they still follow a steady downward trajectory as the magnitude of  $\mathbf{b}$  rises.

Since we now have a model with endogenous production, it is natural to consider another type of experiment, involving a shock to the production function rather than the demand

condition. Table 4 presents numerical results for a shock that raises the technology term  $A$  in period 2 by 1.5 percent. (This shock raises equilibrium output in period 2 by 1.32 percent for the benchmark case of  $\mathbf{b} = 1.5$ ). Note that this is the type of supply shock considered by Dornbusch (1983).

**Table 4: Productivity shock in production economy**

(1)	(2)	(3)	(4)	(5)	(6)
$\mathbf{b}$	$\bar{n}$	$\frac{sdev(p_N/p_T)}{sdev(1/p)}$	$\log\left(\frac{n_1}{n_2}\right)$	$sdev(p_N)$	$sdev(p_T)$
0.1	0.2214	3.3173	0.0202	0.0010	0.0004
0.5	0.4974	0.9293	0.0086	0.0021	0.0013
1.5	0.6490	0.4475	0.0045	0.0034	0.0027
5	0.7948	0.2219	0.0017	0.0044	0.0039
9*	0.8531	0.1704	0.0010	0.0046	0.0042

Benchmark parameter values:  $\mathbf{f} = 10$ ,  $p^*/\mathbf{a} = 1$ ,  $\mathbf{q} = 0.5$ ,  $\mathbf{t}_F = 0.1$ ,  $r = 0$ ,  $A = A_1 = 1$ ,  $L = 1$ ,  $a = 0.5$ .

Computed for a rise in  $A$  in period 2 by 1.5%.

The volatility of variables, reported as ‘sdev,’ is computed as the absolute value of the log deviation between the period 1 and steady-state values.

\* Numerical solutions converge for values of  $\mathbf{b}$  only up to 9.

Results for a productivity shock are extremely similar to those for the demand shock. While the movements in the share of nontraded goods are different, they still move in the manner needed to buffer the change in nontraded prices and facilitate movements in the price of traded goods. Once again the role play by nontraded prices in column (3) varies inversely with  $\mathbf{b}$ , and low magnitudes of relative price movement are possible for the appropriate choice of this heterogeneity parameter. We conclude that our main insight from the simple endowment economy extends to a model including production and even including supply shocks.

## B. Heterogeneous productivity and homogeneous transport costs

While the focus of this paper is on the important role of heterogeneity in terms of trade costs, given that the preceding literature has focused on heterogeneity in terms of productivities, we briefly consider this alternative here.

In particular, we assume a production function

$$y_i = A_i (l_i)^a, \quad 0 \leq a \leq 1 \quad (19')$$

where productivity is an increasing function of  $i$

$$A_i = A i^{b_A}$$

with  $A$  denoting the homogenous component constant across goods and  $b_A$  capturing the degree of heterogeneity across varieties.

To highlight the role of productivity differences we also assume trade costs are homogenous, i.e.  $b = 0$  in (5), implying the prices of all traded goods are identical:

$$p_i = \frac{p^*}{1+t_i} = \frac{p^*}{a} \quad \text{for } i \in \{n,1\}. \quad (5')$$

Hence

$$p_T = \frac{p^*}{a}. \quad (6')$$

Thus the average price of traded goods is now independent of  $n$ .

The equalization of marginal costs and price implies output of each good depends on its productivity

$$y_i = \left( p_i \frac{a(A_i)^{1/a}}{W} \right)^e \quad (20')$$

implying in turn

$$\frac{y_i}{y_j} = \left( \frac{p_i}{p_j} \right)^e \left( \frac{A_i}{A_j} \right)^{1+e}.$$

It follows from the equilibrium condition for nontraded goods  $c_i / c_j = y_i / y_j$  that (noting that  $e \equiv a/(1-a)$  implies  $1+e = e/a$ )

$$\frac{p_i}{p_j} = \left( \frac{A_i}{A_j} \right)^{-\frac{e+1}{e+f}}, \quad \frac{y_i}{y_j} = \left( \frac{A_i}{A_j} \right)^{f \left( \frac{e+1}{e+f} \right)} \quad \text{for } i \in \{0,n\}$$

or, for  $j = n$

$$p_i = p_n \left( \frac{A_i}{A_n} \right)^{-\frac{e+1}{e+f}} = p_n \left( \frac{i}{n} \right)^{-b \left( \frac{e+1}{e+f} \right)}, \quad y_i = y_n \left( \frac{A_i}{A_n} \right)^{f \left( \frac{e+1}{e+f} \right)} = y_n \left( \frac{i}{n} \right)^{bf \left( \frac{e+1}{e+f} \right)} \quad (25)$$

Thus, in contrast to the case with homogenous productivity, heterogeneous productivity implies that the prices and output of the intramarginal nontraded goods differ, with their prices falling and

output rising as productivity increases across varieties. It follows that the price index of nontraded goods is

$$\begin{aligned}
p_N &= \left( \left( \frac{1}{n} \right) \left[ \int_0^n (p_i)^{1-f} di \right] \right)^{1/(1-f)} = \left( \left( \frac{1}{n} \right) \left[ \int_0^n p_n \left( \frac{A_i}{A_n} \right)^{\frac{1+e}{e+f}} \right]^{1-f} di \right)^{1/(1-f)} \\
&= p_n \left( \left( \frac{1}{n} \right) \left[ \int_0^n \frac{A_i^{\frac{1+e}{e+f}(\mathbf{f}-1)}}{A_n^{\frac{1+e}{e+f}(\mathbf{f}-1)}} di \right] \right)^{1/(1-f)} = p_n \left( \mathbf{b}_A \left( \frac{1+e}{e+f} \right) (\mathbf{f}-1) + 1 \right)^{1/(\mathbf{f}-1)}
\end{aligned} \tag{7'}$$

where the appearance of  $n$  in the integral cancels that in the multiplicative weighting term, so that  $n$  is eliminated in the final form of the expression (7'). Since  $p_n$ , the price of the marginally traded good, is pinned down by its export price,  $p^*/\mathbf{a}$ , which as noted above is independent of  $n$ , the price index of nontradeds is independent of  $n$  as well. Because  $p_T$  and  $p_N$  depend only on constant parameters, their ratio, the relative price of nontradeds  $p_N/p_T$ , is clearly invariant to shocks, even if the tradability of goods changes. This does not mean that individual goods prices are invariant; solving for the price of individual nontraded goods prices (see eqn. 25) indicates that these goods prices all rise when a shock raises  $n$ . (The mechanism through which this occurs is rising wages, which are passed on to higher marginal costs.) But it is this same shift in  $n$  that guarantees that the aggregate price index of nontraded goods does not change. In particular, as the distribution of prices of individual nontraded goods shifts up, the support of this distribution expands to include a new set of cheaper goods, enough to hold constant the average price among nontradeds as a group.

Nor does this result imply that there are no effects on broader price aggregates. Comparison of (6') and (7') indicates  $p_N > p_T$ . Since nontraded goods by definition display lower average productivity than traded goods, their prices are higher. This contrasts with our earlier analysis where traded prices always exceed nontraded prices (because the latter are pinned down by the marginal traded good which has a *lower* price than that of traded goods on average). Given this fact, inspection of (4) implies that an increase in  $n$  raises  $p_H$  since it raises the weight of the higher priced nontradeds in the home goods basket. And this in turn raises the overall price level  $p$ . Further details of the model in this case are relegated to appendix C.

Since the analytical equations (6') and (7') make clear that shocks have no effect on the relative price of nontraded goods through changes in tradability regardless of the value of the heterogeneity parameter  $\mathbf{b}_A$ , there is little benefit in presenting numerical simulations in tables

analogous to Tables 3 and 4. However, such numerical simulations do confirm that a demand shock raises the share of nontraded goods as the rise in demand in period 1 generates a current account deficit in that period. Similarly, if we consider the same experiment as in Table 4 of a rise in period two technology  $A_2$ , this also has very similar effects: an anticipated rise in future output generates a rise in current consumption and hence a current account deficit, which again raises the endogenous share of nontraded goods. The price effects discussed above then naturally ensue.

We conclude that, despite the very different nature of this model with productivity heterogeneity, it generates results broadly consistent with our main insight from the earlier models with endowments or production with homogeneous productivity. Once again it is adjustment in the endogenous share of nontraded goods that buffers the effect of shocks on the relative price of nontraded goods. In fact for the case considered with heterogeneous productivity, the movement in  $n$  completely neutralizes the effect that any movement in individual goods prices will have on the nontraded price aggregate. Further, similar to our previous results, this fact does not rule out movements in the overall national price level. The particular mechanism generating this portion of the result is somewhat different in this model specification, in that it no longer is a matter of nontraded and traded prices moving together, but the fact that nontraded prices receive a greater weight in the overall aggregate. But again it is the endogenous movement in the nontraded margin  $n$  that facilitates this result.

### **C. Transport cost vs. productivity heterogeneity**

We considered the case of heterogeneous productivity in our analysis because the trade literature has tended to focus on productivity as a source of heterogeneity. This is also true of recent macro models aimed at incorporating lessons from trade into macro, notably Ghironi and Melitz (2004). It is reassuring that our general claim that endogenous tradability reduces the volatility in the relative price of nontraded goods is robust to the source of heterogeneity and applies across a range of models. What is central to the result is the simple idea that there is an endogenous margin between traded and nontraded goods. While we argued earlier in the paper in favor of including heterogeneity in terms of trade costs as an essential part of what distinguishes traded from nontraded goods, we in principle are open to the idea that both sources of heterogeneity exist together, with their relative importance perhaps varying by sector. Our results in the previous section show that this in no way limits the validity of our main insight regarding the behavior of relative prices.

Nevertheless, we end this section by making an argument in favor of our benchmark model based on transport cost heterogeneity, in preference to the norm in the trade literature



based on technology heterogeneity. The trade approach is rooted in the classic model of Dornbusch, Fisher and Samuelson (1977), which used a continuum of goods ranked by unit labor costs to determine exported and imported goods based on the implied comparative advantage. This model also yielded predictions regarding which goods might be nontraded, specifically those goods for which comparative advantage was smaller than the size of a uniform iceberg transportation cost.

We would contend that while this approach is useful for understanding the distinction between exported and imported goods, it is unhelpful if one instead is interested in understanding the distinction between traded and nontraded goods. In particular, the model of Dornbusch et al. (1977) implies that traded goods prices deviate from the world price by a constant amount, the uniform iceberg cost. This conflicts with evidence that deviations from the law of one price are very heterogeneous among goods (Crucini, Telmer, and Zachariadis, forthcoming), which is easily resolved by allowing heterogeneity in transport costs. But further, the Dornbusch et al. (1977) model implies that nontraded goods are characterized as those goods whose price deviation from the world price is consistently smaller than the iceberg cost; it is the very fact that this price gap is small that makes it unprofitable to trade these goods. However, there is also empirical evidence showing that failures in the law of one price are larger for nontraded goods than for traded goods, not the other way around (Crucini, Telmer, and Zachariadis, forthcoming). Haircuts differ more across countries in price than do electronic goods. This fact is readily explainable if one thinks that the small transport costs that lead to small price deviations are also the factor that makes such goods highly tradable. Models that allow heterogeneity in transport costs to shape which goods are nontraded are appealing as an approach, in that they intrinsically are able to capture this basic fact about relative prices.

## **5. Conclusions**

This paper has proposed a new way of thinking about nontraded goods in a macro model, focusing on tradedness as an endogenous decision in the face of good-specific trading costs. The paper develops a very tractable way of dealing with this endogeneity, and explores its implications in the context of a simple general equilibrium macro model. This way of thinking about tradedness proves to be quite appealing, in that it helps the model replicate a puzzling stylized fact: the relative price of nontraded goods tends to move much less volatily than the real exchange rate. This fact stands in contrast to standard theoretical models such as Balassa-Samuelson, which rely almost entirely on such relative price movements.

The paper then shows that the endogeneity of tradability can have implications for other macroeconomic issues. In particular, the ability of nontraded goods to discourage international trade will be less severe than in past models, which assumed goods were exogenously nontraded. Goods will tend to switch categories in a manner that minimizes the costs of intertemporal trade.

The mechanism developed here is sufficiently simple that we think it has the potential for being applied to a wide variety of macro models to analyze a range of macroeconomic issues. These include the international transmission of business cycles and the effects of monetary and exchange rate policy.

We should emphasize that we do not view endogenous tradability as the sole explanation for the many puzzles in international macroeconomics. Rather we view our mechanism as complementary to other explanations that suggest roles for sticky prices, nontraded distributive services, vertical production arrangements, etc. In fact, we view the incorporation of our approach into models with these other features as a fruitful line of research. Further, because the key relationships in our formulation are approximately log-linear in form, we suspect that it even will be possible to incorporate this mechanism into quite complex business cycle models, which typically require log-linear approximation for analysis. As a result, we suspect that this approach will be employed fruitfully in a wide range of models to analyze a wide range of issues in international macroeconomics.

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## Appendix: Derivation of equilibrium conditions

### A. Endowment economy

Combine (8) and (12) to solve out for  $c_N$ :

$$c_H = y(p_N / p_H)^f \quad (\text{A1})$$

Substitute in (A1) for  $p_N$  with (7):

$$p_H c_H = (p^* / a)^f y n^{bf} p_H^{1-f}. \quad (\text{A2})$$

Substitute in (4) for  $p_T$  with (6) and for  $p_N$  with (7):

$$p_H^{1-f} = \left(\frac{p^*}{a}\right)^{1-f} \frac{1}{w} [n^{-w}(1+w) - 1] \quad (\text{A3})$$

where  $w \equiv b(f-1) - 1$ . Combine (A3) with (A2) to obtain

$$p_H c_H = \frac{p^* y}{a} \left(\frac{n^{bf}}{w}\right) [n^{-w}(1+w) - 1]. \quad (\text{A4})$$

Note next that the domestic value of aggregate home production can be derived as

$$\begin{aligned} p_H y_H &= \int_0^n p_i y_i di + \int_n^1 p_i y di = \int_0^n p_N y di + \int_n^1 p_i y di \\ &= (p^* / a)(n^b)ny + y \int_n^1 \left(\frac{p^* i^b}{a}\right) di \\ &= \frac{p^* y}{a} n^{b+1} + \frac{p^* y}{a} \left(\frac{1}{b+1}\right)(1 - n^{b+1}) \end{aligned}$$

implying

$$p_H y_H = \frac{p^* y}{a} \left[ \frac{1 + n^{b+1} b}{1 + b} \right]. \quad (\text{A5})$$

With balanced trade,  $p_H y_H = pc$ . Noting that (10) implies  $p_H c_H = q pc$  and combining this with the balanced trade condition gives

$$p_H y_H = \left(\frac{1}{q}\right) p_H c_H. \quad (\text{A6})$$

Substituting in (A6) on the lefthand side for  $p_H y_H$  with (A5) and on the righthand side for  $p_H c_H$  with (A4):

$$\left(\frac{p^* y}{a}\right) \left[ \frac{1 + n^{b+1} b}{1 + b} \right] = \frac{p^* y}{qa} \left(\frac{n^{bf}}{w}\right) [n^{-w}(1+w) - 1].$$

Canceling  $p^* y / a$  from both sides, recalling  $w \equiv b(f-1) - 1$ , and rearranging gives equation (15) in the text, the equilibrium condition for  $n$  in the case of a zero trade balance surplus  $Z$ :

$$Z \equiv \frac{1 + n^{b+1} b}{1 + b} - \frac{1}{wq} [n^{b+1}(w+1) - n^{bf}] = 0. \quad (\text{15})$$

To show a unique solution exists for condition (15), it is straightforward to see that for  $n=0$ ,  $Z = 1/(1+\mathbf{b}) > 0$ , and for  $n=1$ ,  $Z = -(1-\mathbf{q})/\mathbf{q} < 0$ . Showing that  $\partial Z/\partial n < 0$  implies that  $Z$  crosses the 0 axis only once and is sufficient to establish the existence of a unique solution for  $n$ :

$$\begin{aligned}\frac{\partial Z}{\partial n} &= \frac{(\mathbf{b}+1)n^{\mathbf{b}}\mathbf{b}}{1+\mathbf{b}} - \frac{1}{\mathbf{q}\mathbf{w}} \left[ (\mathbf{b}+1)n^{\mathbf{b}}(\mathbf{w}+1) - \mathbf{b}\mathbf{f}n^{\mathbf{b}\mathbf{f}-1} \right] \\ &= \frac{1}{\mathbf{q}\mathbf{w}} \left[ n^{\mathbf{b}}\mathbf{b}(\mathbf{q}-1)\mathbf{w} - n^{\mathbf{b}}\mathbf{b}\mathbf{f}(1-n^{\mathbf{w}}) \right] < 0\end{aligned}$$

since  $\mathbf{q} < 1$  and  $1-n^{\mathbf{w}} > 0$  for  $0 < n < 1$  and  $\mathbf{w} > 0$ .<sup>27</sup>

Given the level of  $n$  that implicitly solves condition (15), it is straightforward to solve for the other endogenous variables: first the prices,  $p_T$  and  $p_N$  through (6) and (7),  $p_H$  through (A3),  $p$  through (3); and then the quantities,  $c_N$  and  $c_T$  through (8) and (9),  $c_H$  and  $c_F$  through (10) and (11), and  $c$  through (1).

For the multiperiod case, we introduce time subscripts and solve out for  $c_{Ht}$  with (A2) and (10) together to get

$$\frac{y_t}{\mathbf{a}^{\mathbf{f}}} n_t^{\mathbf{b}\mathbf{f}} p_{Ht}^{1-\mathbf{f}} = \mathbf{q} p_t c_t. \quad (\text{A7})$$

Substitute in (3) for  $p_{Ht}$  with (A3) to get

$$p_t = \frac{1}{\mathbf{a}^{\mathbf{q}}} \left\{ \frac{1}{\mathbf{w}} \left[ n_t^{-\mathbf{w}} (1+\mathbf{w}) - 1 \right] \right\}^{\mathbf{q}/(1-\mathbf{f})} p_{Ft}^{1-\mathbf{q}}. \quad (\text{A8})$$

Substitute in (A7) for  $p_{Ht}$  with (A3) and for  $p_t$  with (A8):

$$\frac{y_t}{\mathbf{a}} n_t^{\mathbf{b}\mathbf{f}} \frac{1}{\mathbf{w}} \left[ n_t^{-\mathbf{w}} (1+\mathbf{w}) - 1 \right] = \mathbf{q} \frac{1}{\mathbf{a}^{\mathbf{q}}} \left\{ \frac{1}{\mathbf{w}} \left[ n_t^{-\mathbf{w}} (1+\mathbf{w}) - 1 \right] \right\}^{\mathbf{q}/(1-\mathbf{f})} p_{Ft}^{1-\mathbf{q}} c_t. \quad (\text{A9})$$

Rearranging gives the equations (16) and (17) that express the intratemporal consumption allocation relation between  $c_t$  and  $n_t$  that holds for each period  $t=1,2$ :

$$y_t n_t^{\mathbf{b}\mathbf{f}} \left\{ \frac{1}{\mathbf{w}} \left[ n_t^{-\mathbf{w}} (1+\mathbf{w}) - 1 \right] \right\}^{\frac{1-\mathbf{f}-\mathbf{q}}{1-\mathbf{f}}} = \mathbf{q} \mathbf{a}^{1-\mathbf{q}} p_{Ft}^{1-\mathbf{q}} c_t. \quad (16,17)$$

Lastly, we rearrange the intertemporal budget constraint (13) to get

$$c_2 = \left[ (1+r)(p_{H1}y_{H1} - p_1c_1) + p_{H2}y_{H2} \right] / p_2. \quad (\text{A10})$$

Substituting in (A10) for  $p_{Ht}y_{Ht}$  with (A5) and for  $p_t$  with (A8),  $t=1,2$  gives (18):

$$\begin{aligned}c_2 &= \left[ (1+r) \left( \frac{y_1 \left[ 1 + n_1^{\mathbf{b}+1} \mathbf{b} \right]}{\mathbf{b}+1} - \left( \left[ n_1^{-\mathbf{w}} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{1}{1-\mathbf{f}}} \right)^{\mathbf{q}} (\mathbf{a} p_{F1})^{1-\mathbf{q}} c_1 \right) \right. \\ &\quad \left. + \frac{y_2 \left[ 1 + n_2^{\mathbf{b}+1} \mathbf{b} \right]}{\mathbf{b}+1} \right] \cdot \left\{ \left[ n_2^{-\mathbf{w}} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{-\mathbf{q}}{1-\mathbf{f}}} \right\}^{-\mathbf{q}} (\mathbf{a} p_{F2})^{\mathbf{q}-1}.\end{aligned} \quad (18)$$

<sup>27</sup> If  $\mathbf{w} < 0$ , then  $1-n^{\mathbf{w}} < 0$ , but it is straightforward to see that  $\partial Z/\partial n < 0$  still.

The system of three equations – (16), (17), and (18) -- can be solved numerically for  $n_1$ ,  $n_2$ , and  $c_2$ , given a value of  $c_1$ . The Euler equation (14) completes the system.

### B. Production economy with homogenous productivity

Equations (1) to (11) continue to apply when the model includes production. Given the property that  $y_i = y_n$  and  $p_i = p_n = p_N$  for  $i \in \{0, n\}$  when productivity is homogenous, the market-clearing condition for nontradeds (12) becomes

$$c_N = \int_0^n y_i \frac{p_i}{p_N} di = n y_n \quad (\text{B12})$$

where  $y_n \equiv \left( \frac{p^* n^b a (A)^{1/a}}{\mathbf{a} W} \right)^e$  is the output of the marginally traded good  $n$ ,  $e \equiv a/(1-a)$ ,  $a$  is the

output elasticity of labor in the production function (19). Following the same sequence of substitutions in deriving (A1)-(A4) yields

$$c_H = y_n \left( p_N / p_H \right)^f \quad (\text{B1})$$

$$p_H c_H = y_n \left( \frac{p^*}{\mathbf{a}} \right)^f n^{bf} p_H^{1-f} \quad (\text{B2})$$

$$p_H^{1-f} = \left( \frac{p^*}{\mathbf{a}} \right)^{1-f} \frac{1}{\mathbf{w}} [n^{-w} (1+\mathbf{w}) - 1] \quad (\text{B3})$$

$$p_H c_H = \frac{y_n p^*}{\mathbf{a}} \left( \frac{n^{bf}}{\mathbf{w}} \right) [n^{-w} (1+\mathbf{w}) - 1] \quad (\text{B4})$$

where  $\mathbf{w} \equiv \mathbf{b}(\mathbf{f}-1) - 1$ . (Comparing with (A1)-(A4), note that  $y_n$  replaces  $y$  in (B1), (B2), and (B4), while (A3) and (B3) are identical.) The value of aggregate home production can be derived as :

$$\begin{aligned} p_H y_H &= \int_0^n p_i y_i di + \int_n^1 p_i y_i di = \int_0^n p_n y_n di + \int_n^1 \left( \frac{i^b p^*}{\mathbf{a}} \right) \left( \frac{p^* i^b a (A)^{1/a}}{\mathbf{a} W} \right)^e di \\ &= n p_n y_n + \left( \frac{1}{\mathbf{a}} \right)^{1+e} \left( \frac{a (A)^{1/a}}{W} \right)^e (p^*)^{1+e} \frac{(1 - n^{b(1+e)+1})}{\mathbf{b}(1+e)+1} \end{aligned}$$

by again utilizing the property that  $p_i = p_n = p_N$  and  $y_i = y_n$  for  $i \in \{0, n\}$  and by substituting

for  $p_i, y_i, i \in \{n, 1\}$  with (5) and (21), respectively. Substituting in for  $p_n = \frac{p^* n^b}{\mathbf{a}}$ ,

$y_n \equiv \left( \frac{p^* n^b a A^{1/a}}{\mathbf{a} W} \right)^e$  then gives

$$p_H y_H = \left( \frac{a (A)^{1/a}}{W} \right)^e \left( \frac{p^*}{\mathbf{a}} \right)^{1+e} \left[ \frac{1 + \mathbf{b}(1+e) n^{b(1+e)+1}}{1 + \mathbf{b}(1+e)} \right]. \quad (\text{B5})$$

The trade balance condition can be derived by first substituting for  $y_n$  in (B4) and then substituting the resulting expression for  $p_H c_H$  on the righthand side of (A6) and substituting (B5) for  $p_H y_H$  on the lefthand side of (A6) to obtain:

$$\left(\frac{a(A)^{1/a}}{W}\right)^e \left(\frac{p^*}{a}\right)^{1+e} \left[\frac{(b(1+e)n^{b(1+e)+1} + 1)}{b(1+e)+1}\right] = \frac{1}{qa} p^* \left(\frac{p^* a(A_n)^{1/a}}{aW}\right)^e \left(\frac{n^{b(e+f)}}{w}\right) [n^{-w}(1+w)-1].$$

Cancelling the term  $(p^*/a)^{1+e}$  from both sides and rearranging gives the trade balance condition (24) in the text:

To derive the wage equation, substitute for  $l_i$  with the production function (19) into the labor market equilibrium condition  $\int_0^n l_i di + \int_n^1 l_i di = L$ , implying

$$\int_0^n \left(\frac{y_i}{A}\right)^{1/a} di + \int_n^1 \left(\frac{y_i}{A}\right)^{1/a} di = L.$$

Further substitution for  $y_i$  with (21) and (22) gives

$$\int_0^n \left(\frac{\left(\left(\frac{p^*}{a}\right) \frac{n^b a(A)^{1/a}}{W}\right)^e}{A}\right)^{1/a} di + \int_n^1 \left(\frac{\left(\frac{p^* i^b a(A)^{1/a}}{aW}\right)^e}{A}\right)^{1/a} di = L$$

which, upon noting  $e/a = 1+e$  and integrating, results in

$$\left(\frac{p^* a A}{aW}\right)^{1+e} n^{b(1+e)} n + \left(\frac{p^* a A}{aW}\right)^{1+e} \frac{1}{b(1+e)+1} (1 - n^{b(1+e)+1}) = L.$$

Solving for  $W$  and noting  $1/(1+e) = 1-a$  gives expression (23) in the text.

To derive the analogues to (16), (17), and (18) in the multiperiod case, we reintroduce time subscripts and solve out for  $c_{Ht}$  with (B2) and (10) together to get

$$\left(\frac{p^*}{a}\right)^f y_{nt} n_t^{bf} p_{Ht}^{1-f} = q p_t c_t. \quad (\text{B7})$$

Next substitute in (3) for  $p_{Ht}$  with (B3) to get

$$p_t = \left(\frac{p_t^*}{a}\right)^q \left\{ \frac{1}{w} [n_t^{-w}(1+w)-1] \right\}^{q/(1-f)} p_{Ft}^{1-q} \quad (\text{B8})$$

which is identical to (A8). Substituting in (B7) for  $p_{Ht}$  with (B3) and for  $p_t$  with (B8) gives an gives expression equivalent to (A9) with  $y$  replaced by  $y_n$ . Rearranging gives the equations (B16) and (B17) that express the intratemporal consumption allocation relation between  $c_t$  and  $n_t$  that holds for each period  $t = 1, 2$ :

$$y_{nt} n_t^{bf} \left\{ \frac{1}{w} [n_t^{-w}(1+w)-1] \right\}^{\frac{1-f-q}{1-f}} = q \left(\frac{p_{Ft}}{p_t^*/a}\right)^{1-q} c_t. \quad (\text{B16, B17})$$



where (recall)  $y_m \equiv \left( \left( \frac{p_t^*}{\mathbf{a}} \right) (n_t^b) \frac{a(A_t)^{1/a}}{W_t} \right)^e$ . Lastly, substitute for  $p_{Ht} y_{Ht}$  with (B5) and for  $p_t$

with (B8) in the rearranged intertemporal budget constraint (A9) to get (B18):

$$c_2 = \left\{ \begin{aligned} & (1+r) \left[ \left( \frac{p_1^*}{\mathbf{a}} \right)^{1+e} \left( \frac{a(A_1)^{1/a}}{W_1} \right)^e \frac{1 + \mathbf{b}(1+e)n_1^{b(1+\theta)+1}}{1 + \mathbf{b}(1+e)} - \left[ (n_1)^{-w} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{q}{1-f}} \left( \frac{p_1^*}{\mathbf{a}} \right)^q (p_{F1})^{1-q} c_1 \right] \\ & + \left( \frac{p_2^*}{\mathbf{a}} \right)^{1+e} \left( \frac{a(A_2)^{1/a}}{W_2} \right)^e \frac{1 + \mathbf{b}(1+e)n_2^{b(1+\theta)+1}}{1 + \mathbf{b}(1+e)} \\ & \bullet \left[ \left[ (n_2)^{-w} \left( \frac{1+\mathbf{w}}{\mathbf{w}} \right) - \frac{1}{\mathbf{w}} \right]^{\frac{-q}{1-f}} \left( \frac{p_2^*}{\mathbf{a}} \right)^{-q} (p_{F2})^{q-1} \right] \end{aligned} \right\}$$

The system of five equations – (B16), (B17), (B18) and the wage equation (23) for periods 1 and 2 – can be solved numerically for  $n_1$ ,  $n_2$ ,  $c_2$ ,  $W_1$ ,  $W_2$ , given a value of  $c_1$ .

### C. Production economy with heterogeneous productivity

Equations (1) – (11) continue to apply as in the homogenous productivity case.

Using (25) to substitute for  $p_i$  and  $y_i$  in (12), it follows that

$$\begin{aligned} c_N &= \int_0^n y_i \frac{p_i}{p_N} di = \frac{1}{p_N} \int_0^n y_n \left( \frac{i}{n} \right)^{b_A f \left( \frac{1+e}{e+f} \right)} p_n \left( \frac{i}{n} \right)^{-b_A \left( \frac{1+e}{e+f} \right)} di \\ &= \frac{y_n p_n}{p_N} \int_0^n \left( \frac{i}{n} \right)^{b_A \left( \frac{(f-1)(1+e)}{e+f} \right)} di = \frac{y_n p_n}{p_N} \left( \frac{1}{b_A \left( \frac{(1+e)(f-1)}{e+f} \right) + 1} \right) n. \end{aligned}$$

which, after substituting for  $p_N$  with (7'), yields

$$\begin{aligned} c_N &= \frac{y_n p_n}{p_n \left( b_A \frac{(1+e)(f-1)}{e+f} + 1 \right)^{1/(f-1)}} \left( \frac{1}{b_A \left( \frac{(1+e)(f-1)}{e+f} \right) + 1} \right) n \\ &= \left( \frac{1}{1 + \mathbf{w}_A} \right)^{f/(f-1)} n y_n \end{aligned} \tag{C12}$$

where  $\mathbf{w}_A = b_A \frac{(1+e)(f-1)}{e+f} > 0$ ,  $p_n = \frac{p^*}{\mathbf{a}}$ ,  $y_n \equiv \left( \frac{p^* a (A n^{b_A})^{1/a}}{\mathbf{a} W} \right)^e$ .

The analogue expressions obtained for (A1)-(A4) are given by<sup>28</sup>

$$c_H = y_n (1 + \mathbf{w}_A)^{\frac{-f}{f-1}} (p_N / p_H)^f \quad (\text{C1})$$

$$p_H c_H = \left( \frac{p^*}{\mathbf{a}} \right)^f (p_H)^{1-f} y_n \quad (\text{C2})$$

$$p_H^{1-f} = \left( \frac{p^*}{\mathbf{a}} \right)^{1-f} \left[ 1 - n \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right] \quad (\text{C3})$$

$$p_H c_H = \left( \frac{p^* y_n}{\mathbf{a}} \right) \left[ 1 - n \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right]. \quad (\text{C4})$$

Following the same sequence of substitutions as in prior variants of the model, we can then derive expressions for the value of aggregate home output:

$$p_H y_H = \left( \frac{a(A)^{1/a}}{W} \right)^e \left( \frac{p^*}{\mathbf{a}} \right)^{1+e} \left( \frac{1 - \frac{\mathbf{w}_f}{\mathbf{w}_e} + \frac{\mathbf{w}_f}{\mathbf{w}_e} n^{b_A(1+e)+1}}{1 + \mathbf{w}_A} \right) \quad (\text{C5})$$

the trade balance:

$$Z = \frac{1}{\mathbf{w}_e} + \frac{(\mathbf{w}_f / \mathbf{w}_e)}{1 + \mathbf{w}_A} n^{b_A(1+e)+1} - \left( \frac{1}{\mathbf{q}} \right) \left[ n^{b_A(1+e)} - n^{b_A(1+e)+1} \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right] \quad (\text{C15})$$

intra-temporal consumption allocation:

$$y_{nt} \left[ 1 - n_t \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right]^{\frac{1-f-q}{1-f}} = \mathbf{q} \left( \frac{p^*}{\mathbf{a}} \right)^{q-1} p_{Ft}^{1-q} c_t \quad (\text{C16, C17})$$

budget constraint (C18):

$$c_2 = \left[ (1+r) \left( \frac{p_1^*}{\mathbf{a}} \right)^{1+e} \left( \frac{a(A_1)^{1/a}}{W_1} \right)^e \left[ \frac{1 - (\mathbf{w}_f / \mathbf{w}_e) + (\mathbf{w}_f / \mathbf{w}_e) (n_1)^{w_e}}{1 + \mathbf{w}_A} \right] - \left\{ 1 - n_1 \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right\}^{q/(1-f)} \left( \frac{p_1^*}{\mathbf{a}} \right)^q p_{F1}^{1-q} c_1 \right] \\ + \left( \frac{p_2^*}{\mathbf{a}} \right)^{1+e} \left( \frac{a(A_2)^{1/a}}{W_2} \right)^e \left[ \frac{1 - (\mathbf{w}_f / \mathbf{w}_e) + (\mathbf{w}_f / \mathbf{w}_e) (n_2)^{w_e}}{1 + \mathbf{w}_A} \right] \left[ \left\{ 1 - n_2 \left( 1 - \frac{1}{1 + \mathbf{w}_A} \right) \right\}^{-q/(1-f)} \left( \frac{p_2^*}{\mathbf{a}} \right)^{-q} p_{F2}^{q-1} \right]$$

and the wage equation:

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<sup>28</sup> Solving out for  $c_N$  with (8) and (C12) gives (C1). Substituting in (C1) in turn for  $p_N$  with (7') gives (C2). Substituting into (4) with expressions for  $p_T$  (6') and  $p_N$  (7') gives (C3). Combining (C2) and (C3) gives (C4).

$$W_t = \left( \frac{p_t^* a A_t}{\mathbf{a} L^{1-a}} \right) \left( \frac{1 - (\mathbf{w}_f / \mathbf{w}_e) + (\mathbf{w}_f / \mathbf{w}_e) (n_t)^{b_A (1+e)+1}}{1 + \mathbf{w}_A} \right)^{\frac{1}{1+e}} \quad (\text{C23})$$

where  $\mathbf{w}_e \equiv \mathbf{b}_A (1+e) + 1 > 1$ ,  $\mathbf{w}_f \equiv \mathbf{b}_A \left( \frac{1+e}{e+f} \right) (1+e) > 0$ ,  $\mathbf{w}_A = \mathbf{b}_A \frac{(1+e)(f-1)}{e+f} = \mathbf{w}_e - \mathbf{w}_f - 1 > 0$ ,

$e \equiv \frac{a}{1-a} > 0$ , and  $y_n \equiv \left( \frac{p^*}{\mathbf{a}} \frac{a (A n^{b_A})^{1/a}}{W} \right)^e$ .